July 16, 2001

The $500 Billion Opportunity: The Potential Economic Benefit of Widespread Diffusion of Broadband Internet Access[1]

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and

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July 2001

1 The authors are grateful to Verizon Communications for its support for this study.

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Executive Summary

Broadband access to the Internet in all its forms – ADSL, cable modems, and various wireless services – will bring enormous benefits to our economy. No doubt many of the impacts cannot be foreseen at this time, but some of the benefits are already on the horizon. In this report, we attempt to calculate the eventual economic benefits of this new technology using two quite different methods. The first approach uses a conjecture of the demand function for high-speed access once broadband has had time to diffuse throughout the country, which may require 15 years to 25 years. From this demand function we calculate the "consumer surplus" associated with high-speed access priced at $40 per month. We also estimate the benefits to consumers from non-broadband use of the higher-quality network and computing equipment that they would purchase to use with their high-speed network access.

Our second approach examines specific benefits that high-speed access can eventually provide and calculates the consumer surplus associated with each source of benefits. For example, if high-speed access means that a consumer no longer needs to buy a second telephone line at $20 per month for dial-up access, we would count that as a $20 per month benefit of high-speed access. These estimates, while more conjectural, serve as a check on our first, direct approach.

As the table below shows, these two different approaches provide quite comparable estimates.

Summary of Annual Consumer Benefits from Universal Broadband Deployment

($ Billions per Year)

Source	Low Estimate	High Estimate
Direct Estimates:		
Broadband Access Subscription	284	427
Household Computer and Network Equipment	13	33
Total Benefits	**297**	**460**
Alternative Estimates – Benefits Deriving from:		
Shopping	74	257
Entertainment	77	142
Commuting	30	30
Telephone services	51	51
Telemedicine	40	40
Total Benefits	**272**	**520**

Using these two approaches, we conclude that the eventual consumer benefit for *universal diffusion* of broadband could be $300 billion or more. Were broadband to spread to only 50 percent of U.S. households, this estimate would be only about $100 billion per year. These estimates assume that broadband spreads to 94 percent or 50 percent of all U.S. households, the former figure reflecting the current penetration of ordinary telephone service among U.S. households. If this does not occur, the consumer benefits would obviously be much lower.

Producers will also benefit from the greater demand for electronic equipment used in the delivery of broadband service, increased spending on household computer and networking equipment, and increased spending on household entertainment. These benefits could easily amount to another $100 billion per year if broadband became ubiquitous. If it spread to only 50 percent of households, we estimate that producers would ultimately gain less than $50 billion per year.

Thus, a reasonable figure for the total annual benefits to the U.S. economy of the widespread adoption of broadband access in all its forms – ADSL, cable modems, satellites, 3G wireless, and others – could be more than 400 billion dollars per year. Faster rollout of high-speed access services gives us these benefits earlier. A reasonable estimate of the net present value of faster rollout of broadband is as much as 500 billion dollars. Under the more modest scenario of 50 percent adoption, the net present value of faster rollout would be about 140 billion dollars.

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I. Introduction

After twenty years in the doldrums, U.S. productivity growth has finally taken off, driven by the information technology (IT) revolution and the Internet. For more than two decades after the OPEC oil shock of 1973–74, total factor productivity growth languished at about 0.1 percent per year.[2] But since 1995, this broad measure of U.S. productivity growth has surged to more than 1 percent per year. Similarly, labor productivity growth has accelerated from 1.4 percent per year in 1973–95 to 2.9 percent per year in 1995–99.

This large surge in productivity growth, spawned by the IT revolution, has been crucial to the remarkable performance of the U.S. economy since 1995. Between 1973 and 1995, real gross domestic product (GDP) grew at an average rate of only 2.8 percent per year.[3] Since 1995, GDP growth has averaged more than 4 percent annually, a rate that has propelled the median family income in the United States to $49,000 in 1999.[4] Had the IT revolution begun in 1973 and added just 1 percent per year to economic growth between 1973 and 1995, the average household income would have been nearly $64,000 in 1999, rather than $49,000—an increase of $15,000!

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2 Economic Report of the President, (Feb. 2000), at 83.

3 Economic Report of the President, (Jan. 2001), at Table B–2.

4 *Id*., at Table B–33.

Sadly, this stunning surge in economic growth may not be sustainable if the U.S. economy does not encourage the deployment of the infrastructure required to continue the IT revolution. As we went from personal computers to *networked* personal computers, our standard phone connection to the Internet was sufficient. But today we need much faster connections to allow us to exploit the ever-expanding opportunities of Internet connectivity. This report provides a rough estimate of the potential that could be unleashed by more rapid connections – by the evolution to a *broadband* environment.

We conclude that the universal adoption of broadband Internet connections by U.S. households could eventually provide consumers with benefits in the range of $200 billion to $400 billion per year. Moreover, producers of networking equipment, household computers, ancillary equipment, and software, and producers and distributors of entertainment products could also benefit by as much as $100 billion per year. Other firms will be more likely to prosper in world markets because of their earlier experience with the needs and opportunities created by households with modern networks and high-speed connections.

II. Information Technology and U.S. Economic Growth

The vibrant performance of the U.S. in the 1990s has spurred a great deal of research on the sources of economic growth, especially the sources of differential growth between the first and second half of the 1990s. In the first half of the decade, GDP grew at an annual rate of 2.4 percent, whereas in the second half GDP grew at a rate of 4.1

percent per year.[5] At the same time, the estimated annual rate of price decline for computers more than doubled in the second half of the decade, from 15.8 to 32.1 percent.[6] A consensus is now developing among economists that the surge in economic growth is attributable to investment in information technology, which in turn is attributable to the price decline in information technology equipment.[7]

A. Technical Progress in the Information Technology Sector

The revolution in electronics that has engulfed us is obvious by now. The prices of computers, monitors, printers, fax machines, and telephone terminal equipment have been falling dramatically. The prices of telecommunications networking equipment – such as switching gear and transmission equipment – have fallen at similarly spectacular rates. These price declines for information technology equipment can affect GDP growth in two ways. The first is through capital deepening. Lower prices for information technology equipment lead producers to substitute capital for labor, which results in more capital per unit of labor and makes labor more productive. The second is through productivity growth. The new information technology allows producers to use networking to employ more efficient means of production, thereby leading to higher levels of output per each unit of input. This second process is referred to as *technological change* and is generally measured in terms of productivity growth. Professor Erik Brynjolfsson of M.I.T. and Professor Lorin Hitt of the University of Pennsylvania

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5 Dale W. Jorgenson, "Information Technology and the U.S. Economy," *American Economic Review*, 91(1), March 2001, at Table 2.

6 *Id.*

7 In particular, *see* Dale W. Jorgenson and Kevin J. Stiroh, "Raising the Speed Limit: U.S. Economic Growth in the Information Age," *Brookings Papers on Economic Activity*, 2000–1, (125-235) and the discussion following the paper.

conclude that technological change is likely to have been more important than capital deepening during the 1990s.[8]

The dramatic declines in prices for information technology equipment are obviously important for the economy because they provide businesses and consumers with more computing power at lower prices. Equally important, however, is the fact that these less expensive, more powerful devices allow for new applications of IT technology that were not even imaginable a decade ago. Today's broad Internet did not exist a decade ago. Consumers did not buy securities, books, or airline tickets by sitting at their home computers in 1990. Indeed, less than one in five households even had a computer in 1990.[9]

B. Measuring IT's Contribution to Economic Growth

Until recently, economists were puzzled by the absence of evidence that the revolution in electronics was contributing very much to economic growth. Now, however, such evidence is emerging, and it appears that IT *networking* is a crucial link. A recent article by Professor Dale Jorgenson of Harvard University provides the most detailed decomposition of the sources of growth in GDP and total factor productivity.[10] Jorgenson concludes that the surge in growth in the second half of the 1990s is a result of the rapid decline in semiconductor prices, which led to falling IT equipment prices. The rate of price decline for IT equipment doubled in the second half of the 1990s, which

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[8] Erik Brynjolfsson & Lorin M. Hitt, "Beyond Computation: Information Technology, Organizational Transformation and Business Performance," *Journal of Economic Perspectives,* 14(4), Fall 2000, at 45.

[9] See Figure 2 below.

[10] *See* Jorgenson, *supra* note 5.

caused massive investment in IT and, in turn, led to capital deepening and productivity growth.

Jorgenson disaggregates average labor productivity (output per hour) growth into growth in labor quality, capital deepening, and growth in total factor productivity. He shows that average labor productivity grew by 1.2 percent in the first half of the decade and by 2.1 percent in the second half of the decade. The growth in total factor productivity – the growth in output per unit of capital, materials, and labor – tripled between the first and second halves of the decade from 0.24 to 0.75 percent per year. The growth in total factor productivity due to IT doubled from 0.25 to 0.50 percent per year. Between 1995 and 1999, two-thirds of the growth in labor productivity was attributable to information technology.

In a separate investigation, Stephen Oliner and Daniel Sichel of the Federal Reserve Board conclude that information technology accounted for about two-thirds of the increase in labor productivity growth between the first and second halves of the 1990s.[11] Oliner and Sichel calculate that the information technology sector, which includes computers and semiconductors, accounted for two-fifths of the growth in total factor productivity between the first and second halves of the 1990s. They point out that "[t]hese are remarkable percentages given the tiny share of this integrated computer

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[11] Stephen D. Oliner & Daniel E. Sichel, "The Resurgence of Growth in the Late 1990s: Is Information Technology the Story," *Journal of Economic Perspectives*, 14(4), Fall 2000, at 21. An article by Gordon in the same issue argues that there is no productivity growth outside the IT production sector and that the investment in computer equipment has been unproductive. Oliner and Sichel show that the key difference between Gordon's and their analysis is the removal of what Gordon calls the cyclical factors in the growth of labor productivity. Oliner and Sichel conclude, "Whatever opinion one has of the particulars of Gordon's cyclical adjustment, the fact remains that his numbers embed our basic finding – that the production and use of information technology have contributed importantly to the actual pickup in productivity growth since 1995." (19).

sector in total current-dollar output and they attest to the extraordinary pace of innovation in this part of the economy."[12]

A third study by two members of President Clinton's Council of Economic Advisers, Martin Baily and Robert Lawrence, confirms the findings of the Jorgenson and Oliner and Sichel analyses.[13] Baily and Lawrence show that there has been a substantial acceleration in total factor productivity outside the IT production sector since 1995. The authors conclude that even though it is hard to definitively attribute the acceleration in total factor productivity growth to investment in IT, the observation that total factor productivity grew faster in IT-intensive industries shows that the increase in productivity growth is mainly attributable to IT investment.

In a separate article, Professor Jorgenson and his co-author Kevin Stiroh of the Federal Reserve Bank of New York provide evidence that the surge in productivity is due to the effects of information technology outside the computer and software industries.[14] This contribution results from the use the new technology to deliver goods and services, including the use of networking, in general and the Internet, in particular. Given the difficulty of measuring the prices of computers and semiconductors, Jorgenson and Stiroh provide three separate estimates of the contribution of IT technology to productivity growth for different assumed rates of price decline in IT. Their results are shown in Figure 1.

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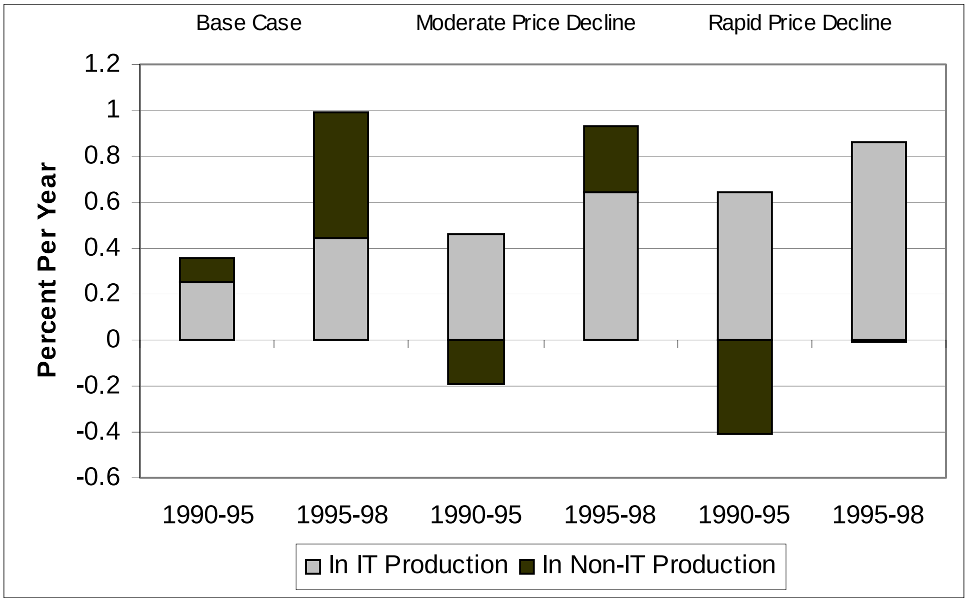
12 *Id*,, at 17.

13 Martin N. Baily & Robert Z. Lawrence, "Do We Have a New E-conomy," *NBER Working Paper 8243*, April 2001 (downloaded from http://www.nber.org/papers/w8243).

14 Jorgenson and Stiroh, *supra* note 7.

FIGURE 1
Contribution of IT and Non-IT Producing Industries to Total Factor Productivity



Source: Jorgenson and Stiroh (2000), Table 5.

Note that IT accounts for more than the *entire* increase in total factor productivity growth under the "rapid price decline" assumption. Given these results, Jorgenson and Stiroh suggest that these increases probably reflect the spillovers from IT to other industries. Always cautious, they offer the following important observation:

> If these productivity gains do indeed reflect spillovers from IT into non-IT industries, this would provide some evidence for the "new economy" argument.[15]

This "new economy" argument is at the center of the need for broadband deployment.

III. The Contribution of Networks

The digital revolution began long before productivity began to climb in 1995. IBM began to sell digital computers in the 1950s. Apple introduced the first personal computer in 1977. Bill Gates and Paul Allen founded Microsoft in 1975. By the mid 1980s, personal computers were proliferating rapidly, and digital stored-program control telephone switches were replacing the older analog switches. Fiber optics began to spread in the telecommunications network in the 1980s.

Despite all of these remarkable advances in information technology, productivity growth continued to languish. Real GDP growth remained modest throughout the late 1980s and early 1990s. But then suddenly, the economy began to surge, fed by accelerating productivity. Something had clearly changed.

A. The Rise of the Internet

The obvious candidate for the sudden acceleration in economic growth after 1994 is the Internet. In the 1980s, the computer revolution was limited by the absence of *networking* capabilities. A personal computer can read and transform information faster than earlier models, but until it is connected to a source of information, an increase in processing power provides limited benefits. However, once one computer can access remote sources of information and transmit the information generated to other computers, its benefit expands enormously. This networking capability developed slowly within large businesses in the 1980s and – to a lesser extent – among small businesses. Until 1983, the predecessor to the Internet – the Arpanet – was limited largely to government and research institution use. Indeed, the TCP/IP protocol that is at the core of the current Internet was not even adopted by the Defense Advanced Research Projects Agency (DARPA) until 1983.

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[15] *Id.*, at 160.

However, it was not until the 1990s that even large businesses routinely networked with other entities to exchange information or conduct transactions. The World Wide Web was born at the end of 1990 with the deployment of a server in a laboratory in Geneva, Switzerland.[16] As recently as 1990, few businesses even had e-mail.

B. Household Computer Use

For small businesses and individual households, the networking of computers for rudimentary access to information and e-mail communications did not develop in earnest until Internet use rose in the mid 1990s. The term *Internet* did not even enter the popular lexicon until 1994,[17] and few households or small businesses would even have known about the possibilities of such networking until at least 1994.

Home computer ownership accelerated in the mid 1990s as the Internet developed. Twelve years after Steve Jobs introduced the Apple II, only 12 percent of households had a computer. In the next eleven years, this percentage would more than quadrupled to 51 percent (see Figure 2).

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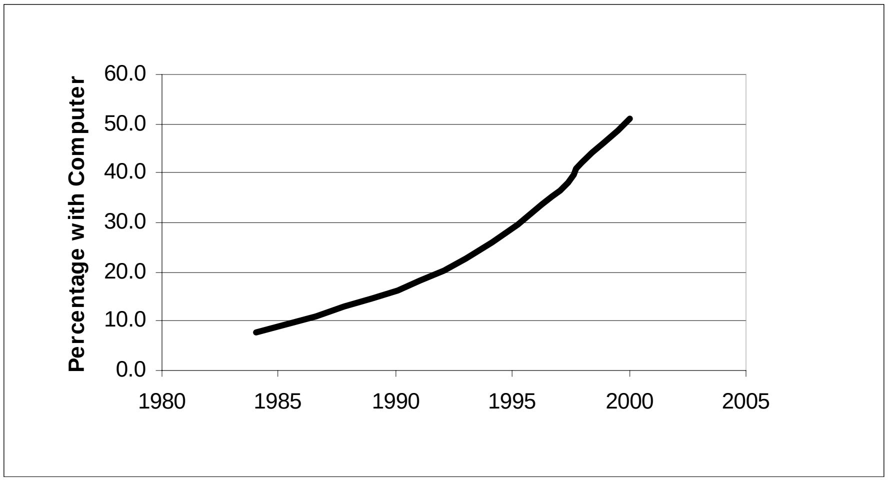
16 *See* Tim Berners-Lee, "The World Wide Web: Past, Present and Future," (Aug. 1996), (downloaded from: http://www.w3.org/People/Berners-Lee/1996/ppf.html).

17 *See* National Research Council, "Realizing The Information Future: The Internet and Beyond," (1994), (downloaded from: www.nap.edu/readingroom/books/rtif.html). This report provided the first popular dissemination of the notion of an "Internet."

FIGURE 2
Percentage of U.S. Households with a Computer



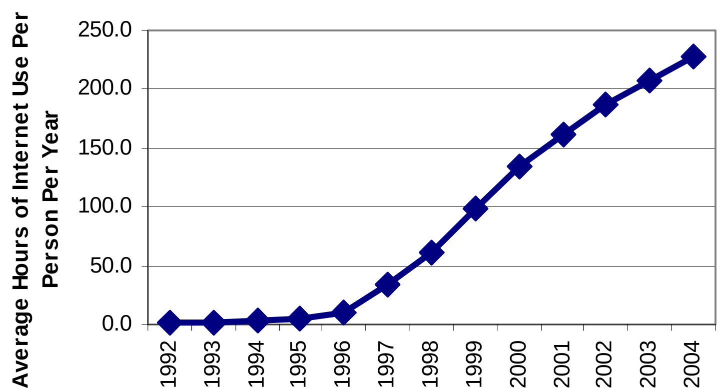
Source: U.S. Bureau of the Census, *Current Population Survey*.

C. The Growth of the Internet

At first, most households used the Internet for the most rudimentary of searches or for e-mail. Then e-commerce developed, allowing consumers to buy airline tickets, books, home electronic equipment, compact discs, and even securities on the Internet. But even these applications were limited by the slow speeds at which consumers accessed the Internet – dial-up speeds range between 2.4 and 56 kilobits per second. This may be sufficient to send simple e-mails and to download small documents, but hardly fast enough to download large audio or video files, to obtain complicated visual images required for real-time computer games, or to conduct advanced e-commerce. As these and other applications began to appear, households began to demand higher-speed Internet connections, but the network infrastructure for delivering them simply did not exist. Without this infrastructure, the evolution of the Internet to its full potential is temporarily blocked and its contribution to the acceleration in economic growth may soon come to an end.

The sharp rise and subsequent deceleration in the growth of Internet *use* is shown in Figure 3. Although household computer ownership has continued to grow and Internet penetration has recently risen to about 50 percent of all households,[18] the growth in the average number of household hours on the Internet is slowing. It is possible that each new household uses the Internet less than early adopters, and the latter group's use is not continuing to grow sufficiently to maintain a constant growth rate. This is surprising given the new uses of the Internet that are appearing daily.

FIGURE 3
Average Hours of Internet Use



Sources: Bureau of the Census, *Statistical Abstract of the United States,* and Veronis, Suhler, and Associates, *Telecommunications Industry Report.*
Note: Figures for 2000 to 2004 are estimates.

The slowdown in the growth rate of Internet *use* is likely, in part, the result of users' frustration at trying to use innovative new network applications at the slow speeds allowed by ordinary dial-up connections. Unfortunately, only about 15 percent of households with Internet service subscribe to one of the new broadband technologies –

[18] The most recent estimate from the Bureau of the Census for June 2000 was 41.5 percent. More recent estimates from TNS suggest that about 50 percent of households now have access to the Internet. *See* TNS Telecoms, ReQuest Market Monitor National Consumer Survey, v.3 (2001).

DSL, cable modem service, or satellite service.[19] With so few broadband households, the new network applications we describe below will not develop fully.

IV. The Network Revolution Has Just Begun

It is obvious that the Internet revolution has just started – after all, the Internet only appeared on the scene in the 1990s. Many in the computing industry now see a future of *pervasive computing*.[20] Vinton Cerf, one of the key pioneers of the Internet and a senior vice president of WorldCom, offered the following observations in an essay titled, “A Glimpse of the Future of the Internet”:

> What is the future of the Internet? It will become the 21st Century's telecommunications infrastructure. It will become our medium of commerce and education, of research and medicine. It will become a repository of the knowledge, wisdom and creativity of the human spirit. Internet will be there, for everyone.[21]

In another essay, Cerf wrote:

> The Internet is here to stay, if the regulators/legislators of the world don't kill it. I am convinced that software companies and service companies will find the Internet a highly attractive and effective medium in which to conduct e-commerce and provide a variety of services that would otherwise not be feasible. Many devices will be internet-enabled, including a number of household appliances, portable devices, etc. and software-based services will be provided to and through them.[22]

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19 *Id.*

20 The National Institute of Standards and Technology (NIST) held a conference at the beginning of May 2001 on pervasive computing. The conference agenda was downloaded from: http://www.nist.gov/pc2001/agenda.html. A search on the web using the Google search engine yields 16,800 hits for the term “pervasive computing” and 16,600 hits for “ubiquitous computing."

21 Vint Cerf, “Cerf’s Up: Social, Economic and Regulatory Issues – A Glimpse of the Future of the Internet”, (downloaded from: http://www.worldcom.com/about_the_company/cerfs_up/issues/glimpse.phtml).

22 Vint Cerf, “Cerf’s Up: Internet History”, (downloaded from: http://www.worldcom.com/about_the_company/cerfs_up/internet_history/q_and_a.phtml#question_4).

The basic idea behind pervasive computing is relatively simple. As computing elements continue to proliferate in the environment, consumers will benefit if those computing elements can communicate with one another and with the outside world. The digital clocks around the house can set themselves to the right time by checking with a master clock. The furnace can measure its performance and determine that it needs to have its filters changed – and then e-mail the homeowner a reminder. Appliances can respond to time-of-day power prices or, in a world in which time-of-day metering is not implemented, to load-shedding commands from the authorities. Blacking out all the water heaters in California for two hours would probably do less harm than would the rolling blackouts currently being used to limit peak demand. Radios (radio-receiver-like appliances) can be tuned to any of thousands of Internet radio stations. If the home has a wireless local network, one can even carry such radios about in the home or listen to them over earphones while mowing the lawn – just as is done with traditional radios.

A. Opportunities with Network-Aware Products

The combination of broadband access and network-aware products will drive the market for home networking. It is quite possible that the most important benefits of pervasive computing cannot be foreseen. The same applies to key innovations in personal computing. No one forecast modern spreadsheets before Dan Bricklin developed the ideas that led to VisiCalc.[23] File sharing over the Internet was possible from almost the beginning using e-mail and FTP, but the development of the World Wide Web was a key factor in the growth of the Internet. No one forecast anything quite like the Web.

Although the idea of linked hypertext had its predecessors in Engelbart's path-breaking NLS and Nelson's unimplemented Xanadu, the rapid adoption of the Web took almost everyone by surprise.[24] It appears highly likely that pervasive computing will lead to other innovations that are as revolutionary as spreadsheets or the Web.

Three elements of the communications infrastructure are needed to operate in most residences to support pervasive computing and the future innovations it will bring. The first is local networking – wire or radio communications connecting many devices in the home to the Internet. The second is an always-on connection from the home to the Internet. High-speed access is necessary for some applications, and it adds value to many. The third requirement is a router or switch to connect the various devices in the home to the single connection to the larger Internet.

Networking inside the home presents issues that must be solved by individual consumers. Several technologies are possible – wireless, the existing telephone wiring, and the electrical power wiring. Products using these technologies are already on the market and are being used.

The need for a router can be met by installing the proper software in home computers or by building the function into the modem device. Microsoft Windows, the Linux operating system, and the Apple Mac all support the network routing functions needed to support many devices in the household from a single connection to the Internet.

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[23] *See* Dan Bricklin, "Was VisiCalc the First Spreadsheet?" (downloaded from: http://www.bricklin.com/firstspreadsheetquestion.htm).

[24] *See* Robert Cailliau, "A Little History of the World Wide Web", (1995), (downloaded from: http://www.w3.org/History.html).

The key issue of public policy concern is how to provide the incentives to deploy the new, higher-speed connection from the home or small office to the larger Internet. We discuss the nature of this connection below.

B. Two Essential Attributes of Network Connections

The next generation of networking applications will rely heavily on two attributes of high-speed services – always on and much higher speed. Each substantially increases the value of connections from the home or office to the Internet. For many applications, each of these attributes is essential – for other applications, they are only convenient.

Always on refers to an Internet connection that is immediately available. ADSL, cable modems, some radio-based systems, and traditional high-speed T1 lines provide always-available connections. With an always-on or always-available connection, the delay from the time that a user goes to the computer and clicks on a web page icon to the time when the request for information is delivered to the remote server is measured in milliseconds. The alternative to always on is dial-up, or its equivalent. Using a dial-up connection to the Internet requires that a connection first be established, after which communications can proceed. Establishing a dial-up connection requires dialing a telephone call, connecting the telephone call to the terminating modem, synchronizing and training the modem, and logging in to the dial-in server. Typically, this process takes 30 to 45 seconds, or even more.

Without an always-on connection, some services, such as instant messaging, cannot be used until the user has taken the step of connecting to the Internet. Always-on connections are essential for certain applications, such as power load shedding and security services. Always-on connections facilitate other services, such as e-mail. With an always-on connection, e-mail software downloads messages before notifying the user that mail has arrived. Consequently, e-mail can be browsed at the speed of the local machine. Always-on connections also increase the use of the Internet. If one has a quick impulse to check on the Web for data, using a connection that is already established, rather than establishing a dial-up connection, improves the response time by about a factor of ten.[25]

High-speed refers to connections that are significantly faster than dial-up connections. Cable modems and ADSL modems provide access at data rates of 1 to 2 megabits per second – twenty to fifty times faster than typical dial-up connections.[26] The satellite services offered for home use today deliver data at about 500 kilobits per second – about ten times faster than a dial-up connection.[27]

C. Network Service Alternatives

How can consumers get high-speed access? Large organizations can obtain high-speed connections to the Internet using traditional telecommunications carrier offerings such as T1 lines, DS3 service, or Sonet services. The prices for these services are typically measured in the thousands of dollars per month – unaffordable for many small business locations and essentially for households.

Residential and small business users have several high-speed, always-on broadband service options, including cable modems, ADSL, and wireless services. These alternatives are described in detail in Appendix 1.

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25 The size of the improvement depends on how responsive the server is at the other end, the speed of the line, and the complexity of the page viewed.

26 The authors are old enough to remember when the backbone of the Arpanet, predecessor of the Internet, ran at 56 kilobits per second and was considered high speed.

27 Two firms, DirecPC and StarBand Communications, offer two-way satellite-based Internet access.

V. Economic Benefits from Broadband Connections

Any new product or product improvement creates benefits for both consumers and producers. Consumers gain because they are able to purchase a new or improved product that was previously unavailable. They consume it up to the point at which the marginal value of the product to them is equal to its price. In the case of typical broadband services, consumers either subscribe to the service, or they do not. As the uses of broadband multiply, the value to subscribers rises far above the monthly subscription price. This is the *consumer surplus* from the innovation.

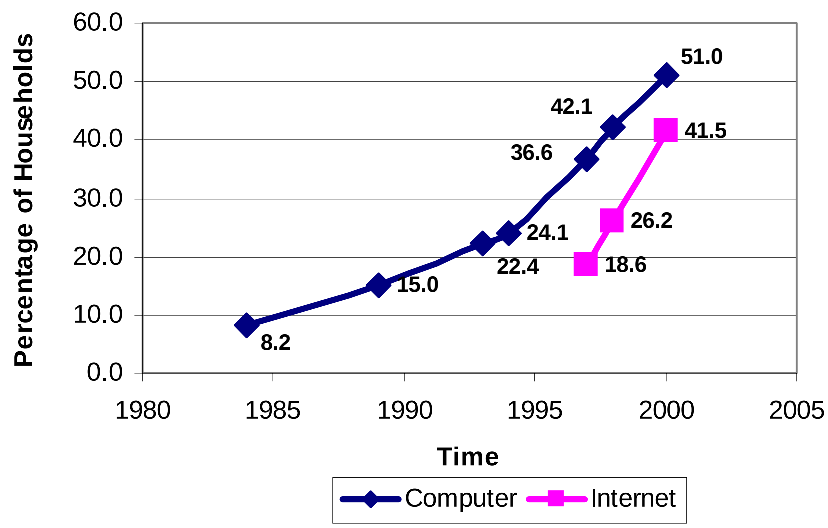
Producers of new services that rely on broadband, of products used in conjunction with broadband service, and even of the broadband service itself also gain from the greater diffusion of broadband. They bid resources away from other sectors of the economy and earn returns over and above those available elsewhere, until the marginal value of each type of resource is equalized across all alternatives. The *producer surplus* that is generated by inframarginal sales is a real benefit to producers and, therefore, to the economy.

In this section, we attempt to provide a rough estimate of the likely long-term gains to the economy – the sum of consumer and producer surplus – generated by widespread diffusion of broadband access. By *long-term,* we mean a time period sufficient for broadband to become virtually ubiquitous, given the appropriate policy environment – a time period that could stretch out to twenty-five years or even more.

A. Estimates of Consumer Value

We use two related approaches to estimating the potential benefits to consumers from a more rapid diffusion of broadband services. First, we estimate the direct benefits from the prospective demand for greater high-speed connectivity. Internet penetration grew rapidly between 1997 and 2000. (See Figure 4.) Today, approximately 50 percent of households have residential Internet connections,[28] and less than 8 percent have broadband Internet connections. Greater broadband availability would increase the fraction of households that use the Internet and thus would create larger increases in consumer welfare than can be deduced directly from current estimates of the demand for broadband alone. Moreover, the demand for broadband will increase as new applications requiring high-speed connections are developed for Internet distribution.

FIGURE 4
Percentage of U.S. Households with a Computer and Internet Access



Source: National Telecommunications and Information Administration, Falling through the Net: Toward Digital Inclusion, (Oct. 2000), (downloaded from: www.ntia.doc.gov/ntiahome/fttn00/contents00.html).

In addition, increasing the diffusion of broadband would lead to a greater household demand for personal computers and related devices because households would need faster computers with greater storage capacity to interconnect with services

28 TNS Telecoms, *supra* note 18.

available at these higher speeds. The shift in demand for these products would create additional consumer surplus from non-broadband uses of this equipment that can be deduced directly from information on such demand.

Our second approach is based on indirect evidence of the potential value of the greater diffusion of broadband and more powerful home computing equipment by examining the new services that households could obtain from faster Internet connections. This approach involves estimating the increase in consumer welfare generated by the new services themselves, in addition to the savings in time and commuting that this new technology will allow.

B. Direct Evidence of Potential Consumer Surplus

The most straightforward estimate of the value of enhanced availability of broadband derives from information on consumer subscriptions to broadband services. At present, no more than 8 percent of households subscribe to a broadband service; only slightly more than 50 percent subscribe to an Internet service of any kind; and 94 percent subscribe to ordinary telephone service.[29] Were broadband to become ubiquitous, it would resemble current telephone service in its household penetration.

1. An Estimate Based on Today's Demand Curve

Given current broadband penetration of 8 percent and an average price of the service of $40 per month, total broadband revenues may be estimated at $480 times 8.4 million, or $4 billion per year. Assuming that the demand for such service is linear with

[29] The number of broadband subscribers (DSL plus cable modems) was 7.3 million as of March 2001. *See* "Failure of Free ISPs Triggers First-Ever Dip, To 68.4 Million Online Users: Cable Modem Boom Continues, As DSL Sign-ups Lag," *Telecommunications Reports*, April 2001, at 1. The

an elasticity of –1.0, the value of the service to these consumers – the consumer surplus – is $2 billion per year in addition to the $4 billion they pay. If the demand elasticity is –1.5, the consumer surplus falls to $1.4 billion.[30]

Were broadband to spread to 50 percent of households at $40 per month through a shift of a linear demand curve with constant slope, the annual expenditure on the service would rise to $31.2 billion.[31] At 50 percent penetration, the additional value to consumers would rise to between $80 billion and $121 billion per year at these two price elasticities.

If broadband service were to become truly ubiquitous, similar to ordinary telephone service, annual consumer expenditures on the service would rise $58.7 billion per year, assuming the continued shift of the linear demand curve at constant slope and an annual price of $480. The additional value to consumers – over and above their expenditures on the service – would be $284 billion to $427 billion per year, assuming that the linear demand curve with a current elasticity of –1.0 or –1.5 simply shifted outward.[32]

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estimates for Internet and telephone service are from authors' tabulations using the Current Population Survey for August 2000.

[30] Some earlier estimates of the value of broadband might even be lower. For instance, using data on broadband connections in 1998–99, Austan Goolsbee of the University of Chicago finds that the consumer surplus from broadband services is only $700 million per year. *See* Austan Goolsbee, "The Value of Broadband and the Deadweight Loss of Taxing New Technology," *University of Chicago Working Paper*, (November 2000).

[31] These calculations assume it takes 25 years to reach universal broadband penetration. We assume a total of 105 million households at present and 130 million households in 2025. The calculations assume a 0.91 percent rate of growth, which is slightly more conservative than the Census projection of 1.08 percent.

[32] At this "ubiquitous" level of demand, the price elasticity of demand would be between –0.068 and –0.103, still substantially above the current estimates of the price elasticity of demand for telephone service but somewhat below current estimates of the elasticity of demand for dial-up Internet service. Note that linear demand curves with such demand elasticities imply that *someone* would be willing to pay as much as $428 to $622 per month for the service. This seems reasonable to us.

It is likely that the real price of broadband service will fall over time, given the declining cost of electronics equipment. Thus, the value to consumers of the enhanced availability of broadband could be more than $300 billion per year, assuming that an outward shift of a linear demand curve from today's equilibrium is appropriate.

These estimates of the potential value of broadband to consumers are based on the assumption that broadband evolves from its "luxury" status into a household necessity over time. If broadband were to become as much of a necessity as ordinary telephone service, the demand for it would no longer be price elastic. Household demand for ordinary telephone service is extremely price inelastic. Recent estimates of this elasticity are -0.03 or even less in absolute value.[33] If broadband becomes as essential as ordinary telephone service is today, we would expect that the demand for it would become similarly price inelastic. As broadband becomes more "essential" and, therefore, less price elastic in demand, its value rises sharply.

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[33] For a survey of these estimates, *See* Lester D. Taylor, *Telecommunications Demand in Theory and Practice*, Kluwer, (1994). For more recent estimates, *See* Robert W. Crandall and Leonard Waverman, *Who Pays for Universal Service: When Telephone Subsidies Become Transparent*, Brookings Institution Press, 2000, at Chapter 5.

TABLE 1
Estimated Ultimate Annual Consumer Surplus from Increased Broadband Penetration[34]
($ Billions)

	Current Price Elasticity of Demand	
	–1.5	–1.0
At 8% Penetration	1.4	2.0
At 50% Penetration	80	121
At 94% Penetration	284	427

Source: Authors' calculations.

2. The Attractiveness of New Technologies Is Often Underestimated

The above methodology is obviously quite speculative. It is possible that current estimates of the demand for broadband underestimate the future demand for broadband because they are based on inferences drawn from the current demand for the service. Surely, consumers today do not have the range of uses for broadband that will be available in the future. Without such alternatives before them, consumers cannot provide us with evidence on how much they will value broadband. Indeed, in the past thirty years, market participants and analysts have frequently underestimated the prospective demand for new services. In Appendix 2, we provide a few prominent examples to demonstrate this fact.

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34 These are estimates of the Marshallian consumer surplus from increased broadband penetration. *See* Jerry Hausman, "Valuing the Effect of Regulation on New Services in Telecommunications," *Brookings Papers on Economic Activity, Microeconomics*, 1997, pp. 1-38. Hausman uses Hicksian compensating variation instead of Marshallian consumer surplus. Because income is not held constant along a Marshallian demand curve, the Hicksian compensating variation would be slightly different from the Marshallian consumer surplus, however, the difference would be small. *See* Robert Willig, "Consumer's Surplus without Apology," *American Economic Review*, 66(4), September 1976, pp. 589-97.

C. Additions to Household Computing Capacity

The expansion of the demand for broadband will create additional demand for computers and networked home appliances. Approximately 40 percent of all U.S. households do not currently have a computer.[35] Clearly, these households are not equipped to connect to the Internet at any speed. Of the 60 percent of households with computers, many will need to upgrade their equipment to obtain greater processing speed, more random-access memory, or greater hard-drive capacity. Still others will choose to buy more advanced equipment.

Eventually, it is likely that households will invest in multiple computers – a reasonable limit is about one computer per person in the household. Household networking equipment will be needed. Computers will require bigger disk drives. Today's 30 or 40 gigabyte drives will become commonplace. Noncomputer devices will be upgraded with connections to the Internet (as discussed above). Obviously, it is much easier for a consumer to add an MP3 player or Internet radio than to add an Internet-ready furnace to her household.

Therefore, the broadband-induced demand for household equipment must include additional or better computers and home networking equipment. About 60 to 80 million households have cordless phones today; computer networking should eventually enjoy a similar popularity.[36] There are, however, some difficult standardization problems that must be solved before we move to the widespread deployment of household devices with Internet connectivity.

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35 *See* TNS Telecoms, *supra* note 18.

Connections to the Internet place new demands on computers. It is not unusual for people to download hundreds of megabytes of audio and video clips. An e-mail message with some attached photographs of the grandchildren can take up five megabytes of storage. Downloaded video clips can be massive – up to a hundred megabytes for each minute of DVD-quality video. Households with older computers will find that their hard disks are quickly exhausted. Other households will find that the memory or processor of their computer systems no longer provides adequate service. Many such consumers will upgrade – either adding the resources they lack or, for the sake of simplicity, buying new computers.

Some households will purchase multiple computers, and many households will find that adding networking capabilities inside the household creates significant benefits. As discussed above, always-on networking creates the opportunity for household equipment to perform more subtle diagnostics, to interact with remote systems, and to present a more convenient interface to consumers.[37]

Personal consumption expenditures on computers, peripheral equipment, and software have risen from $6.2 billion in 1987 to $31.9 billion (in current dollars) in 1999,

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[36] Approximately 130 million cordless phones have been sold in the United States since 1995. Electronic Industries Association, “Factbook” (2000).

[37] For example, one can buy thermostats today that have many features – the settings vary by time-of-day and day-of-the-week. Settings can be overridden. Operating such thermostats is difficult. The display shows only a few characters and the controller requires navigating a complex tree of options. It would be far easier if the thermostat presented a web interface and allowed the user to set the time, date, and desired settings in a more natural and convenient manner. But, such a communicating thermostat can provide many other valuable features at hardly any additional cost. It can be programmed to check energy prices and to base its actions on the price and forecasted prices of energy (cool the house down fast before the price of electricity goes up or let the temperature rise until the price goes down), it can signal abnormal conditions, say household temperatures lower than 40 degrees or higher than 95 degrees to an outside monitor – thus avoiding circumstances that might lead to frozen pipes or health problems. It is reasonable to expect that, over the next two or three decades, always-on networking and home networks will lead to the installation of many devices in the home that take advantage of the network in the home and the connection to the Internet.

but the rate of increase in nominal spending has declined substantially in the last four years.[38] Were broadband to diffuse widely through the population, the share of households with computers would rise and the number of computers per household would also increase.

A conservative estimate of broadband's stimulus on household purchases of IT equipment would be that U.S. household spending on computer equipment, peripherals and software would resume its 1991–95 rate of growth of 14.3 percent per year, rather than continuing at its 1995–99 growth rate of 10.4 percent per year. Assuming that growth continued at only 10.4 percent through 2001, total expenditures will be $39 billion this year. If growth returns to its 1991-95 pace, by 2006 total spending would be $80 billion, rather than $66 billion, an increase of $14 billion. By 2011, the difference would be $53 billion per year. Were the broadband revolution to accelerate household equipment expenditures by another 3 percent per year to 17.3 percent annual growth, the additional spending in ten years would be $110 billion per year.[39,40]

The increase in consumer welfare from this expansion of demand due to new broadband services depends on the elasticity of demand for household computing and networking equipment and software. For instance, if the price elasticity is –1.0 ten years from now at the prevailing level of demand growth without ubiquitous broadband, and if the demand curve is linear, then the $53 billion increase in expenditures would imply an

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[38] Bureau of Economic Analysis. "National Accounts Data", (downloaded from: http://www.bea.doc.gov/bea/dn1.htm).

[39] These calculations are in nominal dollars. Obviously, the rate of growth of the purchase of *real* computing power has been much greater. *See Id*.

[40] In order to be conservative, we do not extend these projections past ten years.

increase in consumer surplus of $65 billion per year.[41] The $110 billion increase in expenditures would convey $164 billion per year in additional consumer surplus. In a recent paper, Professor Jerome Foncel of the University of Lille and Professor Marc Ivaldi of the University of Toulouse estimate the price elasticity of household demand for computers to be –1.66.[42] At this elasticity, the additional consumer surplus is $39 billion and $99 billion, respectively. Not the entire surplus is *in addition* to the previous estimates of the benefits from broadband. However, we might assume that one-third of this surplus from the new household networking equipment accrues from non-Internet services. Thus, our estimate of the *additional value* from new household equipment, over and above that conveyed through broadband connections, is between $13 billion and $33 billion once broadband becomes ubiquitous.

We could perform a similar analysis for other household equipment, such as our example of the thermostat with a web interface. However, we expect that such equipment will be a weaker complement to high-speed networking than household computing, and consumer surplus in the former instance will not be as driven by broadband access, as will computers and networking equipment. Given this factor and the more speculative nature of these benefits, we have not tried to quantify them.

To reiterate, broadband access will stimulate the sales of both computers and network-enabled household devices. The growth of networked household devices, other

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41 Technically, *consumption* of these services is related to the consumers' stock of equipment, not new additions. The additional purchases generate such surplus over several years following purchase. We do not attempt to project the growth of consumer expenditures on computers and related equipment past ten years.

42 Jerome Foncel & Marc Ivaldi, "Operating Sustem Prices in the Home PC Market," *University of Toulouse Working Paper*, (May 2001), (downloaded from http://www.idei.asso.fr/English/ECv/CvChercheurs/EcvIvaldi.html).

than computers and entertainment equipment, will probably be a slow process, driven in part by the natural pace of updating the expensive systems in the home. Ultimately, it will induce substantial expenditures for each household.

D. New Services Provided by Broadband Connectivity

We now turn to the somewhat more speculative indirect estimates of the value of the new services that broadband will make possible in order to buttress the direct estimates above. Forecasting the future is always difficult. Undoubtedly, many of the benefits of broadband deployment will be applications that can only be seen dimly at present, if at all.

An interesting example is provided by the OnStar service. OnStar provides a variety of useful services using wireless radio and GPS location information, such as unlocking the doors of a car. An OnStar customer who locks his or her keys in the car can call OnStar and have the doors unlocked. This is a straightforward enough application of wireless technology – one can easily imagine it being forecast in 1970 or 1980 by a futurist thinking about mobile telephony.

Another OnStar service is triggered when the front air bags of a car deploy. The OnStar operator immediately tries to contact the driver of the car. If anyone is injured or if there is no response from the car, then the OnStar operator contacts a local emergency services agency, notifies the agency of a probable accident, and gives the location of the car. This useful service requires combining three separate technologies – air bags, GPS, and wireless telephony – and depends on the widespread coverage of wireless networks. We can forecast benefits that will be brought by broadband that are similar in nature to using a remote service to unlock a car door, but forecasting the equivalent of OnStar's emergency notification service is much more difficult because that service is dependent on the earlier adoption of several innovations.

We believe that the most readily forecast economic benefits of broadband fall into four general areas – retailing, transportation, home entertainment, and health care – and we consider each below. This is not to say that there could not be equivalent sources of benefit from other services, such as education, but we simply lack the tools or vision to analyze them at this time.

1. Retailing/Wholesaling

Broadband services will provide enormous benefits to consumers by improving the delivery of goods and services. We are already seeing the tip of this iceberg. Everyone knows of Amazon.com, the Internet bookstore. Other bookstores, such as Borders and Barnes & Noble, have emulated Amazon.com. Typically, Internet bookstores offer convenience, but not necessarily lower prices. Buying a book over the Internet saves the consumer the time it takes to go to the bookstore, find the book, wait in the checkout line, check out, and return from the bookstore. For most of us, the costs in time, effort, and transportation are significant. They can be reduced if one stops at the bookstore while shopping for other items – but the time and other resources generally required for book shopping are substantial.

Books are well suited for sale over the Internet. The physical condition of a new copy of the latest Harry Potter tome is the same whether you buy it at the local store or have it shipped from a warehouse a thousand miles away. The key information needed to decide whether to buy a book, such as reviews, the table of contents, and perhaps a summary or excerpt, can be displayed efficiently even over a dial-up connection.

Some other goods have attributes that make them good candidates for sale over the Internet. Many types of brand-name manufactured goods, covered by the manufacturer's warranty, are just as suitable for sale over the Internet as are books. If one wants an HP 8550 laser printer, one will get the same equipment whether one buys it over the Internet or from a local retailer.

Other goods have attributes that make them poorer candidates for sale over the Internet. For example, it helps to see and feel a piece of clothing – perhaps even to try it on. Many firms sell clothing through catalog sales. Although catalogs do not permit one to feel the clothing or try it on, they do provide relatively high-resolution images that can be browsed easily and quickly. Broadband Internet connections permit a browsing experience more like that of a catalog. The user can move quickly from one view to another.

Broadband Internet connections provide a new option for retailing and product distribution. They provide alternative ways of doing business that can be used if and when they are more efficient. Thus far, retail e-commerce accounts for only about 1 percent of total retail sales, or about $26 billion in 2000.[43] The transition to broadband retailing as an alternative will increase this share and, therefore, increase consumer choice and economic efficiency.

The value added by retail and wholesale trade accounts for about 16 percent of GDP. Wholesale trade in the United States contributed $643 billion in value added in

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[43] U.S. Department of Commerce, "Estimated U.S. Retail E-Commerce Sales: 4th Quarter 1999 - 1st Quarter 2001", (downloaded from: www.census.gov/mrts/www/mrts.html).

1999 (7 percent of GDP), and retail trade contributed $856 billion (9 percent).[44] These retailing costs are in addition to the cost of consumers' time involved in shopping.

Consumers must travel to traditional retail establishments and compare the choices at one or more of these establishments. Additional time is required to select items, pay for them, and transport the goods home. Estimates suggest that the average adult spends about 30 minutes per day shopping for nongrocery items and about 15 minutes traveling for such shopping – a total of 45 minutes per day for nongrocery shopping.[45] The official accounting of retail trade's contribution to GDP does not include the time a consumer spends in these activities. It does, however, include the time a retail store's buyers spend going from supplier to supplier examining products and comparing prices. The disparate treatment of these two quite similar activities arises from the fact that one involves a market transaction, and the other does not.[46] Nevertheless, the time a person spends shopping is an important economic cost.

Assuming that the average person values his or her time at one-half the average wage of $12.40 per hour, the time spent in non-grocery shopping or traveling for non-grocery shopping is worth $4.65 per day.[47] At 365 days per year, this comes to $1,697 per

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[44] *See* Bureau of Economic Analysis, "Industry Accounts Data – Gross Domestic Product by Industry" (downloaded from www.bea.doc.gov/bea/dn2/gpoc.htm#1993-99).

[45] *See* National Science Foundation, "Family Time Use Study: 1998-1999 Time Diaries", (downloaded from: http://www.webuse.umd.edu/data_analysis.htm) .

[46] Such disparities in the treatment of economic activities abound in our system of accounting for economic activities. If one pays a painter $1,000 to paint one's house, that thousand dollars shows up in the GDP. In contrast, if the same person buys $100 worth of paint and supplies and paints his or her house, the GDP measurements only show $100 of GNP. State and federal income tax are not applied to the $900 of labor and skill supplied by the homeowner.

[47] The hourly value of $12.40 is used in the congestion analysis by the Texas Transportation Institute in its urban traffic studies discussed below. *See* Texas Transportation Institute, "*The 2001 Urban Mobility Report*", The Texas A&M University System, (May 2001), (downloaded from: http://mobility.tamu.edu/).

year per person. Multiplying by total persons 18 years of age or older (approximately 200 million), we get a total of $339 billion per year worth of time spent on nongrocery shopping.[48]

Combining producer value added for wholesale and retailing together with our estimate of consumer time expenditures, we see that retail activities create annual costs of roughly $1.9 trillion per year.[49] Even modest increases in the efficiency of an activity worth such a massive amount will result in substantial benefits. If speeding up the deployment of broadband improved the efficiency of this sector by only 3 percent, as compared with the savings under a slower scenario, the savings would total $57 billion per year. If such deployment improved efficiency by 10 percent, the savings would total $190 billion per year at current values. Assuming that the retailing/wholesaling costs are fully passed on to consumers, these savings accrue to consumers for *existing* consumption levels. If the demand elasticity for all consumer goods is –1.0, another $1 billion to $10 billion must be added for the consumer surplus gains from additional consumption. Thus, the total gains may be estimated at $58 billion to $200 billion under these cost-savings assumptions.

When universal broadband service is achieved, these gains will be much greater because of general economic growth. Assuming that the economy grows at an average rate of 2.5 percent per year for ten years, these savings would grow to $74 billion and

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48 If we were trying to model future effects with exactitude, we would use future population levels. However, our goal here is to provide a general calculation that provides a solid feel for the magnitude of benefits associated with more rapid broadband rollout. In this context, refining the population figures would be spurious precision.

49 We allow for 2.5 percent annual growth between 1999 and 2001.

$257 billion (current dollars), respectively.[50] These gains obviously depend on the share of households with broadband and the assumed savings available from improvements in the efficiency of retailing/wholesaling. In Table 2, we show the consumer benefits under various alternative values of these two crucial parameters.

TABLE 2
Consumer Gains from Broadband's Contribution to e-Commerce
($ Billions per Year)

	Improvement in Wholesale/Retail/Shopping Efficiency				
Share of Households with Broadband Access	0%	5%	10%	15%	20%
10%	$0	$12	$24	$36	$54
25%	$0	$30	$60	$90	$120
50%	$0	$60	$120	$183	$239
85%	$0	$102	$204	$306	$407
100%	$0	$120	$240	$360	$480

One can use his or her own estimates of the magnitude of the speedup in the adoption of broadband access and of the potential savings that broadband access will bring to the product distribution and shopping process. As the share of households that have broadband increases, however, one should increase one's estimates of the potential savings because of the "network effects" inherent in developing new shopping sites.

2. Reductions in Commuting

Telecommunications can substitute for travel – an oft-repeated truism. Substantial telecommuting has been just around the corner for the last three decades. In fact,

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50 In order to be conservative, we do not extend these projections past ten years.

telecommuting has grown slowly but steadily; helped in part by technologies such as personal computers, modems, fax machines, and high-quality telephone service.

As we have gained experience with telecommuting, our vision of this activity has changed. The image of an office worker working from home every day has faded, replaced with the image of an office worker who sometimes works at home but appears often at the office for face-to-face meetings. Obviously, many jobs – such as a car repair technician or a receptionist – are not suited for telecommuting. But many other jobs are. With modern telephone systems, some customer service representatives can work from home. With broadband Internet access, essentially every customer service representative or call center operator could work from home. In fact, with modern PCs and broadband access, most knowledge workers can have the same access to information at home as they have at their desks. The modern view of telecommuting takes many forms. For some people, for example, someone with a significant physical disability, telecommuting may entail working almost entirely from home. For others, perhaps a litigator, most days may be spent in the office, but a crash-writing project may be most effectively conducted from home.

a. An Example: Operation Job Match

Operation Job Match in Washington, D.C., illustrates the current status of telecommuting. Operation Job Match is "an employment program that assists people with adult-onset physical disabilities, such as multiple sclerosis, arthritis, diabetes, and lupus, to secure competitive employment." [51] A major element of the Operation Job Match

[51] Operation Job Match, "Telework: Connecting to the Job Market," (downloaded from: http://www.msandyou.org/programs_services/ojm/index.html).

program is finding what it calls *Telework* options for employees who suffer from physical disabilities. For some employees, Operation Job Match assists with the purchase of computers, printers, and fax machines and provides computer training. The textbox below, describing the breadth of telecommuting possibilities, was taken from the Operation Job Match website.

Operation Job Match

Telecommuting is a viable work alternative and a modern approach to employment. Approximately 250,000 employees currently telecommute in the Washington, DC region – a number that is sure to increase. The following are a sample of jobs that are conducive to telework:

- Customer service
- Writing, editing, drafting
- Computer programming
- Medical/legal transcription
- Software development
- Accounting, analysis and auditing
- Information technology
- Administrative/clerical/data entry
- Design work, graphics
- Project management
- Research and technical writing
- Preparing or monitoring contracts

b. The Texas Transportation Study

The primary direct benefits of telecommuting occur from the reduction in travel required by the employee and the reduction in infrastructure costs at the office. But a significant secondary benefit is a reduction in congestion costs. The Texas Transportation Institute's Urban Mobility Study reports estimates of the costs of traffic congestion in 68 urban areas.[52] Its 2001 report states:

> Congestion costs can be expressed in a lot of different factors, but they are all increasing. The total congestion "bill" for the 68 areas in 1999 came to $78 billion, which was the value of 4.5 billion hours of delay and 6.8 billion gallons of excess fuel consumed. To keep congestion from growing between 1998 and 1999 would have required 1,800 new lane-miles of freeway and 2,500 new lane-miles of streets – or – 6.1 million new trips taken by either carpool or transit, or perhaps satisfied by some electronic

[52] *See* Texas Transportation Institute, *supra* note 47.

> means – or – some combination of these actions. These events did not happen, and congestion increased.[53]

Analysis of the TTI report shows that 80 percent of these $78 billion in costs occurs in only 24 cities (comprising most of the larger cities in the United States), and 90 percent occurs in 36 cities. In Los Angeles, traffic congestion imposes estimated costs of $1,000 per person per year. Of course, the marginal congestion – that created by one additional commuter – is much higher than the average. Examining these data, Professor Paul Krugman of Princeton University concludes, "Do the arithmetic and you find that each individual's decision to commute by car in Atlanta imposes congestion costs of $3,500 per year, or $14 per workday, on other people. These are costs over and above the costs actually paid by the driver himself – that is, they are costs that drivers don't take into account. And this number does not take into account environmental impacts (air quality in Atlanta is steadily deteriorating)."[54]

The benefits from modest increases in telecommuting are thus far greater than would be indicated by the average values of congestion costs. Krugman's analysis indicates that in the case of Atlanta, the marginal congestion cost is 3.8 times the average

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[53] *Id,* at iii.

[54] Paul Krugman "Nation in a Jam," *New York Times*, Op-Ed page, (May 13, 2001). Professor Krugman's statement must be read carefully. He is asserting that the average marginal congestion costs of a single added commuter are about $3,500 per year. It is well known that, in queueing systems, the marginal congestion externalities are far worse than the average externality.

congestion cost.[55] Thus, a 1 percent reduction in busy-hour traffic in Atlanta could be expected to save almost $100 million per year.[56]

c. A National Estimate

The quantifiable benefits of telecommuting are the savings in transportation costs – both the time and expense of the worker and the reduction in congestion and pollution costs imposed on others. Non-quantifiable (or at least much harder to quantify) benefits of telecommuting include improvements in worker productivity and the expansion of employment opportunities for people with disabilities.

Various studies estimate that 20 to 40 percent of jobs permit telecommuting at least part of the time.[57] If we assume that 30 percent of jobs permit telecommuting an average of 20 percent of the time (1 day per week or 50 days per year) and that the average commuter trip for a telecommuter is 20 minutes, then we can calculate the potential savings in travel costs and congestion. The savings in travel time are:[58]

(180 million civilian labor force) · (30% possible telecommuters) ·
(33 hours/year) · ($6.20/hour) = $11.1 billion per year.

Similarly, the savings in travel costs are:

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55 The average congestion cost was $915 per person. *See* Texas Transportation Institute, *supra* note 47, at Appendix 9, (downloaded from: http://mobility.tamu.edu/2001/study/tables/A9.pdf).

56 TTI estimated total congestion costs in Atlanta of $2.62 billion. The calculation is (3.8) · (1%) · $2.62 billion = $99.6 million.

57 *See* International Telework Association and Council, "Telework America" (2000), (downloaded from: http://www.telecommute.org/twa2000/research_results_key.shtml) and U.S. Dept of Transportation, "Secretary Slater Challenges Federal Agencies to Increase Telecommuting Goals", (Oct. 24, 2000), (downloaded from: http://www.dot.gov/affairs/2000/dot21200.htm).

58 To project the civilian labor force in 2025, we multiplied the over-16 population estimate for 2025 times the current labor force participation rate. The Bureau of Labor Statistics does not project the civilian labor force past 2008.

(180 million civilian labor force) · (30% possible telecommuters) ·
(450 miles/year) · ($0.3/mile) = $7.3 billion per year.[59]

We take Krugman's model for congestion externalities described above (that the marginal commuting trip has congestion externalities 3.8 times those of the average commuting trip). However, we use a lower multiple (2.0 rather than 3.8) in recognition of the fact that Krugman's analysis was for Atlanta – the city that had the greatest increase in per capita congestion costs over the period considered. We reduce the estimated national congestion costs of $78 billion per year by 50 percent to reflect a more reasonable estimate of the value of travel time. Therefore, the external cost savings from telecommuting would be:

(30% possible telecommuters) · (average 20% reduction in commuting) ·
(2 peak multiple) · ($39 billion/year congestion costs) =
$4.7 billion per year.

Summing up, the potential savings from telecommuting are $11.1 billion/year travel time for telecommuters, $7.3 billion/year for travel costs, and $4.7 billion per year for reduced (external) congestion costs, yielding total savings of over $23 billion per year. Note that this is not an estimate of the savings from accelerated deployment of broadband access – this is an estimate of the total transportation system savings from widespread adoption of telecommuting. Assuming that these savings grow at a rate similar to the general growth rate we assume for the economy, these savings could be as much as $30 billion in ten years.[60]

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59 In accordance with the TTI report, we use an average trip length of 9 miles.

60 In order to be conservative, we do not extend these projections past ten years.

3. Home Entertainment

The multi-channel video revolution of the 1980s and 1990s created enormous value for consumers. No longer confined to the limited diet of off-air broadcasting, consumers could now choose from among scores or even hundreds of channels of movies, sports, news, travelogues, town meetings, and informational programs. As we show below, this explosion in choice created between $77 billion and $142 billion in annual value beyond the costs of the service (consumer surplus).[61]

The Napster sensation probably provides only a prelude to what is possible over household broadband connections. Downloading motion pictures or other video material, interactive television, interactive games, and even home editing of digitized entertainment material have not even begun in earnest. It is reasonable to assume that eventually the contribution to consumer surplus of new video and other entertainment options created by widespread diffusion of broadband Internet access would be at least as great as that already created by cable television and direct broadcast satellites. This provides us with an estimate of $77 billion to $142 billion per year.

This estimate is consistent with the remarkable growth in home-entertainment spending by U.S. consumers since 1980, the year that cable began to grow as the result of FCC deregulation of cable signal carriage (see Table 3). Total expenditures have risen by about $56 billion since 1980 (nominal dollars). If the price elasticity of demand at current prices is substantially less than one, the consumer surplus from this increase could easily be more than $100 billion per year. We see no reason why the next broadband revolution – delivered by the Internet – should not be of equivalent value.

TABLE 3
Total Home Entertainment Spending, 1980–99

Year	Entertainment Expenditures by U.S. Households ($ Millions)	Year	Entertainment Expenditures by U.S. Households ($ Millions)
1980	4,657	1990	29,822
1981	6,292	1991	32,160
1982	8,199	1992	34,009
1983	10,374	1993	38,016
1984	12,742	1994	39,513
1985	14,708	1995	42,380
1986	16,915	1996	46,647
1987	19,869	1997	50,730
1988	23,250	1998	55,231
1989	23,685	1999	60,765

Source: Paul Kagan Associates, *Media Trends 2001,* at 44.

4. Home Health Care

Health care is the biggest industry in the United States economy. In 1999, health care expenditures were $1.2 trillion, or 13 percent of GDP.[62] Chronically ill patients, who represent 1 percent of the population, account for one-third of health care expenditures. Telemedicine could provide substantial cost savings in the monitoring of chronically ill patients, by substituting remote monitoring for in-person monitoring.[63]

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[61] See Section VI.D, below.

[62] Health care expenditures in 1999 were $1,210.7 billion (HCFA), and GDP was $9,299.2 billion (BEA) in current dollars. *See* HCFA, "National Health Expenditures Aggregate Amounts and Average Annual Percent Change, by Type of Expenditure: Selected Calendar Years 1960-99", (downloaded from: http://www.hcfa.gov/stats/nhe-oact/tables/t2.htm) and Bureau of Economic Analysis, "GDP and Other Major NIPA Series", (downloaded from: http://www.bea.doc.gov/bea/ARTICLES/NATIONAL/NIPA/2000/0800gdp.pdf).

[63] "Electronic House Call Knocks on Door of Telemedicine Market", *Medical Industry Today,* (June 19, 2000).

Remote monitoring can reduce the response time needed to address problems of chronically ill patients who are at home, resulting in fewer hospitalizations and emergency room visits. Because the health care industry is very competitive, we would expect almost all of the savings in cost to be passed on to consumers.

Telemedicine cost savings could not only reduce labor hours due in the delivery of home health care and in chronic patient management, but it could also reduce the incidence of emergency room visits and hospitalization, due to better disease management.[64] According to Cyber-Care, the manufacturer of Electronic HouseCall, an Internet-based system that allows caregivers to monitor patients in their homes, independent industry studies have shown that remote monitoring of patients' conditions can reduce costs by 35 to 40 percent, while also improving care.[65]

Assuming that chronic care patients are responsible for $400 billion in health care expenditures, the following table represents the potential cost savings from increased efficiency in chronic care management.

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64 Kaiser Permanente, the largest health maintenance organization in the United States, conducted a quasi-experimental study of telemedicine between May 1996 and October 1997, in which both the treatment and control groups received routine health care and the treatment group also received interactive remote health care in real time. On average, a traditional in-person visit took 45 minutes, whereas remote video visits required less than half as much time (18 minutes). Clearly, remote video visits allow health care professionals to see more patients in a day. In addition, even though the average direct cost of health care delivery was higher for the treatment group ($1,830 versus $1,167), the total mean cost of care excluding home health care was lower for the treatment group ($1,948 versus $2,674). Much of the lower healthcare costs were a result of lower hospitalization costs ($1,087 versus $1,940). Considering that some of the costs of remote health delivery are one-time costs (such as purchasing and setting up the equipment), cost savings would exceed the additional cost of remote home health care. Source: "Outcomes of the Kaiser Permanente Tele-Home Health Research Project," *Archives of Family Medicine* 9(1), (Jan. 2000).

65 *Medical Industry Today*, *supra* note 63.

TABLE 4
Ultimate Cost Savings from Telemedicine
($ Billions per Year)

	Improvement in Chronic Care/Disease Management				
Share of Households with Broadband Access	0%	5%	10%	15%	20%
10%	0	2	4	6	8
25%	0	5	10	15	20
50%	0	10	20	30	40
85%	0	17	34	51	68
100%	0	20	40	60	80

Despite the sheer size of the health care industry in the United States, access to health care remains problematic for underserved regions, such as rural and inner city urban areas, and for less mobile populations, such as the elderly and disabled. Telemedicine would make health care more readily available to these populations, leading to an increase in consumer surplus. Already, a number of telehealth projects in the United States use high-speed data connections and videoconferencing technology to bring high-quality health care to rural and small-town residents.[66] In addition, the substantial savings in time associated with telemedicine would reduce the cost of health care for patients, thereby creating additional consumer surplus.

Consumer satisfaction is the key to widespread adoption of remote health monitoring. Several studies have examined patient and physician satisfaction with telemedicine. Results for patient satisfaction with telemedicine were positive in all studies. A University of Oregon report, funded by the Agency for Healthcare Research and Quality in the Department of Health and Human Services, examined 18 studies that assessed patient satisfaction with telemedicine and 10 studies that evaluated physician satisfaction with telemedicine. Only one study showed a preference for face-to-face assessments; the remaining reports all indicated high levels of satisfaction with telemedicine. A similar review conducted through the Telemedicine Center of the East Carolina University School of Medicine found overall high patient satisfaction. According to the Center's own study, 98 percent of patients are satisfied with telemedicine.[67]

Broadband access and reliable home networking will greatly facilitate the adoption of telemedicine. As David Schwartz, director of systems and networks for West Virginia University, Morgantown, and former director of the West Virginia Network, a state telemedicine initiative, points out, "the main concern with transmitting 3D images over a telecommunications network is the high consumption of bandwidth."[68] On the same point, Texas Telemedicine Project's Dr. Jane Preston says,

> And while local projects are making progress, telemedicine is not yet reaching into the homes because homes are still not linked to broadband networks. However, the technology is rapidly advancing and the price is dropping. When America's communications infrastructure evolves into wide access to two-way video, potential health care applications will

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[66] *See*, for example, Jeff Tieman, "Dialing up High-Tech Medicine; L.A. University Opens Doors to its Third Telemedicine Center to Serve Urban Patients," *Modern Healthcare*, (Jan. 1, 2001) and "Telemedicine: Catching the Wave of the Future," *American Health Line* (Sept. 15, 1994).

[67] Department of Health and Human Service, Health Resources and Services Administration, Office for the Advancement of Telehealth, "2001 Report to Congress on Telemedicine*"*, (downloaded from: http://telehealth.hrsa.gov/pubs/report2001/intro.htm). .

[68] "Telemedicine News: Starvision to Test Market Potential for Three-Dimensional Telemedicine Systems," *Health Data Network News,* (Mar. 20, 1998).

include a full range of screening, diagnosis and the delivery of services, monitoring and treatment.[69]

Unfortunately, it is difficult to quantify the consumer surplus resulting from the greater availability of health care, so we do not attempt to do that here. Moreover, we have not included the potential benefits from telemedicine's contribution to improvements in the quality of health care in our quantitative estimates of the potential benefits from widespread adoption of broadband. It is easier to quantify cost savings from telemedicine. Assuming telemedicine results in a 10 percent decrease in health care expenditures and all the savings are passed on to consumers in terms of lower health care costs, the increase in consumer surplus would be $20 billion with 50 percent broadband penetration and $40 billion with universal service. These estimates assume that the demand for health care does not change when prices fall. If consumers demand more health care at lower prices, then the increase in consumer surplus would be higher.

5. Broadband Access and Telephone Services

Soon the demand for broadband will reflect not only the growing potential uses of the Internet, but also the prospect for using these broadband connections to obtain voice telephone services currently provided over a narrowband connection. The use of broadband access to carry voice – ordinary telephone calls – as well as data will deliver substantial savings to consumers that are not captured in current demand estimates. Voice communications can be compressed, put in packets, and sent over an IP connection. If one has a network in the home or office, it is relatively easy to build a telephone that

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[69] *American Health Line, supra* note 66.

connects to the network and uses a Voice over Internet protocol (VoIP).[70] Today, a combined router/voice interface box costs about $170 – but that cost should fall considerably over the next few years.[71] Microsoft Windows includes the software needed to place voice calls over the Internet – usually all one has to do to enable voice communications on a networked PC is to plug a headset into the audio ports on a computer and run Microsoft Netmeeting. Cisco sells an Analog Telephone Adapter – a box that connects two analog phones to the Internet – for about $200.

A broadband connection can support several voice connections – the exact number depends on the speed of the connection and the degree of compression of the voice signal. The current structure with two networks in the home (a voice and an IP network) and two connections to the outside world (a narrowband analog connection and a high-speed digital connection) appears inefficient. However, the transition to Internet telephony will take many years. The existing inside wiring, designed for voice systems, must be upgraded or replaced. The analog telephones must be replaced or connected to digital adapters, and there will be difficult issues of addressing, numbering, and directory services. Broadband connections must become highly reliable, and the quality of packet telephone calls must improve.

The cost savings from integrated access will be significant. Reliable Internet telephony would eliminate the need for second or third lines in households for teenagers or fax machines. The Federal Communications Commission (FCC) estimated that the

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70 *See*, for example, Cisco, "Technical Tips – Voice over IP (VoIP) Frame Relay (VoFR) and ATM (VoATM)" (downloaded from: http://www.cisco.com/warp/public/788/voip/voip.shtml).

71 The Linksys BEFN2PS4 - EtherFast Cable/DSL & Voice Router is advertised at $170. *See* Erwincomp.com, "Linksys BEFN2PS4 Cable / DSL and Voice Router" (downloaded from: http://www.erwincomputers.com/linbefcabdsl2.html).

average household spent $55 per month on local and long-distance telephone service in 1999, and there were 0.289 additional lines for each household with telephone service.[72] Within a few years, broadband access will permit consumers to substitute other services for these services that now cost $55 per month.

The FCC estimates that the average residence spends $34 per month for local telephone service and $21 for long-distance telephone service. Part of that local telephone service cost is for the loop that is used for the broadband service. Consumers continue to incur most of those loop costs when broadband service is used, but they avoid the cost of the analog line card, the voice switch, and the voice transmission lines. IP telephony should lower the costs of both local and long-distance telephone service, while providing residences with the equivalent of several telephone lines. We estimate that such savings could average $25 per month per household. In addition, households with broadband service would get the equivalent of multiple voice telephone lines. We estimate that this additional service or option of service could be worth $10 per month to the average household.[73] Thus, in the longer run (say a decade from now), broadband access could deliver voice communications benefits of about $35 per month, or $420 per year, to the average household with telephone service. If we assume that 122.2 million households

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[72] FCC, "Trends in Telephone Service", 2nd Report (2000), (downloaded from: http://www.fcc.gov/Bureaus/Common_Carrier/Reports/FCC-State_Link/IAD/trend200.pdf), at Tables 3.2 and 8.4. Note that, because some households may have three or four telephone lines, this ratio has to be described carefully.

[73] The FCC's numbers indicate that the average household with telephone service has 1.289 access lines and pays local service fees of $34 per month. Assuming that all lines cost the same (which is not quite right but is reasonable), the average household with telephone service in 1999 paid $7.62 per month for additional line service. If those households without a second line today place an average value of no more than $3.40 per month for second line of service, then the average household will value a second line at $10 per month or more.

have telephone service, these benefits would total $51.4 billion per year, assuming no growth in voice usage. The actual value could be much higher.

The substantial economic benefits (principally savings from expenditures on telephone service) created by providing multiple services over a high-speed line almost cover the cost of a high-speed line – we have estimated that benefits of $35 per month are created by a broadband connection that costs $40 per month. These savings are one reason why we believe that it is reasonable to expect that the fraction of households with high-speed access services will ultimately approach the fraction that has telephone service today.[74]

E. Summing Up the Consumer Benefits

Given the vast uncertainty about the future effects of broadband access, it is difficult to offer compelling quantitative forecasts of the economic benefits of speeding the deployment of broadband access. Because broadband provides consumers and producers with a new alternative that has few harmful external effects that we can identify, it is reasonable to focus only on the benefits of broadband access.[75] These benefits are summarized in Table 5.

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[74] Another way to look at it is to consider the engineering design. Why have two line cards at the telephone central office – one in the voice switch and one in the DSLAM – if the line card in the DSLAM has roughly ten times the capacity of the line card in the voice switch? If we were building the telephone network from scratch today, broadband access connections would be the natural building block.

[75] We are not aware of any significant harmful externalities associated with the wider deployment of broadband access. Obviously, there are minor harmful externalities, such as the hydrocarbon emissions associated with the trips by installers to the residence and any externalities associated with the generation of electricity to operate the broadband equipment and computers. However, these systems use little power and the continuing externalities appear to be minor. If it turns out that broadband access will create significant harmful externalities, then our estimates will overstate the net benefits.

TABLE 5
Summary of Consumer Benefits from Universal Broadband Deployment
($ Billions per Year)

Source	Low Estimate	High Estimate
Direct Estimates:		
Broadband Access Subscription	284	427
Household Computer and Network Equipment	13	33
Total Benefits	**297**	**460**
Alternative Estimates – Benefits Deriving from:		
Shopping	74	257
Entertainment	77	142
Commuting	30	30
Telephone services	51	51
Telemedicine	40	40
Total Benefits	**272**	**520**

F. Producers' Surplus

Obviously, a successful innovation generates value for producers, as well as for consumers. For example, consumers have benefited handsomely from the development of automobiles and personal computers, but these two innovations left Henry Ford and Bill Gates among the wealthiest persons of their times. Their ability to produce automobiles or computer software and to sell them at prices above the cost of the inputs required in the production process provided them with substantial producer surplus. But others, such as skilled workers, owners of natural resources, and holders of complementary patents, also received some of this surplus.

It is extremely difficult to estimate the potential flow of producer surplus from the widespread diffusion of broadband, but we can attempt to provide one based on various possible measures of the elasticity of supply of the services involved. The principal effects of greater broadband connectivity are registered in four different sectors of the economy:

1. Telecommunications – the direct revenues from greater broadband connectivity.
2. The computer equipment and software industries – increased household purchases of equipment and software.
3. The retail and wholesale sectors of the economy – greater efficiency in the distribution of consumer products.
4. Entertainment – greater demand for entertainment products through the Internet.

We begin with our estimates of the increase in total sales to consumers of broadband services, computer equipment, general consumer goods, and new services that are developed because of widespread diffusion of broadband Internet access. We then calculate the share of such revenues that could be reasonably assumed to accrue to suppliers as producer surplus.

1. Broadband Services

The delivery of broadband services requires the use of existing telecommunications networks plus substantial expenditures on new electronics within such networks (multiplexers, line cards, etc.), as well as expenditures on consumer modems. Therefore, any increase in the demand for broadband will generate additional revenues not only for the suppliers of that service but also for the suppliers of the equipment used to deliver the service.

A substantial share of the revenues for modern electronics equipment accrues as rents to the intellectual capital required to develop it and to the substantial initial costs of building the facilities to produce it. It is obvious that today's price of a microprocessor or storage device does not reflect its marginal production costs. But it is difficult to estimate – in general – how much of any increase in demand will accrue as rents to the owners of the risky capital invested in the technology required for the production of such equipment.

For broadband services, we conservatively assume that 50 percent of the revenues are spent on the electronics and related equipment to deliver the service and that 20 percent of the remainder accrues as "quasi-rents" to the supplier of the communications service itself. We further assume that between 20 and 40 percent of the revenues absorbed by purchases of the requisite electronics equipment accrue as rents to the owners of scarce intellectual and physical capital required to produce it. Under these assumptions, we may calculate the producers' surplus for an expansion of broadband to 50 percent of households and to "universal service" proportions of 94 percent of households. The results range from $6.2 billion to $17.6 billion per year. (See Table 6 below.)

TABLE 6
Estimated Increases in Producer Surplus from Greater Broadband Connectivity
($ Billions per Year)

	Share of Revenues that Accrue as Rents to Producers		
Source	20%	30%	40%
	At 50 % penetration		
Broadband Access Subscription	6.2	7.8	9.4
Household Computer Equipment	10.6	15.9	21.2
Entertainment	7.9	11.9	15.8
	At 94 % Penetration		
Broadband Access Subscription	11.7	14.7	17.6
Household Computer Equipment	22.0	33.0	44.0
Entertainment	26.3	39.4	52.5

2. Computer Equipment

For computer equipment, we assume that the growth rate of spending would resume its 1991–95 growth rate of 14.3 percent at 50 percent broadband penetration. Were broadband to become universal, we assume a growth rate of 17.3 percent. These growth rates are much higher than the 10.4 percent growth rate that was experienced in the period between 1995–99.

To estimate the share of increased revenue that accrues to suppliers as producers' surplus, we estimated the percentage of revenues that will accrue as rents to intellectual capital. Similar to broadband service, a substantial share of the revenues for computer equipment accrues as rents to the intellectual capital used developing the technology. The price of a computer exceeds the marginal cost of building it. We examined the market-to-book ratios of major computer hardware and software producing firms (Dell, Gateway, Hewlett Packard, Microsoft, and Intel). The market-to-book ratios range from 2.83 for Gateway to 11.90 for Dell[76], implying capitalized rents above the acquisition cost of assets of 65 to 92 percent. Given the variable costs of production, these rents are likely to be a substantially smaller fraction of revenues. We use a range of 20 to 40 percent of revenues as an estimate of the amount of additional revenues that are likely to accrue to producers as surplus. Under these assumptions, producers' surplus generated in the computer sector from widespread broadband deployment could range from $10.6 billion to $44 billion per year.

3. General Consumer Goods Distribution

Consumer goods distribution is a $1.5 trillion sector of the economy today. The efficiency of distribution will increase with the penetration of broadband, as more consumers move to online shopping. Because the consumer goods industry is a very competitive industry, we would expect the supply curve to be very elastic. This means that most of the savings in cost will be passed on to consumers. The savings in distribution costs will largely be registered through a shift of from traditional distribution to on-line commerce. Traditional retailers will grow more slowly, and on-line retailers will grow more rapidly.

There likely will be substantial gains to the successful first movers in e-commerce, despite the current pessimism over the inability of some, such as Amazon.com, to achieve profitability. To achieve a reduction in total distribution costs of 3 to 10 percent, e-commerce will surely have to account for more than 10 percent of all

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[76] Market-to-book ratios downloaded from Yahoo! Finance.

retailing in 25 years. However, we have no basis for estimating how much of the substantial commerce involved will be appropriated as surplus by the successful innovators.

4. Entertainment

Entertainment spending by U.S. consumers has been growing consistently every year since 1980, the year the FCC deregulated cable signal carriage. We assume that entertainment spending with universal broadband service will continue to grow at the same rate that it did in the period between 1980–99 (14.5 percent). With 50 percent broadband penetration, we assume that entertainment spending will only grow at 11 percent. With no broadband penetration growth, we assume that spending will increase at its 1995-99 rate of 9 percent.

The fraction of revenues that accrue to "talent" in the motion picture industry is substantial but very hard to estimate. Assuming rents of 20 to 40 percent of revenues, the increase in producers' surplus from an increase in entertainment spending ranges from $7.9 to $52.5 billion (see Table 6).[77]

G The Benefit of Faster Adoption of Broadband

The analysis in the preceding section offers estimates for the annual benefits from the universal or near-universal adoption of broadband access. The estimates do not account for the time required to reach this universality of broadband. Rather, they simply

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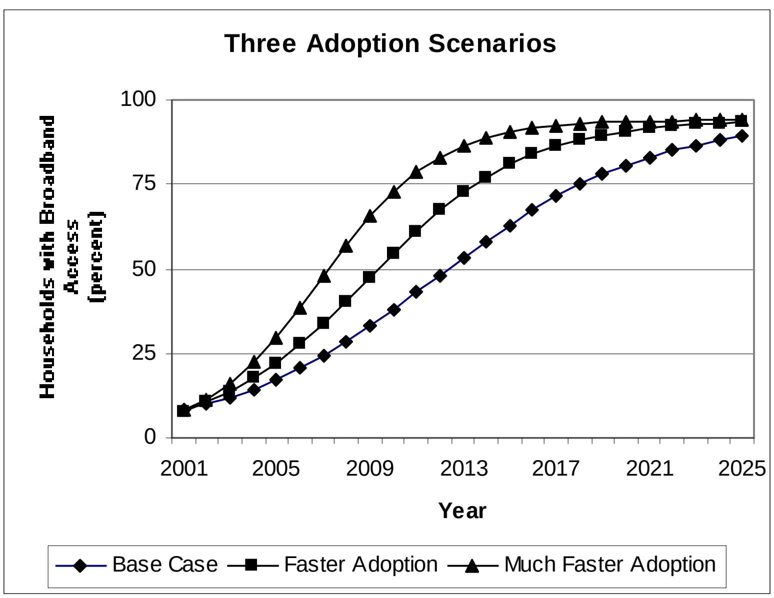
[77] This estimate is based on a ten-year projection from 2001. The 2001 estimate is equal to 1999 spending of $60.8 billion increased at a 9 percent rate, or $72.8 billion.

reflect the potential benefits available when broadband reaches maturity and perhaps becomes as ubiquitous as today's ordinary telephone service.

The value of these ultimate benefits *today* is lower because they are achieved gradually over time. The proper way to estimate such benefits is to calculate a time stream of benefits and then to discount those benefits back to the present. Figure 5 below illustrates three possible scenarios for the adoption of broadband access over the next 25 years. The graph shows the fraction of households with broadband access. Each scenario begins with 8 percent of households having broadband access at the beginning of 2001 and ends with 94 percent having broadband access in 2025.

FIGURE 5
Adoption of Broadband Access



The lowest of the three curves is for a pessimistic "base case" scenario, which represents a relatively smooth transition from today's levels of broadband deployment to a level comparable to that of telephone subscription over a period of 25 years. Although the base case scenario is an S-shaped adoption curve, the curvature is gentle. In this scenario, the peak growth rate occurs in 2011 and is twice the average growth rate over the period. The middle curve represents a faster adoption scenario in which the growth rates are higher in the early years and peak growth occurs in 2009. The top curve represents a very rapid adoption scenario in which growth rates peak in 2007 at 11 percent of households per year.

Speeding up the adoption of broadband access provides benefits earlier. The present value of the difference between the base adoption scenario and the much faster adoption scenario of our example above is 140 percent of one year's worth of the benefits of ubiquitous broadband adoption by households.[78] Thus, if one assumed that, when fully adopted, broadband generated benefits of $300 billion per year to American consumers, a policy change that moved our society from the baseline adoption curve to the much faster curve in the Figure 5 would generate benefits with a net present value of about $420 billion.[79] The increase in the present value of producers' surplus would be about $80 billion. This acceleration is therefore worth $500 billion to U.S. consumers and producers.

A skeptic, on reading this, will necessarily have doubts – how could speeding up the adoption of a technology have such massive benefits? The key lies in the substantial benefits that ubiquitous broadband can convey to consumers. Once virtually everyone has the service, the network effects from developing new services become very large. Moving these benefits forward a few years can create very large benefits – even when evaluated from today's perspective.

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[78] This was calculated using a discount rate of 10 percent and assuming a 2 percent per year growth in the economy.

Obviously, if these assumptions prove to be incorrect because some other innovation intercedes in the next 25 years, these benefits will prove to have been overestimated.

VI. The Benefits from Earlier Innovations in Network Industries

Broadband communications is hardly the first example of a revolutionary network technology. The development of railroads, electricity, the interstate highway system, the airline industry, energy pipelines, the telephone, and multi-channel video distribution (cable and satellite) are obvious examples of forerunners to the Internet and broadband. Each of these new technologies made major contributions in terms of economic value and wealth and in most cases the magnitude of their influence and the variety of their use far exceeded initial expectations at the time of their introduction. In this section, we review the published estimates of the benefits of some of these revolutionary technologies.

A. Railroads

Early research on the effect of railroads on economic growth found that the railroad was the most important innovation of the last two-thirds of the nineteenth century. For example, Jenks points out that the railroad

> [a]ppears as the *sine qua no*n of America economic growth, the prime force behind the westward movement of agriculture, the rise of the corporation, the rapid growth of modern manufacturing industry, the regional location of industry, the pattern of urbanization, and the structure of interregional trade.[80]

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[79] These present values are 2.8 and 4.2 times the ultimate value of broadband adoption when evaluated at an interest rate of 10 percent per year.

[80] As quoted by Robert W. Fogel, "A Quantitative Approach to the Study of Railroads in American Economic Growth: A Report of Some Preliminary Findings," *Journal of Economic History*, (22)2, (June 1962), at 164.

Cootner also maintains that the railroad was a crucial factor in American economic growth:

> Without the cheap land transportation that railroads provided, the United States – and more particularly the trans-Appalachian region – would have found it more difficult to use the economies of specialization that were so important to both the level of per capita income and its rate of growth in the nineteenth century.[81]

Cootner claims that the railroad expansion was due to several factors: (1) demand for coal driven by urbanization had increased, (2) water canals did not reach the higher altitudes where the coal mines were located, (3) passenger traffic between cities required faster transportation than the water canals could provide, and (4) cotton railroads were put in place where there was no other alternative.

Nevertheless, Fogel's pathbreaking research finds that the effect of railroads was not as great as previously thought. There is considerable evidence that shows a strong association between the diffusion of the railroad and economic growth. The causal relationship between railroad diffusion and economic growth, however, is predicated on the assumption that railroad transportation was cheaper than the alternative, water transportation. In the absence of water transportation (when the only alternative to railroad transportation would be land transportation by wagon), the social saving from railroads would be $4 billion per year, or more than one-third of gross national product in 1890. However, with water transportation as an alternative, the social saving was only $70 million per year, or less than 1 percent of gross national product in 1890. Thus, the

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[81] Paul H. Cootner, "The Role of Railroads in United States Economic Growth," *Journal of Economic History*, 23(4), (Dec. 1963), at 477.

development of canals and improvements to other inland waterways, in combination with the huge investments in railroads in the nineteenth century, were responsible for a very large share of U.S. GDP.

B. Electricity

The shift from steam to electric power took place between 1880 and 1930 in the United States. The use of electricity reduced the cost of energy, but more important, increased the productivity of labor and capital input. Devine summarizes the advantages of electric power over other forms of power:

> The form value of electricity was due to the precision in space, in time, and in scale with which energy in this particular form could be transferred. Motors could convert electrical energy to mechanical energy precisely where the conversion was needed – the drive shaft of a machine. This conversion and transfer of energy could be exactly controlled with respect to time – that is, it could be started, stopped, or varied in rate as needed. And finally, electric motors could be accurately matched to the power requirements of machines. Thus, electric unit drive was an extremely flexible technique for driving machinery; and because of this flexibility, manufacturers could turn their attention away from problems of power production and distribution and toward improving the overall efficiency of their operations.[82]

Electricity was an invention that truly transformed manufacturing. The flexibility of electric power allowed for improvements in factory organization; machinery could now be arranged according to the natural sequence of manufacturing operations, rather than close to the source of power. Labor and capital productivity rose as electricity replaced steam as the source of motive power. In 1919, electricity accounted for 53 percent of the country's motive power and in 1929, 78 percent. During the same period, output per unit of labor rose from 186.6 to 321.5, and output per unit of capital rose from

48.9 to 74.5.[83] Perhaps not all of this increase in productivity is attributable to the switch to electric power. Anecdotal evidence, in the form of manufacturers' reports, however, suggests that most of it is. Crocker summarizes a number of these reports:

> It is found that the output of manufacturing establishments is materially increased in most cases by the use of electric driving. It is often found that this gain actually amounts to 20 or 30 percent or even more, with the same floor space, machinery, and number of workmen.[84]

C. The Telephone

As John R. Pierce of the California Institute of Technology points out, when Bell invented the telephone in 1876, society appeared to have been doing very well without it. Quickly, however, "the telephone has become more than a luxury or a convenience; it has become a basic part of man's world."[85] Colin Cherry, Professor of Telecommunication at the Imperial College, London, credits the development of the telephone system with having facilitated "revolutionary" progress in both the economic and social spheres of society.[86] From an economic standpoint, "telephone service is essentially organizational in function; it creates *productive* traffic"[87] by its very existence. According to Cherry, the importance of telephone networks lies in their "contribution to the organized bureaucracy

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82 Warren D. Devine, Jr., "From Shafts to Wires: Historical Perspective on Electrification," *Journal of Economic History*, 43(2), June 1983, at 371.

83 *Id.*, at Table 2.

84 Crocker, *Electric Distribution of Power,* as cited by Devine, *supra* note 82, at 364.

85 John R. Pierce, "The Telephone and Society in the Past 100 Years," in Ithiel de Sola Pool, ed., "The Social Impact of the Telephone", MIT Press, (1977), at 159.

86 Colin Cherry, "The Telephone System - Creator of Mobility and Social Change," in Ithiel de Sola Pool, ed., "The Social Impact of the Telephone", MIT Press, (1977), at 113.

87 *Id.*, at 114.

that is the hallmark of modern industrial society."[88] The introduction of telephone networks changed the way businesses were organized. It was no longer necessary to be at the same location to conduct business. Weiman suggests an affinity between long-distance telephone service and two industries that rely on communication between two distant points: wholesale trade and hotels.

> The largest users of toll and long-distance service in the mid-1920s were hotels, which furnished business executives and sales agents with lodging and vital services during their routine trips to the nation's economic capital. The second set of establishments included the corporate offices, often headquarter facilities, of national and multi-national firms. In both cases, toll connections were essential to conduct wholesale trade, whether to reach retail customers in the trade area or to keep close contact with distant production facilities and distribution centers.[89]

In two separate articles published in *Telecommunications Policy,* Cronin *et al*. show the effect of telecommunications infrastructure on the growth of the economy and productivity growth. Both articles analyze data from 1958 to 1990. Cronin concludes that the causal relationship runs both ways: investment in telecommunication infrastructure stimulated economic growth, and economic growth stimulated investment in telecommunications infrastructure:

> [A] feedback process [exists] in which telecommunications investment enhances economic activity and growth while economic activity and growth stimulate demands for telecommunications investment.[90]

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[88] *Id*., at 113.

[89] David F. Weiman, "Building Universal Service in the Early Bell System: The Reciprocal Development of Regional Urban Systems and Long Distance Telephone Networks," mimeo, Russell Sage Foundation, (2001).

[90] Francis J. Cronin, Edwin B. Parker, Elizabeth K. Colleran, and Mark A. Gould, "Telecommunications Infrastructure and Economic Growth: An Analysis of Causality," *Telecommunications Policy,* 15(6), (Dec. 1991), at 533.

Productivity growth in the telecommunications sector has been far higher than average productivity growth, and investment in telecommunications infrastructure has contributed to overall productivity growth.

> Without advances in telecommunications production, the U.S. economy would have experienced greater declines during the 1970s and a slower recovery during the 1980s.[91]

The authors also report that over the time period between 1975–90, the percentage of productivity gains in the economy due to telecommunications advances ranged from 18 to 37 percent, averaging 25 percent.

D. Multi-channel Video Distribution

Until the 1980s, most U.S. households were limited to three or four television viewing options because of the FCC's spectrum allocation policy. Some communities had even fewer viewing options because of their remote location or because of topographical obstructions. To relieve the latter problem, small "cable" television systems began to retransmit signals from nearby locations in the 1950s. In time, cable television evolved into a delivery system with enormous capacity, but only after nearly two decades of struggling against restrictive FCC regulation.

The most restrictive of the FCC cable rules were relaxed in 1979, a year in which there were only 15 million cable television households in the United States. Twenty years later, the number of cable subscribers had expanded to more than 65 million.[92] Moreover,

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[91] Francis J. Cronin, Elizabeth K. Colleran, Paul L. Herbert, and Steven Lewitzky, "Telecommunications and Growth: The Contribution of Telecommunications Infrastructure Investment to Aggregate and Sectoral Productivity," *Telecommunications Policy,* 17(9), (Dec. 1993), at 679.

[92] U.S. Bureau of the Census, "Statistical Abstract of the United States" (downloaded from: http://www.census.gov/prod/2001pubs/statab/sec18.pdf), at 567.

in the 1990s, two new high-powered satellite broadcast services were launched. These two services, DirecTV and Echo Star, each offer more than 200 channels of programming and now have more than 15 million subscribers between them.[93] To counter this new form of competition, cable television operators have adopted digital transmission techniques to increase their capacity to 100 or more channels.

This remarkable expansion in television service has created substantial value directly and indirectly for consumers. Hundreds of new program services have been developed and placed on satellite transponders to feed the thousands of local cable systems. These services are available to the satellite broadcasters, as well. More than 80 percent of all television households subscribe to cable, a satellite service, or both. The value of the packages they can now receive is many times the value of the three to four off-air channels that were available to generations ago.

In a recent book, one of the current authors and Harold Furchtgott-Roth estimate that in 1993, an additional cable channel was worth $0.70 per month to the average household, and an additional broadcast channel was worth $0.93 per month, all expressed in 1992 dollars.[94] Because the average household was offered 23 basic cable channels and 6 off-air stations at the time, one may conclude that the 30th channel choice would be worth $0.70 per month, while the 7th choice would be worth $0.93 per month. For purposes of extrapolating to hundreds of channels, therefore, we assume that this rate of decline holds as we move out from the 30th channel. Quadrupling the number of choices

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[93] Paul Kagan Associates estimates 15.3 million subscribers by year-end 2000. *See* Paul Kagan Associates, "Economics of Basic Cable Networks 2001," (July 2000), at 106.

[94] Robert W. Crandall and Harold Furchtgott-Roth, *Cable TV: Regulation or Competition*, Brookings Institution Press, (1996), at Table 3.2.

from 30 to 120 would reduce the marginal value of a channel by about 25 percent to about $0.53 per month in 1992 dollars.

How much is the option to receive up to 200 channels worth to households today, given the above results? Assuming that households could receive 6 channels off the air today without cable or satellite services, the next 94 channels would be worth $61.43 per month. For all 105 million U.S. households, these 94 channels are worth $77.4 billion per year. An additional 100 channels would increase this total value to $142.1 billion per year. Thus, the development of these two new technologies that offer as many as 200 channels per year directly create nearly $150 billion in value for consumers every year, but they also create value indirectly. By expanding the network of opportunities for exploiting the value of new entertainment, information, and interactive services, cable and satellite broadcasting have induced the production of new products that would never have been possible had cable simply remained a limited retransmission service with less than 10 million subscribers, as it was for nearly two decades.

The proliferation of cable and satellite has clearly created new video production opportunities that are exploited on other media, such as videocassettes, foreign television, and movie theaters. In addition, widespread cable and satellite coverage of sports leagues have created new markets for such sports as soccer, lacrosse, tennis, horse racing, and a variety of regional college athletics.

Finally, the growth of the multi-channel distribution systems has created huge rents for the inputs to the *production* of cable-satellite programming. This value is not captured in the consumer welfare calculations above. These rents have become so large that the entire Los Angeles MSA's economy is now being put at risk by the threat of a writers' strike.

VII. Conclusions

Although it will take many years, the widespread adoption of broadband access service will bring enormous economic benefits to our economy. No doubt many of the impacts cannot be foreseen. But some benefits can. We have calculated estimates of the economic benefits using two quite different methods. The first approach uses a prospective demand function for high-speed access and then calculates the consumer surplus associated with that demand function with high-speed access priced at $40 per month. We also include the benefits to consumers of any higher-quality network and computing equipment that they would purchase to use with their high-speed network access and the benefits to producers of greater purchases of network services and computer equipment.

Our second approach attempts to identify the sources of the specific benefits that broadband access can provide and to calculate the consumer surplus associated with such benefits. For example, if broadband access means that a consumer no longer needs to buy a second telephone line at $20 per month for dial-up access, we would count that as a $20 per month benefit of high-speed access.

TABLE 7
Summary of the Estimated Consumer Benefits from Universal Broadband Deployment
($ Billions per Year)

Source	Low Estimate	High Estimate
Direct Estimates:		
Broadband Access Subscription	284	427
Household Computer and Network Equipment	13	33
Total Benefits	**297**	**460**
Alternative Estimates – Benefits Deriving from:		
Shopping	74	257
Entertainment	77	142
Commuting	30	30
Telephone services	51	51
Telemedicine	40	40
Total Benefits	**272**	**520**

As Table 7 shows, these two different approaches provide quite comparable estimates of the prospective consumer benefits from broadband. From these two approaches, we conclude that the annual consumer benefits from broadband could eventually reach three hundred billion dollars per year. In addition, producers will also benefit from increased demand for electronic equipment used in the delivery of broadband service, increased spending on household computer and networking equipment, increased spending on household entertainment, and improvements in health care delivery. These benefits could easily amount to another $100 billion per year if broadband becomes ubiquitous. Thus, a reasonable figure for the total annual benefits to the U.S. economy of the widespread adoption of broadband access in all its forms – ADSL, cable modems, satellites, 3G wireless, and others – is $400 billion per year.

A faster rollout of high-speed access services gives us these benefits earlier. Under optimistic – but still reasonable – scenarios the net present value of a faster rollout of high-speed access could be as high as $700 billion, and a mid-range estimate of the value of faster rollout is $500 billion.[95]

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[95] We calculated the net present value of the difference between various adoption scenarios. With a discount rate of 8 percent the NPV of the difference between the base scenario and the faster scenario shown in Figure 5 is 100% of the end-year benefits and the NPV of the difference between the base scenario and the much faster scenario is 180% of the end-year benefits.

Appendix 1: Alternative Delivery Systems for Broadband Service

A. ADSL

ADSL is a simple concept. Equipment much like an ordinary modem can transmit data over the copper wire running from the home or office to the telephone company central office. Such digital subscriber line (DSL) modems can transmit data at far higher rates than is possible over voice-grade connections because they can take advantage of capacity in the copper wire that is not used for voice communications. Often the term *asymmetric digital subscriber line* (ADSL) is used. ADSL refers to a DSL system in which the transmission capacities in the two different directions are different – a split that can be useful for web browsing or distribution of audio or video programming.

ADSL service is limited by loop quality, distance, and the use of digital loop carrier systems. ADSL connections can be restricted or even made unworkable if the copper loop is impaired. For example, loading coils, which improve voice transmission on longer loops, must be removed for ADSL to work. The ability of copper telephone loops to carry high-speed data signals declines with distance. Thus, a copper loop a mile long might be able to carry ADSL signals at one million bits per second. An essentially identical loop, but two miles long, might be able to carry ADSL signals at only 300 thousand bits per second.

For decades, local exchange carriers have used a technology called digital loop carrier (DLC) to lower the cost of providing telephone service. In digital loop carrier systems, a high-capacity digital transmission line is run to a remote terminal in the neighborhood. At the remote terminal, the digital voice signal is converted to analog and transferred to copper loops. Digital loop carriers save money by substituting one high-capacity transmission system for many lower-capacity copper loops. Unfortunately, DLC systems do not provide a copper connection all the way from the telephone company central office to the subscriber location. The solution to this is to upgrade the capabilities of DLC systems to enable then to support ADSL service over the copper connection to the subscriber premises.

B. Cable Modems

Cable television systems can provide both telephone service and high-speed, two-way data communications service. In order for a cable system to be able to provide high-speed data service, the cable system must be modified to support communications on the return link, and a specialized two-way communications terminal must be installed in the home. Such two-way terminals are usually called cable modems, and the service is often called cable modem service.[96] Cable modem service provides data communications to users at data rates up to a few million bits per second.

Cable modem service has been relatively successful in the marketplace. All data sources agree that cable modem service is the most widely used form of high-speed Internet access. For example, the Yankee Group estimated that there were 3.7 million cable modem households in the United States at year-end 2000. In contrast, the Yankee Group estimated that there were 1.7 million DSL subscribers.[97]

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[96] For a description of the development of the cable modem standard *see* CableLabs' Project Primer at http://www.cablemodem.com/docsisprimer.html.

[97] Michael Goodman, "Residential Broadband: Cable modems and DSL", *The Yankee Group, Boston*, (Mar. 2001).

C. Wireless

The term *wireless* encompasses a wide range of possible technical alternatives, including satellite systems, cellular and PCS services, services in the MMDS and LMDS bands, and services in the unlicensed bands. Unlike DSL and cable modems, most of these technologies will require several years to develop and even longer to gain widespread use. They are also less familiar to many.

Satellite systems are the most widely used of the high-speed wireless options today. Two firms, DirecPC and StarBand, provide two-way satellite-based Internet access. These systems provide service at data rates of about 400 to 500 kilobits per second. Satellite firms appear to be targeting customers in rural areas who will not be offered DSL or cable-modem service. The next generation of satellite systems, due in orbit in about 2002, will offer higher data rates and much more system capacity.

Today, there are about 115 million subscribers to wireless telephone – cellular and PCS – service. Many of these wireless phones can provide Internet connections at about 10 kilobits per second – considerably slower than even today's dial-up connection. Typically, current-generation wireless phones do not provide always-on connections. This will change over the next few years as third-generation wireless systems, sometimes called "3G wireless," replace and supplement the current second-generation systems. The 3G systems promise to provide access at rates in the megabit-per-second range and will have the advantage of portability and lower cost than current systems or 2.5G systems.

The FCC has licensed two radio services, MMDS and LMDS, which also can be used to provide wireless Internet access to fixed locations. MMDS (multi-channel multi-point distribution service) is a radio service that was originally used to provide a wireless alternative to cable television. Sprint and WorldCom have obtained the right to use many of the MMDS licenses and are using some of their licenses to provide high-speed Internet access. MMDS technology can serve customers within a range of about 15 miles of a base station and requires a line-of-sight path between the antenna at the residence and the antenna at the MMDS service provider's base station. The FCC has also licensed a second service, the local multipoint distribution service (LMDS). LMDS operates at frequencies ten times higher than those used by MMDS. Consequently, LMDS transmissions are strongly attenuated by rainfall

Unlicensed radio bands provide yet another alternative for high-speed Internet access. The FCC has made several radio bands available for operation on an unlicensed basis using low-power radios. Perhaps the most well known of the unlicensed operators is Metricom.[98] Metricom offers its Ricochet service in several communities around the country. The original Metricom service ran at 56 kilobits per second; an improved version is being deployed that operates at 128 kilobits per second. A few hundred smaller ISPs have used unlicensed wireless to provide links to their customers. Typically, such systems run at data rates of about one million bits per second and can serve customers at ranges of up to about 15 miles.[99] It is still unclear how successful unlicensed radio services can be for small business and residential Internet access. In rural areas, where the probability of interference is low, unlicensed radio may become a real competitor.

Short-range communications using wireless LAN technologies are much less likely to suffer from harmful interference than longer-range systems. There has been

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98 For a description of their services see http://www.metricom.com/

99 Several ISPs that use unlicensed radio channels for access are listed at

substantial interest in providing broadband Internet access at public points, such as airports and restaurants using such technologies. For example, Starbucks has announced a program to put 11-million bit/second wireless LANs in all three thousand of their U.S. retail outlets.[100] Several airlines now provide wireless LAN connections in their airport lounges. These short-range services will probably not be used to provide access for homes or businesses.[101] However, they show the value that people attach to high-speed Internet access, and they will stimulate the adoption of high-speed Internet access more broadly.

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http://www.cmc.com/lars/engineer/wireless/w-isp-list.htm

100 *See* Bob Brewin "Starbucks Takes Wireless Leap," *ComputerWorld,* (Jan. 8, 2001).

101 Some people envision a world in which many such short-range wireless LANs, by cooperatively sharing capacity and relaying messages to a backbone connection, could provide substantial Internet connectivity. *See* http://www.elektrosmog.nu/.

Appendix 2: Examples of Past Pessimism in New Technologies

A. Cable Television

To estimate future demand for broadband service without knowing what it may bring in the future would be much like trying to predict the demand for cable television service in 1974 when the only viewing alternatives that cable could provide were distant broadcast stations. At that time, pessimistic economists were predicting that cable would only spread to 30 to 40 percent of households in major markets. One of the current authors suggested that these predictions were decidedly too low, suggesting that 65 percent cable penetration was even possible – almost precisely today's level.[102]

B. The Photocopier

Chester Carlson developed a process for dry photocopying. He searched for years for a corporation that would commercialize his invention approaching, among others, General Electric, RCA, IBM, and Remington Rand. IBM hired the technology consulting firm Arthur D. Little (ADL) to assess the technology. After receiving ADL's pessimistic report about the likely demand for copiers, IBM chose not to pursue the technology further. A small firm, Haloid Corporation, subsequently decided to license the technology. After the product began to take off, the firm changed its name to Xerox.

C. Wireless Telephony

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[102] Robert W. Crandall and Lionel L. Fray, "A Reexamination of the Prophecy of Doom for Cable Television," *The Bell Journal of Economics and Management Science,* (Spring 1974).

Many groups vastly underestimated the rate at which consumers would adopt wireless (cellular or PCS) telephone service. For example, a group of researchers at Cornell, in an excellent research effort, attempted to forecast the impacts of the yet-to-be deployed cellular technology.[103] Their analysis considered three scenarios of likely mobile telephone service penetration. Their medium scenario envisioned only 500,000 to 1 million mobile telephone subscribers over a 15 to 20 year horizon, and their most optimistic scenario envisioned no more than 10 million subscribers. By January 2000, actual subscribers were 86 million -- even their most optimistic scenario was exceeded by a factor of almost 9.[104] The Cornell authors were not alone. The forecasts by all parties in the FCC rulemakings for the cellular service fell far short of actual demand.

D. Computer Communications

The pioneers of packet communications and the Internet faced great skepticism from the established communications industry. In 1978, Larry Roberts, one of the pioneers of the Arpanet/Internet, wrote, "AT&T and its research organization, Bell Laboratories, have never to my knowledge published any research on packet switching."[105] He also described how ARPA, in an attempt to commercialize the Arpanet, approached AT&T about taking over the Arpanet, but AT&T declined the opportunity. The Arpanet ultimately became today's Internet.

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[103] Raymond Bowers, et.al., (eds.), Communications for a Mobile Socirty: An Assessment of New Technology. Beverly Hills, CA: Sage Publications, 1978, pp. 386-89.

[104] *See* CTIA, "Frequently Asked Questions and Fast Facts" (downloaded from: http://www.wow-com.com/consumer/faq/articles.cfm?ID=101).

[105] Larry Roberts, "The Evolution of Packet Switching," *Proceedings of the IEEE,* Vol. 66, No. 11, (Nov. 1978), 1307–1313.