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Communications Equipment
What Has Happened to Prices?

Mark Doms

9.1 Introduction

Measuring prices for goods that exhibit rapid rates of technological change raises special challenges. Over the past several decades, new techniques and data sources have been developed in response to these challenges. For instance, an extraordinary amount of attention has been placed on accurately measuring computer prices, and the results of these efforts have been incorporated into the national income and product accounts (NIPAs). Attention was focused on computers because price declines for computers were easily observed and computers were a growing share of total investment.

One area where there has been rapid technological change but relatively little effort in terms of measuring prices is communications equipment. This is surprising since breakthroughs in communications technology have been a necessary ingredient in constructing the "new economy," as witnessed by the widespread use and growth of the Internet, the creation of office networks, the ability to transmit huge amounts of information over a global fiber optic network, the increased use of cell phones, the increased capacity of cable television networks, and so on.

Despite the breathtaking advances in communications equipment, the

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official price indexes for communications equipment from the Bureau of Labor Statistics (BLS) barely changed over the 1990s. According to the BLS, producer prices for communications equipment increased an average of 0.2 percent between 1991 and 2000.[1] The prices for communications equipment stand in stark contrast to those for computers, where BLS shows prices falling an average of 14.5 percent over this period. The Bureau of Economic Analysis (BEA) measure for computers shows prices falling 17.6 percent.[2]

There are several reasons why research has not progressed more quickly in the field of communication equipment prices. First, communications equipment covers a more diverse set of products than computers. For instance, communications equipment covers, among other things, cell phones, alarm systems, fiber optic gear, and local area network (LAN) equipment. Second, obtaining data on communication equipment prices is more difficult than it is for computers. Large chunks of communications equipment are sold to relatively few customers (for instance, telecom service providers), and prices are not regularly published in periodicals such as *Computer Shopper.*

Table 9.1 shows some measures of both computer and communications equipment investment in the 1990s. Line 3 shows that the growth rates in nominal investment for computers and communications equipment were remarkably similar during the 1990s. Additionally, there is also a strong resemblance in the level of investment spending in computer and communications equipment. These facts make it all the more surprising that more research has not been conducted on the prices of communications equipment.

As mentioned before, the biggest difference between the official investment statistics on communications equipment and computers is what has happened to official prices. As shown on line 7 of table 9.1, BEA's official prices for computers fell 17.6 percent on average during the 1990s, whereas communications equipment prices fell an average of 2.1 percent. One reason why the BEA's official prices for communications equipment falls faster than the BLS PPI is that the BEA has incorporated alternative price measures for two communications equipment components. The first is for central office switching equipment, where Grimm (1996) found that prices fell an average of 9.1 percent per year. The second is for LAN equipment, where Chris Forman and I (Doms and Forman 2003) found that prices fell an average of 17.5 percent per year between 1995 and 2000.[3]

1. The producer price index (PPI) for industry 366 increased at an annual rate of 1.1 percent between 1990 and 1997. Between 1997 and 2000, the PPI fell at an annual rate of 1.2 percent.

2. The BEA measure for computers used to rely on its own measure of prices for larger computers, and the BEA price series fell faster than the comparable BLS series. Consequently, the BEA computer deflator falls faster than BLS's.

3. See Doms and Forman (2003).

Table 9.1 **Business investment in computers and communications equipment**

	Computers	Communications equipment
Average nominal growth in investment (%)		
1. 1990–95	5.6	5.0
2. 1995–2000	10.6	10.5
3. 1990–2000	8.0	7.6
Level of investment ($ billions)		
4. 2000	109.3	116.8
Average annual price change (%)		
5. 1990–95	–12.6	–1.1
6. 1995–2000	–21.6	–2.9
7. 1990–2000	–17.6	–2.1
Average real growth rates (%)		
8. 1990–95	20.9	6.2
9. 1995–2000	41.0	13.8
10. 1990–2000	31.1	9.9

Why do I think a priori that communications equipment prices fell faster than the BLS data would lead us to believe? First, the small handful of studies that have examined portions of communications equipment have found that prices have fallen quickly, but perhaps not as much as computers. Second, as stated earlier, there are numerous instances of technological change in several parts of the communications equipment spectrum that have revolutionized communication services.

Given the large expenditures made on communications equipment, deriving more accurate measures of prices would likely have consequences for several top-line measures of economic activity. For instance, Jorgenson and Stiroh (2000) run simulations under different scenarios for communications equipment prices. To illustrate the potential importance of deriving more accurate measures of communications equipment, table 9.2 shows the contributions of computers and communication equipment to gross domestic product (GDP) and equipment and software (E&S) growth during the 1990s.[4] Line 2 shows that computer investment contributed an average of almost 0.3 percentage point to the average annual growth rate of GDP during the last decade, with a larger contribution in the second half of the 1990s. In contrast, communications equipment investment contributed only about a third as much as computers did. A similar pattern holds for E&S spending.

Given the similar nominal shares and growth rates of computers and communications equipment, it seems that the potential payoff of "fixing"

4. The communication equipment GDP calculations were performed by using E&S communication equipment spending and estimates of government and consumer spending. The government and consumer spending estimates were based on the 1992 input-output tables, the last official estimates. The data were further adjusted for imports and exports.

Table 9.2 GDP and equipment and software (E&S) growth: Contributions of computers and communications equipment (%)

	Average annual growth rate		
	1990–2000	1990–95	1996–2000
GDP			
1. Growth	3.08	2.22	4.13
2. Contribution of computers	0.29	0.19	0.38
3. Contribution of communications equipment	0.08	0.04	0.12
E&S			
4. Growth	9.36	7.15	11.85
5. Contribution of computers	2.40	1.94	2.98
6. Contribution of communications equipment	0.24	–0.22	0.77

communications equipment prices relative to the cost of doing so may be high. The question then arises: how can we accurately measure prices of communications equipment? This paper pursues the following, albeit imperfect, approach. First, I map out the different types of communications equipment and how spending on these different types have changed over the years. The national income and product accounts (NIPAs) data for communications equipment is very aggregated, so information from other sources on the types of communications equipment purchased is used. These data help identify those areas within the communications equipment sector where spending is large and where it has accelerated. This analysis is in the second section of the paper.

The third section presents information from past studies on communications equipment pricing. The fourth and fifth sections of the paper can be viewed as continuations of the "house-to-house combat" to improve price measures used in the NIPAs (see Shapiro and Wilcox 1996). Section 9.4 presents new results on the prices of modems and public telephone exchanges. The fifth section delves into fiber optic equipment, the area where technological change has been extremely rapid and spending accelerated sharply in the late 1990s and 2000. In the sixth section, the information developed in this paper is combined with the results from elsewhere to come up with several overall price indexes for communications equipment.

Finally, the seventh section addresses how these alternative price indexes would affect growth rates in various investment categories and how calculations on capital deepening and multifactor productivity (MFP) would change.

9.2 What Is Communications Equipment?

Communications equipment comprises most of the equipment that sends and receives information and the vast array of types of equipment that lies between the sender and receiver. Over time, the types of equipment have multiplied—instead of copper wires connecting homes to central switching offices, equipment now exists that sends information over fiber optic networks, satellites, and cell phone towers, in addition to the equipment that makes computer networks run.

How to classify all of this equipment is therefore a daunting task. The Standard Industrial Classification (SIC) system and the more recent North American Industrial Classification System (NAICS) break down communications equipment into several subcategories: telephone apparatus manufacturing, radio and television broadcasting and wireless communications equipment manufacturing, and other communications equipment manufacturing. Although these categories are useful, over the years there has been movement away from the traditional modes of communication that these systems were based on (namely, the land-line telephone system). Indeed, the industry seems to assign communications equipment into much different categories. To help explain what constitutes communications equipment and to help us think about how the types of equipment should be classified, figure 9.1 presents a simplified diagram of communications networks.

The way to view figure 9.1 is to be aware that information is sent from the left-hand side of the diagram to the right-hand side. The items listed on the

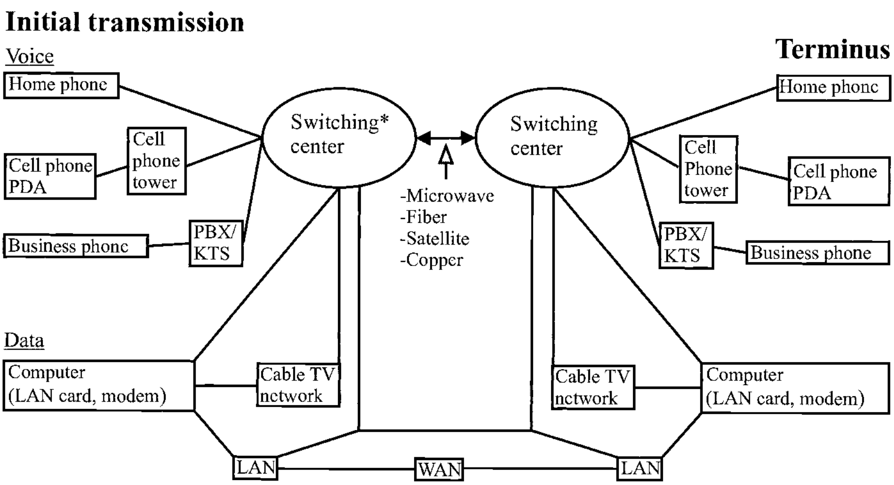

Fig. 9.1 A simplified version of voice and data communication networks

Notes: Equipment in switching centers contains gear that accepts incoming information from many different languages, protocols, and mediums and then decides where to send the information next. This gear includes voice switches and fiber optic equipment.

LAN = local area network; WAN = wide area network; PDA = personal digital assistant; PBX = public branch exchange; KTS = keystone telephone system.

left are those pieces of equipment that initially send out a message, and the pieces of equipment listed on the far right are those that receive the message. The items in the middle are the necessary equipment a message must traverse to get from the sender to the receiver. The diagram focuses on voice and data networks and omits radio, TV, alarm systems, walkie-talkies, and defense-specific communications equipment. With that said, the equipment shown in figure 9.1 makes up the bulk of communications equipment spending.

The elements on the left-hand side are broken into voice and data. The split between voice and data transmission has arisen because a premium has been placed on the quality of the voice network. When a voice message is transmitted, it is essential that each part of that message arrive at its final destination in the correct order and in a timely manner. Therefore, the resources devoted to sending a voice message are greater than the resources required for sending a comparably sized data transmission.[5]

On the left side of figure 9.1, there are three elements under the voice heading and just one element (computer) under the data heading. Each of these systems has evolved somewhat separately, and each has its own protocols and formats. However, these distinctions are blurring. For instance, cell phones are being used to transfer data (such as Verizon's Express Network), phone calls can be made over computer networks, and some personal digital assistants have the ability to communicate with networks. With that said, the connections shown in figure 9.1 represent the routes that a majority of voice and data traffic travels, especially for the time period this paper examines.

Once the information leaves the original sending piece of equipment (phone, cell phone, business phone, or computer), the information is usually sent to a location where information from several sources congregates before being sent on the next leg of its journey. This system is akin to the hub-and-spoke system of the airlines. The hub-and-spoke system is used because it is not economical to have direct connections between everyone on a network to everyone else on a network. Therefore, a good chunk of communications equipment spending is on equipment that takes in many signals and makes the decision where to send the signals to next. Over time, the equipment that performs this routing function has become ever more complex and able to handle greater volumes of information.

Examples of this type of equipment are listed in the middle of figure 9.1. The upper left portion of figure 9.1 shows that most home phones are con-

5. However, as technology improves, the distinction between voice and data transmission will all but disappear. Already, voice-over Internet protocol (VOIP) applications are arising. In the internet protocol (IP) system, a message is broken into packets, and those packets are then routed to their final destination, although not all of the packets will take the same route.

nected to a local telephone-switching center, usually by copper wire.[6] Cell phones instead send a signal over the airwaves to a base station. The signals in the base station are then sent to a switching center, joining calls made from residences. Phones in businesses, government buildings, and academic institutions are often connected to their own phone network. The two dominant types of equipment that run these networks are called public branch exchange (PBX) and keystone telephone systems (KTS). Usually, PBXs and KTSs are then connected to switching centers.

In figure 9.1, the fourth device used to initially transmit information is the computer. Actually, the parts of the computer that are officially considered communications equipment are modems and LAN cards (the most common of which are Ethernet cards). A computer can be linked to larger networks in one of three ways. First, with a traditional analog modem or a digital subscriber line (DSL), a computer can use a copper phone line to connect to a switching center. Second, computers can use cable TV lines. These first two mediums are popular for home computer use. Many business, government, and academic computers are instead linked to a LAN. A LAN can then be linked to other LANs, to switching centers (say, via a T1 line), or to wide area networks (WANs).

Switching centers contain various types of equipment, including telephone switches, satellite dishes, and the gear that transmits and receives information for fiber optic networks. A message sent from the right side of figure 9.1 to the left side may go through many such switch centers. For data communication, a message is broken into packets, and those packets can each take different routes to get to the final destination.

9.2.1 Expenditures

Figure 9.1 shows the basic components of the modern communications system. Using data from a very wide variety of sources, table 9.3 shows estimates of how much was spent on various pieces of equipment.[7] The data in table 9.3 come from a very wide array of sources, mainly from private research firms and trade associations. For instance, the data on expenditures on LAN equipment came from Gartner/Dataquest, the data on expenditures for fiber optic equipment came from two firms that follow the industry—and are described in more detail later in the paper—and data on many of the smaller categories came from various issues of the *Multimedia Telecommunications Market Review and Forecast* by the Telecommunications Industry Association. The data in table 9.3 are only from 1997 to 2000 because those are the years for which I could obtain estimates for all major

6. Switching centers are also referred to as central offices, local central office, exchange, and local exchanges. Also, a home phone may transmit and receive information over its cable TV line.

7. The largest omitted categories in table 9.3 are likely radio equipment (outside of cellular phone equipment), broadcast and studio equipment, and alarm systems.

Table 9.3 Spending on communications equipment ($ millions)

	1997	1998	1999	2000	AAGR (%)
Switching center equipment (1)	27,055	29,577	36,870	46,548	19.8
Central office switching and transmission equipment	12,358	13,562	14,475	15,500	7.8
Fiber optic equipment	7,160	9,059	14,081	22,061	45.5
Cellular phone infrastructure	5,678	4,474	4,955	4,734	–5.9
Data communication (2)	24,134	27,745	30,306	33,870	12.0
LAN Equipment	11,437	13,111	14,027	15,838	11.5
Routers	2,986	3,425	4,525	5,946	25.8
LAN switches	3,787	5,706	6,528	7,645	26.4
Hubs	1,884	1,538	761	419	–39.4
LAN cards	2,780	2,442	2,213	1,829	–13.0
Modems	3,077	3,290	2,800	2,500	–6.7
Other (WAN, ISDN, ATM, frame relay, etc.)	9,620	11,344	13,479	15,532	17.3
Voice equipment (3)	22,855	25,172	26,424	27,437	6.3
Business phone equipment	11,795	13,227	14,195	15,135	8.7
Private branch exchange (PBX)/Key telephone system (KTS)	6,832	7,601	7,980	8,392	7.1
Voice processing equipment (call centers, voice mail, etc.)	4,963	5,626	6,215	6,743	10.8
Wireless handsets (cell phones)	5,787	7,228	7,619	7,692	10.0
Consumer products	5,273	4,717	4,610	4,610	–4.4
Cordless telephones	2,099	2,250	2,240	2,260	2.5
Answering machines	1,173	1,240	1,215	1,210	1.0
Home fax machines	1,367	655	625	620	–23.2
Corded telephones	634	572	530	520	–6.4
Other (4)	3,400	3,850	5,400	6,000	20.8
Capital equipment spending by cable television firms not covered above	3,400	3,850	5,400	6,000	20.8
Total spending (1) + (2) + (3) + (4)	77,444	86,344	99,000	113,855	13.7
Consumer products	8,167	8,331	8,420	8,456	1.2
Total spending – Consumer products	69,277	78,013	90,581	105,399	15.0
E&S communications equipment	73,739	81,236	93,350	116,837	16.6

Sources: Dataquest, FCC, TIA, RHK, KMI, and author's estimates.
Note: AAGR = average annual growth rate; E&S = equipment and software.

categories. In some of the results that follow, results for individual pieces of equipment go back until the late 1980s, and there are some results for 2001.

Most categories experienced growth in nominal spending in the late 1990s. In particular, there was a tremendous surge in spending on fiber optic equipment (the fiber itself is relatively cheap and not considered communications equipment), reflecting a large build-out of the several large new fiber networks. Fiber optic networks and fiber optic equipment are discussed more fully in section 9.5.

Table 9.3 also shows where there were large expenditures made on communications equipment. The largest single major category is switching-center equipment. And within that category, fiber optic equipment made up the bulk of the expenditures in 2000 (in 1997, the share of central office switching equipment was only half as large).

The bottom of table 9.3 shows the total expenditures in the displayed categories in addition to communications equipment investment as reported in the NIPAs. The sums of the categories in table 9.3 are less than the NIPAs because of omissions. However, the sums of the categories have similar growth rates to the NIPA data between 1997 and 2000, and both series show an especially large increase in 2000.

9.3 Previous Research on Prices of Communications Equipment

There has already been research on prices for some of the categories shown in table 9.3. In particular, research has been done on cell phones, central office telephone switches, and LAN equipment. Together, these three categories constitute 42 percent of the communications equipment expenditures in 1997 and 36 percent in 2000. Because one objective of this paper is to devise a best guess for an overall price index, I'll discuss the previous research with an emphasis on what the driving forces were that lowered prices.

9.3.1 Cell Phones

Jerry Hausman (1999) has written a series of papers on the price of cellular telephone service. He cites that when cell phones were first introduced in 1983, they sold for about $3,000. By 1997, they sold for about $200. These are very rough numbers, and it is certain that the average cellular phone in 1997 had a better feature set than an average phone in 1983. With that said, using the Hausman quotes, prices for cellular phones fell an average of 17.0 percent per year between 1983 and 1997. One of the primary reasons for the drop in the price of cell phones has been the advances made in semiconductors. Cell phones are quite complex devices, and it has been said that if a cell phone were made with vacuum tubes, the cell phone would have to be the size of the Washington Monument. An additional factor that may help explain the drop in cell phone prices is economies of scale in production of the phones and its components. In 2000, there were an estimated 400 million cell phones sold worldwide.

9.3.2 Telephone Switches

Kenneth Flamm (1989) and Bruce Grimm (1996) have examined prices of telephone switches. Telephone switches are pieces of equipment usually installed in switching centers that route calls from one center to another and then to the final destination. The first telephone switches were electromechanical; these switches physically moved to complete a circuit over which a conversation could be held. In the early 1980s, digital electronic telephone switches performed the same function but without moving parts. The new switches could perform other functions as well. Grimm used data from the Federal Communications Commission (FCC) to run a hedonic regression where the price of the switch was regressed on a number of explanatory variables. He found that between 1985 and 1996, prices fell an average of 9.1 percent per year. However, in the later years of his study, he found that prices fell an average of 16.1 percent.

9.3.3 LAN Equipment

Doms and Forman (2003) examined the prices of different types of LAN equipment in the second half of the 1990s. Local area network equipment is the equipment that sends and routes information over computer networks. The development of this equipment has made accessing the Internet and e-mailing more affordable. Within the LAN equipment aggregate, there are four primary components: LAN cards (the card in a computer that sends and receives information on a computer network), switches (devices that perform simple routing functions), routers (devices that often sit atop computer networks and determine where information packets should be sent), and hubs (pieces of equipment that act as traffic cops in merging information onto a computer network). Doms and Forman found that prices for LAN equipment fell far faster than the BLS comparable PPI would suggest—between 1995 and 2000, prices for LAN equipment fell at a 17.5 percent annual rate, compared with the comparable PPI, which fell only 0.1 percent.[8]

9.3.4 Indirect Evidence

The aforementioned studies found that prices for various types of communications equipment fell, and fell considerably faster over the time periods examined in contrast to the most comparable PPIs. However, making an inference to total communications equipment from these groups is not prudent, as these groups make up just 36 percent of communications equipment spending in 2000. Also, there is a question of whether these studies represent a random sample of communications equipment. They probably do not.

8. Why did prices of LAN equipment fall so quickly? The reasons are interrelated and speculative, and they include the degree of competition, simplicity of the product, the size of the market, and how many of the devices are made. In terms of competition, prices fell fastest for home and small office routers, the segment of the router market with the most competition (this is the segment where Cisco, the dominant maker of routers, has the smallest market share). One reason for the high level of competition is that designing and producing low-end routers is relatively easy, so that many firms can enter. Also, the quantity of low-end routers allows producers to enjoy economies of scale in production of the routers themselves and in the production of the semiconductors used in the routers. Because of steep competition, prices for switches also fell quickly. Again, although Cisco dominates the market, it did not do so initially.

Other indirect evidence that might also shed light on technological change for communications equipment includes a measure of the rate of innovation and the prices for semiconductors used in communications equipment. Devising metrics that somehow capture the rate of technological progress is difficult. Two commonly used measures are patents and research and development (R&D) spending. Unfortunately, R&D spending figures by industry are not published at a fine enough level of detail (communications equipment, SIC industry 366, is sometimes lumped in with other industries in industry 36, such as semiconductors [SIC industry 367]). However, Manuel Trajtenberg (1989) of Tel-Aviv University maintains a database of patents, and those patents are assigned to classes. Figure 9.2 shows the percent of total patents that are awarded to three high-technology fields—computers, communications equipment, and semiconductors—between 1963 and 1999. The share of patents in the category of computers and peripheral equipment has been increasing much faster than that of the other two categories. Also, the share of total patents going to communications equipment has been increasing. One wild card is how the patents for semiconductors are related to chips that are used in computers versus chips that are used in communications equipment.

Aizcorbe, Flamm, and Khurshid (2002) examined the prices of semiconductors by final use category, examining the semiconductor price indexes for semiconductors that go into computers, communications equipment,

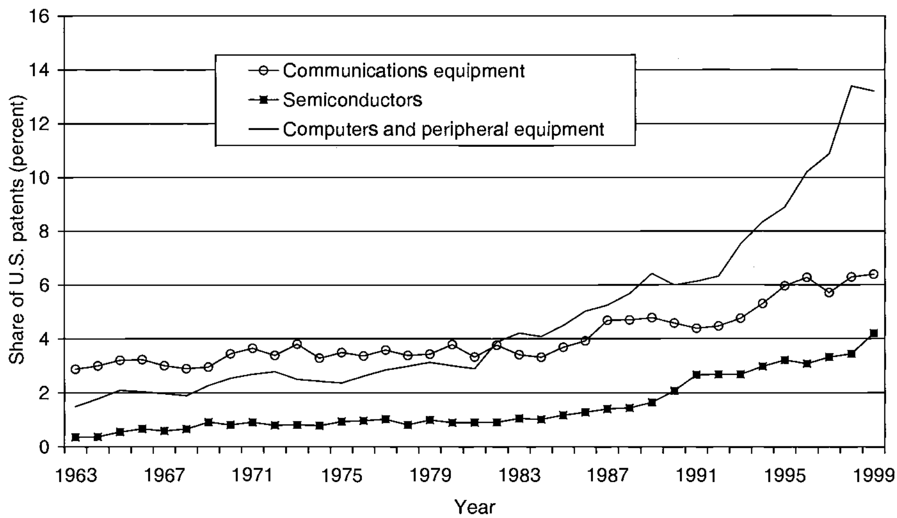

Fig. 9.2 Share of U.S. patents by high-technology category

Source: Manuel Trajtenberg.

Note: Computers and peripherals = computer hardware and software + computer peripherals + information storage.

and so on. They find that the content of semiconductors in communications equipment is about 11 percent. Further, they estimate that in the late 1990s, prices for chips that went into communications equipment fell, on average, about 30 percent per year.

So far I have discussed previous studies on communications equipment prices and some other information that suggests that prices for communications equipment should perhaps be falling faster than the official statistics indicate, but perhaps not as fast as the official numbers for computers. The next two sections present new results on three types of communications equipment to better round out what is actually known about prices.

9.4 Modems and PBX/KTS

Measuring prices for high-tech goods has received a voluminous amount of attention in the past two decades. During this time, several techniques have been employed. Two of the more popular methods are hedonics and match-models. In the results presented below and in the results presented in the next section on prices for fiber optic equipment, matched-model techniques are used. One reason for using matched-model techniques is because the available data are best suited for matched models. For many of the products, I do not have access to all of the performance characteristics to estimate a hedonic model, and I am also constrained by the number of observations. However, as Aizcorbe, Corrado, and Doms (2003) demonstrate, the matched-model approach yields numerically similar results to the hedonic approach when net entry of new products is not large. In most of the results presented in this section and the next, this is indeed the case.

One, albeit small, segment of communications equipment where price information is available for a large number of products is for modems. This first part of this section analyzes modem prices. The second part examines prices for PBX/KTS equipment, the internal phone networks used by many businesses.

9.4.1 Modems

Although modems are a small part of communications equipment spending, prices for analog modems are relatively easy to obtain because they are sold in the same outlets as personal computers. Examining modems is of interest because there has been tremendous technological change over the past decade. For instance, in late 1991, 9600-baud analog modems were introduced, followed by 14400-baud modems in 1992Q3 and 28800-baud modems in 1994Q4.[9] The rate of increase in speed during this period

9. A 9600-baud modem is not faster than a 1200-baud modem—the 9600 baud modem has higher capacity. The speed of the signals is dictated by the speed of electricity over copper wires, whereas the signal can be modified and refined to have higher capacity. Although en-

averaged about 63 percent, a bit less than Moore's law. One might suppose that modems are one type of equipment where prices fell faster than other types of communications equipment because of high competition. Also, it is possible that since most personal computers (PCs) come equipped with modems, firms have been able to achieve higher economies of scale than other segments of the communications equipment industry (modems are similar to LAN cards in many ways).

Our study on modems has two parts. The first part analyzes prices for analog (dial-up) modems for PCs from 1989 to 1998. The second part looks at cable modems from late 1999 to late 2001. There are three modem groups that we do not examine: PCMCIA modems (modems commonly used for laptop computers), modems used for business applications, and wireless modems.[10]

Analog Modems

We gathered information on 681 modems from *PC World* magazine between 1989 and 1998. Finding advertised list prices for modems became more difficult after 1998 as modems were increasingly offered as standard equipment in computers and the market for stand-alone modems shrank. For consistency, we obtained prices in ads from Computer Direct Warehouse and Arlington Computer Products, two large retailers of PCs and components that had placed ads in each issue of *PC World* that we examined. Manufacturers of the data collected were U.S. Robotics, Hayes, and Practical Peripherals. Our database contains the listed retail price and the speed for each modem. We matched unique modem models across consecutive quarters. On average, each modem was in our sample for seven quarters. We calculated the geometric mean of prices in two consecutive periods.[11] Also, we calculated separate price indexes for different classes of modems. For all of the price indexes shown, we required a minimum of six

gineers cringe when "higher speed" is used to describe various forms of bandwidth, it is likely that they have lost the semantic battle.

10. This last category includes wireless network cards. Wireless networks started to gain widespread popularity in 2001.

11. Standard hedonic regressions could not be run because the advertisements did not provide a complete list of the characteristics of the modems. The advertisements always mentioned the speed and the name of the modem but did not mention any of the other characteristics. For instance, modems vary by the software that is included (such as software that allows the user to use the modem as a fax machine), warranty, speakerphone, mike, caller ID, free tech support, and so on. One alternative would have been to run a fixed-effect hedonic regression, as shown in Aizcorbe, Corrado, and Doms (2003). They show that matched models and fixed-effect hedonic regressions yield similar results when entry and exit are relatively small.

A potential problem with using geometric means is that each observation is treated equally. If the revenue shares were known for each modem, then we would use that information to construct a matched-model superlative index. If there is a correlation between prices changes and the size of the revenue shares, then the geo-means approach yields biased results. For instance, substitution bias can occur if revenue moves toward those modems when prices are falling relatively rapidly.

observations. The overall analog modem price index is based on an average of about 100 observations.

Our results are shown in figure 9.3. For comparison, we also place the BEA computer price index on this figure. Our overall modem index falls an average of 15.6 percent over the sample period, compared with the 16.3 percent drop in the BEA computer deflator. Initially, our price index falls more slowly than the BEA computer deflator, when 1200- and 2400-baud modems were commonplace and the 9600-baud modems had not yet been introduced. However, with the advent of 9600- and 14400-baud modems, prices fell more quickly, especially in the case of the 14400-baud modems. Prices continued to fall, although the rate of decline does vary from period to period. Of interest is that prices of the 56K modems increased during their first year in our sample and then quickly fell.

Figure 9.4 highlights modems that are over 10K baud. We computed an over-10K-baud index and compared it with a BLS modem index for this category. Our index fell significantly faster than the BLS index: between 1994Q2 and 1998Q3, our index fell at an average rate of 15.4 percent, compared with 8.7 percent for BLS.

Cable Modems

In the past several years, adoption of modems for broadband access (DSL and cable) has increased markedly. I was able to obtain industry-level estimates on revenue and quantities for cable modems between 1999Q4 and 2001Q1. The data on revenues and quantities come from Gartner, a private research firm that tracks a number of high-technology industries. According to Gartner, most cable modems are similar in that they must meet the Data Over Cable Service Interface Specification (DOCSIS) standard, the standard that defines "the interface requirements for cable modems involved in high-speed data distribution over cable television system networks" (CableLabs website, www.cablemodem.com). The characteristics of cable modems over this period are fairly uniform; that is, a cable modem in 1999 was not that much different from a cable modem in 2001. Using the Gartner data, the average price of a cable modem fell from $228 in 1999Q4 to $145 in 2001Q1, an average price decline of 30.4 percent. The results for the cable modems are shown in the upper left of figure 9.3.[12]

9.4.2 PBX/KTS

My attention now turns to the prices of the phone systems located in many businesses, government offices, and other sites. One reason to examine this segment is that sales of these systems exceeded $8 billion in 2000.

12. Cable modems are now being increasingly sold in retail stores. Recent prices (March 2002) for DOCSIS cable modems are about $100, a decline of about 30 percent from the year-ago Gartner prices.

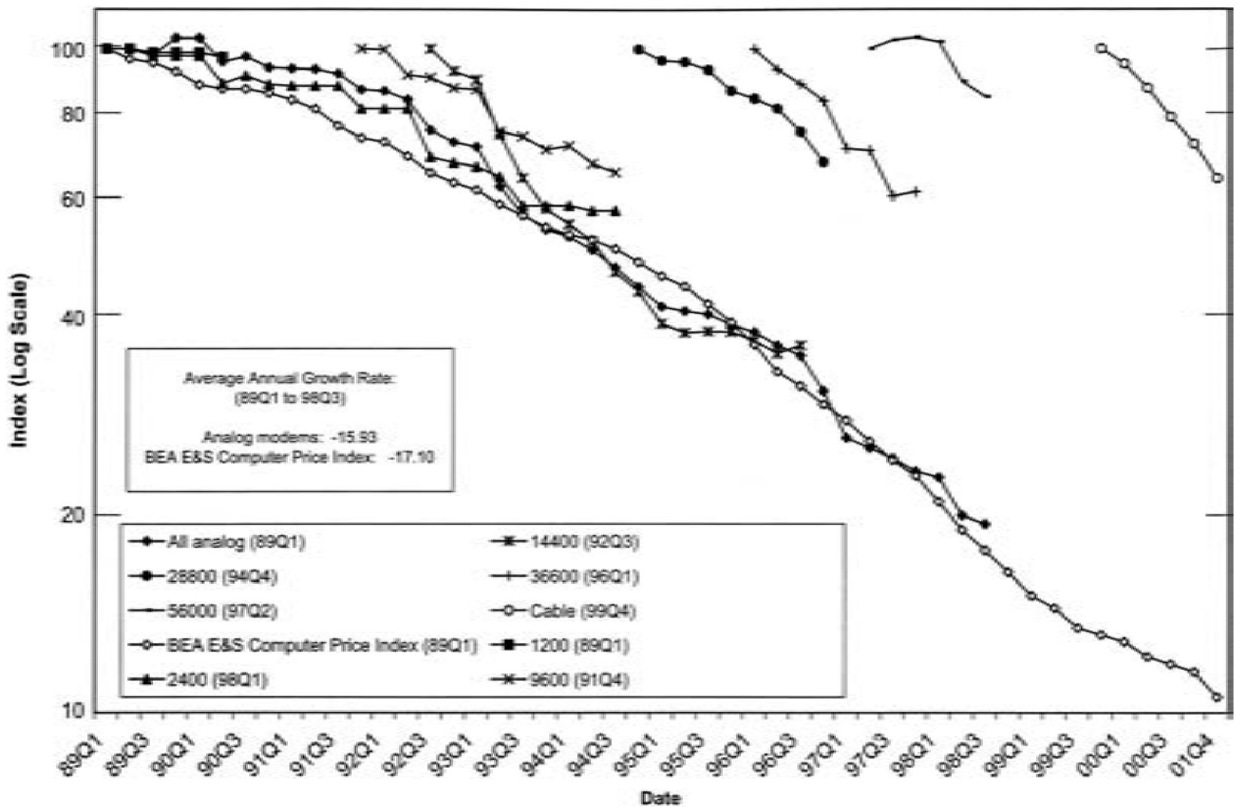

Fig. 9.3 Price indexes for modems

Source: Analog modem data were collected from CDW and ACP advertisements in *PC World* magazine beginning February, 1989 (Q1). The 681 observations were generally U.S. Robotics, Hayes, and Practical Peripheral models. Cable modem figures (1999Q4 to 2001Q4) were derived from market statistics produced by Gartner, Inc. Computer and communications equipment price data are from BEA.

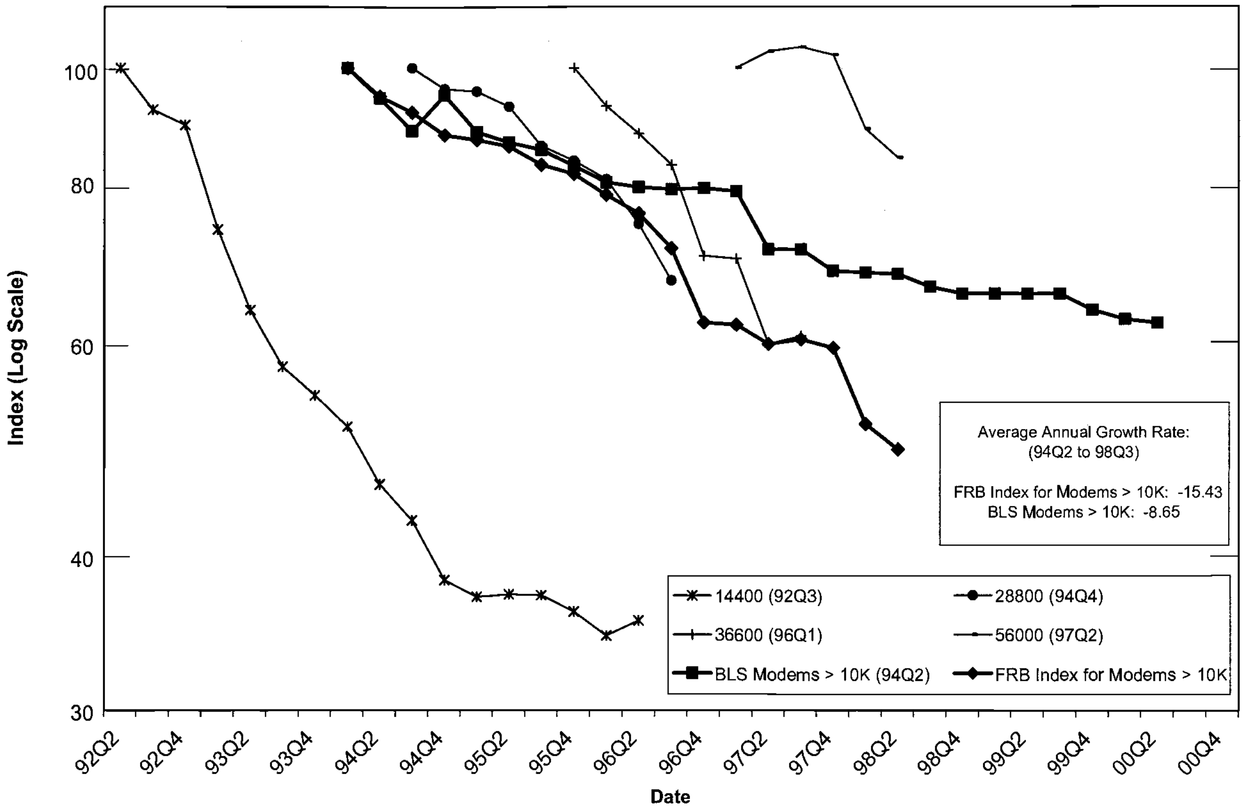

Fig. 9.4 Price indexes for modems over 10K bps

Source: Analog modem data were collected from CDW and ACP advertisements in *PC World* magazine beginning February, 1989 (Q1). The 681 observations were generally U.S. Robotics, Hayes, and Practical Peripheral models. Cable modem figures (1999Q4 to 2001Q4) were derived from market statistics produced by Gartner, Inc. Computer and communications equipment price data are from BEA.

These telephone systems allow users to call one another without using central switching centers. These telephone systems are smart enough to know that when, for instance, you dial a four-digit code, the call you are placing is to another phone within the system. Sometimes on these systems, you have to dial a "9" to get an outside line—that is, a line that is most likely connected to a switching center. These systems fall into two categories: PBX KTS. A PBX is a bit more sophisticated than a KTS in that the number of phone lines entering a location is less than the number of phones in that location.

Both PBX and KTS systems have many features, and the feature set has grown over time. Perhaps this isn't surprising. Newer features include call forwarding, call waiting, caller identification (ID), plug-in capability to a T1 line, message centers, and so on.[13] According to an industry contact, the prices of additional features have been falling over time. However, this contact also said that getting price data would be difficult because prices are usually quoted only after a request for a specific system with specific features has been placed.

I was able to get some data that can produce a bound for prices. Several private firms track the industry and classify PBX/KTS systems by how many lines they have. These firms have revenue estimates for "basic" systems. What exactly constitutes a "basic" system has changed over time, with a "basic" system that is sold today having more features than a "basic" system of five years ago.

The data on revenue and on average prices are presented in table 9.4 and come from Gartner/Dataquest; they appear as they are published. That is, there is no underlying detail that is readily available that is not shown in the table. As shown at the bottom of the table, prices fell an average of 5 percent between 1994 and 2000. Again, I believe these estimates, based on the Gartner data, to be upper bounds—prices likely fell even faster because the basic configurations improved over time, and my estimates do not pick this up. Just how much the estimates are biased is uncertain.

9.5 Fiber Optics

The area within communications equipment where the most rapid technological innovations have occurred within the past several decades is fiber optics. Instead of using electrical signals to carry messages over copper wires, there has been an increasing move toward using pulses of light over thin fibers of pure glass. Although there have been improvements in the

13. There is a trend toward converting traditional circuit-based PBXs to IP technology. A UNIX or NT server would run the phone system instead of a PBX. The phone system would become a computer network, and each phone would have an IP address. Although this technology is gaining popularity, sales of IP-based phones were reported to be small during the sample period considered in this paper.

Table 9.4 **Average prices and quantities for private branch exchange systems, by number of lines**

	Number of lines						
	1 to 8	9 to 24	24 to 48	49 to 100	101 to 400	401 to 1,000	Price index
1994							
Price	2,701	6,856	17,226	47,806	170,511	589,428	1.00
Quantity	190,000	99,200	50,400	27,400	5,400	1,100	
Revenue	513	680	868	1,310	921	648	
1995							
Price	2,851	7,231	18,465	50,057	169,567	567,416	1.03
Quantity	199,200	100,600	47,200	24,600	6,300	1,200	
Revenue	568	727	872	1,231	1,068	681	
1996							
Price	2,374	6,819	18,406	44,295	166,433	530,018	0.96
Quantity	187,814	117,311	46,759	26,863	6,982	1,298	
Revenue	446	800	861	1,190	1,162	688	
1997							
Price	1,900	6,953	17,851	43,054	148,222	498,172	0.90
Quantity	283,544	122,099	50,570	34,798	8,366	1,553	
Revenue	539	849	903	1,498	1,240	774	
1998							
Price	1,732	7,253	17,799	40,319	139,287	435,616	0.86
Quantity	289,765	113,446	52,744	39,974	10,696	1,769	
Revenue	502	823	939	1,612	1,490	771	
1999							
Price	1,733	6,622	16,138	38,462	122,320	413,277	0.79
Quantity	233,233	124,369	63,167	44,283	13,898	1,842	
Revenue	404	824	1,019	1,703	1,700	761	
2000							
Price	1,996	6,424	15,550	36,393	103,316	408,678	0.75
Quantity	228,883	96,716	57,085	36,215	15,734	1,692	
Revenue	457	621	888	1,318	1,626	691	
AAGR (%)							–4.8

Sources: U.S. Premise Switching Systems Market Share and Forecast, 2000; Market Statistics, Gartner Group, Inc. May 8, 2000, U.S. Premise Switching Systems Market Share and Forecast, 1999; Market Statistics, Gartner Group, Inc. April 12, 1999, and U.S. PBX/KTS and PCX Market Share and Forecast, 2001; Market Statistics Gartner Group, Inc. May 31, 2001.

Note: Revenue is in millions of dollars.

glass, the most significant innovations have come in the equipment used to transmit and receive the light impulses. This section provides a brief overview of fiber optics and then presents some information on what has happened to the prices of the equipment used in fiber optic networks.

9.5.1 Overview of Fiber Optics

The use of light in communications has existed for some time, including the use of smoke signals, "one if by land, two if by sea," semaphore, and other visual means when there was direct line of sight. In a development that portended great things to come, Alexander Graham Bell invented the photophone. The photophone is basically a mirror that aims a beam of light to a receiver. The source of the light is the sun. The photophone has a device that vibrates a mirror as someone speaks. At the receiving end, a detector picks up the vibrations in the beam of light and converts the vibrations back into voice (analog technology). The sun is not a reliable light source, and the photophone now languishes on the shelves of the Smithsonian Institution. However, using light to carry information has proven to be as revolutionary as the phone itself.

The next big extension of the Bell idea was to transmit light over a medium that didn't have to go into a straight line and didn't require the cooperation of the sun. Between 1850 and 1960, a series of scientific discoveries led to the use of glass fibers, sheathed in various materials, as a medium through which to transmit light. In 1960, the laser was invented. Lasers are able to focus large amounts of light into very tight streams, making them ideal for sending light down a thin glass fiber strand. Refinements in lasers and fibers continued through the 1960s and 1970s, and in 1977 the first field trials were conducted that used fiber optic cables to transmit voice calls in Chicago. There has been near-continuous improvement since, especially in terms of the amount of information that can be transmitted by a beam of light and the number of light waves that can be simultaneously sent down a piece fiber optic cable.

Fiber optic networks are complex and require many different types of equipment. The basic components of a fiber optic network are the fiber through which the light pulses are sent, a transmitter, a receiver, and a regenerator. As I mentioned before, the fiber itself is not considered communications equipment. A transmitter is a device that takes a signal (perhaps an electrical signal), translates that signal into light pulses, and then sends those light impulses into a piece of glass fiber. Lasers are often used to send the light. Because the capacity of fiber is very high, the transmitter is able to take in many signals simultaneously and translate them all into a single wavelength of light. Taking many signals and merging them into a single data stream is called multiplexing.[14] The devices that take in many tributaries to produce one stream of information are called multiplexers.[15]

At the end of the fiber, there is a receiver, called a demultiplexer.[16] The demultiplexer receives the light signal, converts it into electrical signals,

14. "Multiplexing" is used in a somewhat similar way in juggling.

15. At a point in the process, electrical signals have to be converted to light, and light converted back to electrical signals. The equipment that does this—often the multiplexers—is very expensive. Over the past several years, there has been research on "all-optical" networks, networks that would not need the expensive conversion equipment.

16. Once the pulses of light go merrily down the fiber strand, they begin to disperse somewhat, losing some of the tight form they had initially. This dispersion is called *attenuation.* At certain intervals, a fiber network may have a "regenerator," a device that reads in the signal, cleans it up, and sends it out again. I was not able to find any information about regenerators, either in terms of expenditures or in terms of prices and characteristics.

and then sends them out to multiple conduits, the reverse of what happened at the beginning. That's a simplified version of the basics.

In 1996 the basics got a bit more complicated—and exciting. Instead of using one laser to shoot light down a strand of fiber, why not use two or more that operate at different wavelengths and shoot these beams down the fiber simultaneously? One example of the logic behind why this technology works is that when you are in a roomful of people talking, you can sometimes concentrate and just listen to one voice. Your mind acts as a filter and blocks out the other voices. If too many people are talking, and the voices are similar, then hearing a single voice is difficult. Just as the voices have to be different, the wavelengths of the lasers also have to be different. An amazing consequence of this technology is that the capacity of a single piece of fiber instantly increases. This technology is called dense wave division multiplexing (DWDM). The advent of DWDM technology created quite a hoopla, and references are frequently made to the increased capacity of a piece of fiber because of DWDM. In 1996 (when only a small handful of DWDM systems were initially deployed commercially), the maximum amount of information that could be transmitted through a piece of fiber was 2.5 gigabytes per second (Gb/s). In 2000, DWDM systems could shoot 40 wavelengths, each carrying 2.5 Gb/s, for a total of 100 Gb/s. In just four years, DWDMs alone increased the potential capacity of a piece of fiber by a factor of 40, well above the pace of Moore's law.

Figure 9.5 provides a simplified version of a long-haul fiber optic network (most expenditures on fiber and fiber optic equipment in the 1990s were on long-haul networks). The central circle in figure 9.5 is a fiber ring. Many networks are built using the ring concept—several fibers are used to connect two points so that data can be transmitted in either direction. If the ring is severed at one point, the data can be transmitted in the other direction. Various pieces of equipment are used to send and receive information over fiber.

In the late 1990s and into 2000, fairly large expenditures were made on the various pieces of fiber optic equipment. Estimates of these expenditures are presented in table 9.5, and these estimates came from one of three different private firms: Gartner/Dataquest, RHK, and KMI. RHK is a private firm that tracks the telecommunications industry and KMI is also a private firm that specializes in tracking the fiber industry, especially the amount of fiber cable laid.

The table shows that the growth rate in nominal spending on fiber optic equipment has increased at close to a 20 percent annual rate since 1994.[17]

17. The fiber optic cable is not classified as communications equipment according to the SIC and NAICS. Also, the cost of the fiber cable itself is relatively cheap. Estimates are that in 1999 and 2000, about $3 billion was spent annually on the cable. In contrast, expenditures on the equipment used to transmit and receive information over the cable topped $22 billion in 2000. Also, telecom service providers have to invest in other forms of equipment to get a fiber optic network up and going, including computers.

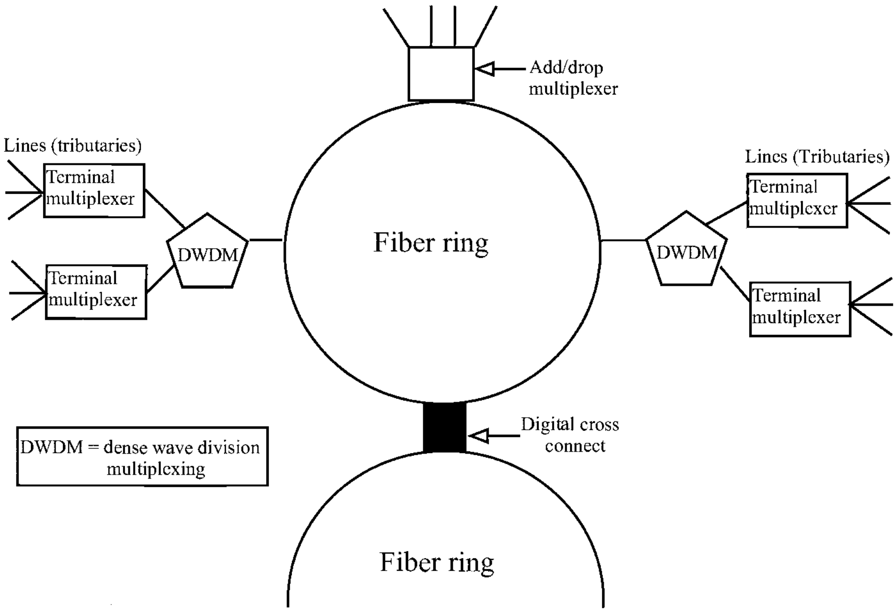

Fig. 9.5 Basic long-haul fiber optic network

Table 9.5 Nominal spending of fiber optic equipment ($ millions)

	1994	1995	1996	1997	1998	1999	2000	2001	AAGR (%)
Total fiber optic equipment	3,443	4,163	5,112	7,160	9,059	14,081	22,061	11,842	19.3
Percent change		20.9	22.8	40.0	26.5	55.4	56.7	–46.3	
Multiplexers[a]	1,865	2,406	2,656	3,562	4,556	7,291	10,573	4,880.0	14.7
DWDM[b]	0	0	381	1,595	1,854	3,427	6,740	4,348	62.7
DCCs[c]	1,111	1,182	1,455	1,581	2,210	2,749	3,950	1,914.0	8.1
Other	467	576	620	422	439	614	799	700	5.9

Sources: RHK, Gartner, KMI.

[a]Multiplexer (also known as a "mux"). Devices that can input multiple signals to produce a single signal, and devices that input a single signal and produce multiple signals. An add/drop mux selectively adds and/or drops wavelengths without having to use terminal equipment. A terminal mux extracts all signals/wavelengths from the fiber.

[b]Dense wave division multiplexing (DWDM), also known as wavelength division multiplexing, transmits multiple lightwaves down a single piece of fiber. For instance, there are DWDM devices that can send and receive 40 different wavelengths, with each wavelength having a maximum capacity of 2.5 gigabytes per second. A DWDM system of this type could send 100 gigabytes per second.

[c]Digital cross-connect (DCC) is a device that is able to perform simple extraction and merging onto a fiber ring.

A large ramp-up in spending for fiber optic equipment occurred in 1999 and 2000 as a flood of companies rushed into the long-haul fiber optic business; at the end of 2000, there were eleven companies that had more than 10,000 route miles of fiber. Unfortunately, there was a tremendous amount of duplication on the main routes, and many of the companies went bankrupt. As a consequence, expenditures on fiber optic gear dropped precipitously in 2001.[18]

9.5.2 Prices of Fiber Optic Equipment

To reiterate, getting information on prices for fiber optic gear is difficult because there are relatively few firms that produce the equipment, and the number of customers is fairly limited as well. Consequently, standard price catalogs do not exist. An analyst at RHK, Brian Van Steen, tracks prices and quantities for a large number of pieces of fiber optic gear, and he was kind enough to share his results for multiplexers and for DWDM equipment. The information for digital cross-connects came from Gartner. A series of tables in this section shows the data used in the analysis. Each table contains information on a different piece of fiber optic equipment, and price indexes were formed by using a matched-model, superlative index number approach. The reader can skip ahead several pages to the discussion of table 9.9 that presents the summary results for fiber optic equipment.

Multiplexers

Multiplexers vary in several dimensions, including the capacity of the signal they produce and their range: ultra long haul (more than 600 kilometers), long haul (60–600 kilometers), or metro (less than 60 kilometers). Through 2000, a plurality of expenditures on multiplexers was for the long-haul add/drop variety.[19] Table 9.6 presents quantity, price, and revenue estimates of long-haul add/drop multiplexers by capacity.

As shown at the bottom of table 9.6, between 1997 and 2001, prices fell an average of 15 percent, with the largest price declines in 2000 and 2001 for the higher-capacity models. In the earlier years (1996–98), prices fell at a more modest pace when, according to industry sources, competition was not very strong; although there are several producers of multiplexers, each market segment was relatively concentrated. However, in 2000 and 2001, prices fell especially fast, particularly for optical channel (OC) 48 devices,

18. The advent of DWDM equipment may have hastened the collapse of several long-haul fiber companies. Because DWDM has increased the potential capacity of a piece of fiber manyfold, when demand on a certain fiber route increases, it is relatively easy (that is, cheap) to increase the capacity of the existing line instead of lighting up another fiber. Therefore, not as many fibers are needed to transport a given amount of information.

19. Another characteristic is the protocol that multiplexers use. In the long-haul market, most networks use the synchronous optical network (SONET) protocol. In the metro market, other protocols are more common, like Ethernet.

Table 9.6 Prices and quantities for long-haul add/drop multiplexers

	1996	1997	1998	1999	2000	2001	AAGR (%)
System units (thousands)							
OC3 (155.62 megabits per second)	3.9	5.0	7.2	8.0	9.3	10.1	24.7
OC12 (622.08 megabits per second)	2.8	3.9	5.8	6.4	8.5	6.1	32.4
OC48 (2,488.32 megabits per second)	6.1	6.5	7.6	11.7	24.0	11.0	41.0
OC192 (9,953.28 megabits per second)			1.5	4.5	11.3	5.8	174.5
Total	12.7	15.4	22.2	30.5	53.1	33.0	43.1
Revenue ($ millions)							
OC3	77.0	90.0	123.0	120.0	125.8	122.2	13.0
OC12	132.0	154.0	216.0	210.0	254.0	165.4	17.8
OC48	917.0	947.0	1,039.0	1,398.1	2,302.2	550.0	25.9
OC192			599.0	1,571.3	3,175.2	1,277.4	130.2
Total	1,126.0	1,191.0	1,977.0	3,299.4	5,857.2	4,880.0	51.0
Average unit values ($000s/unit)							
OC3	20.0	18.0	17.0	15.0	13.5	12.2	–9.5
OC12	48.0	40.0	37.0	33.0	30.0	27.0	–10.9
OC48	151.0	145.0	136.4	120.0	96.0	50.0	–19.8
OC192			398.0	350.0	280.0	220.0	–17.9
Change in prices (%)							
OC3		–10.0	–5.6	–11.8	–10.0	–10.0	–9.5
OC12		–16.7	–7.5	–10.8	–9.0	–10.0	–10.9
OC48		–4.0	–6.0	–12.0	–20.0	–47.9	–19.8
OC192				–12.1	–20.0	–21.4	–17.9
Average		–6.1	–6.1	–11.9	–19.2	–30.3	
Matched model price index	1.00	0.94	0.88	0.78	0.63	0.44	–15.2
Percent change		–6.1	–6.1	–11.9	–19.2	–30.3	

Source: RHK.

in part because the market was flooded with devices from bankrupt firms and because of increased competition from Cisco. Additionally, as demand fell in 2001, producers cut their prices further.

What problems might there be with these results? Generally, the quality of equipment within a capacity category is believed to improve over time. For instance, the size of multiplexers is shrinking and the amount of power they consume is also declining. If there is a bias in the results discussed below, like PBX equipment, it is understating price declines. Based on conversations with industry analysts, the bias is likely to be small since the importance of the unobserved characteristics seems small relative to the capacity of the machines.

Table 9.7 **Average prices for selected long-haul (DWDM) equipment, 1998–2001**

	1998	1999	2000	2001	AAGR (%)
Average prices for terminals ($000s/terminal)					
WDM Terminal					
32 channel OC-48 open	1,316	796	652	457	–29.7
32 channel OC-192 open	2,532	2,236	1,804	1,346	–19.0
32 channel OC-48 integrated	516	636	524	367	–10.7
32 channel OC-192 integrated	1,412	1,436	1,164	866	–15.0
96 channel OC-48 open	3,684	2,076	1,676	1,173	–31.7
96 channel OC-192 open		6,396	5,132	3,842	–22.5
96 channel OC-192 integrated		3,996	3,212	2,402	–22.5
160 channel OC-48 open	6,052	3,356	2,700	1,890	–32.2
160 channel OC-192 open		10,556	8,460	6,338	–22.5
160 channel OC-192 integrated		6,556	5,260	3,938	–22.5
Average percent change		–19.1	–19.2	–27.2	
Price index	1.00	0.81	0.65	0.48	–21.9
Average prices for channel cards ($000s/card)					
OC-48 XCVR transponder cards	37	20	16	11	–32.9
OC-192 XCVR transponder cards		65	52	39	–22.5
SONET OC-48 XCVR line cards	18	15	12	8	–22.4
SONET OC-192 XCVR line cards		40	32	24	–22.5
Average percent change		–31.3	–20.0	–27.5	
Price index	1.00	0.69	0.55	0.40	–26.4
Actual expenditures on channel cards and terminals ($ millions)					
Expenditures on DWDM terminals	926	1,782	3,958	2,531	39.8
Expenditures on channel cards	928	1,645	2,782	1,818	25.1
Overall chain-weighted DWDM price index	1.00	0.75	0.60	0.44	–24.0
Percent change		–25.0	–19.5	–27.3	

Source: RHK.

Note: For DWDM terminals, "open" means that the mux is not part of the box, whereas integrated means the mux and the DWDM are in the same unit.

DWDM

Table 9.7 presents average prices for two types of DWDM gear: terminals and channel cards. Most DWDM terminals are designed so they can easily expand their capacity—that is, the number of wavelengths of light they can transmit. Each wavelength is also referred to as a channel. For each channel, a DWDM terminal needs a channel card. The channel card fits into the DWDM terminal much like expansion cards fit into PCs. If four channel cards are added to a terminal, then that terminal can transmit four different wavelengths simultaneously. As demand increases, additional channel cards are added as needed. Increasing capacity in this way can be done quickly. For instance, according to KMI, the average DWDM terminal had a maximum capacity of forty-two channels, but, on average, only twelve of those channels were used. The sales of cards are quite large—between 1998 and 2001, about 44 percent of DWDM sales was of cards.

The remainder of the expenditures was on the terminals themselves and other miscellaneous equipment.

RHK has collected some information on prices for various pieces of DWDM gear, and those are presented in table 9.7. The first portion of table 9.7 presents price estimates for a sample of DWDM terminals. The terminals vary by the number of cards they can accept and the capacity of each card. Many other possible configurations exist in the market (such as four-channel systems), but I don't have any information on those. Between 1998 and 2001, prices for this set of terminals fell an average of almost 22 percent. The bottom portion of table 9.7 presents average prices for a sample of channel cards. Prices for channel cards fell an average of 26 percent.

Digital Cross-Connects (DCCs)

The smallest of the three fiber optic components in terms of expenditures in 2000 were DCCs. Again, the data used to examine prices in this category are akin to the data for multiplexers and for PBX systems. Therefore, the argument that the estimated price declines are biased upward holds for these categories as well. The data came from Gartner/Dataquest for three types of DCCs: narrowband, wideband, and broadband. The difference between these groups is basically the capacity of the circuits they can tap into. Table 9.8 shows quantities, revenues, and prices between 1994 and 2000. The far right column shows that price declines for DCCs were generally in the single digits.

9.5.3 Summary of Fiber Optic Prices

Table 9.9 presents the summary measures for prices, nominal expenditures, and real expenditures for fiber optic equipment. The price indexes are those that were derived in the previous tables. I extrapolated the price indexes for several years where needed, and those extrapolations are described at the bottom of the table.

Since 1994, fiber optic equipment prices fell an average of 12.4 percent, with the sharpest declines in 2000 and 2001. This result goes against the perception that prices fell dramatically (more dramatically than 12.4 percent a year, at least) for fiber optic equipment, the poster child of rapid innovation. However, digging beneath the surface yields some important clues as to why prices fell only an average of 12.4 percent. First, notice that fiber optic equipment prices fell just a bit more than 5 percent a year between 1994 and 1996 (as shown in the top portion of table 9.9). The relatively slow decline in prices in these years is attributable to the relatively mild declines in DCCs (and the relatively large nominal share of DCCs in those years) and the assumed relatively slow decline in prices for multiplexers. Keep in mind that the price indexes for multiplexers in those years were based on prices falling 6.1 percent, an ad hoc assumption I made. I made this assumption because prices in 1997 and 1998 were estimated to have fallen by that amount. Prices for multiplexers fell much faster in later

Table 9.8 Quantities, revenues, and prices for digital cross connects (DCCs)

	1994	1995	1996	1997	1998	1999	2000	AAGR (%)
Units (thousands)								
Narrowband (T1 ports)	440.3	429.9	452.5	419.5	490.9	601.6	902.4	12.7
Wideband (T3 ports)	31.5	38.2	48.5	97.0	188.7	209.2	311.7	46.5
Broadband (T3 ports)	44.5	51.8	79.1	52.2	61.6	74.6	110.4	16.4
Revenue ($ millions)								
Narrowband	367.7	363.0	382.0	346.1	402.4	490.3	606.6	8.7
Wideband	350.0	401.1	487.0	916.7	1,722.0	1,903.7	2,504.7	38.8
Broadband	376.2	394.0	550.1	339.2	388.0	448.0	601.0	8.1
Total	1,093.9	1,158.1	1,419.1	1,602.0	2,512.4	2,842.0	3,712.3	22.6
Average price ($000s/unit)								
Narrowband	0.84	0.84	0.84	0.83	0.82	0.81	0.67	–3.6
Wideband	11.11	10.50	10.04	9.45	9.13	9.10	8.04	–5.3
Broadband	8.45	7.61	6.95	6.50	6.30	6.01	5.44	–7.1
Change in prices (%)								
Narrowband		1.1	0.0	–2.3	–0.6	–0.6	–17.5	–3.6
Wideband		–5.5	–4.4	–5.9	–3.4	–0.3	–11.7	–5.3
Broadband		–10.0	–8.6	–6.6	–3.1	–4.7	–9.4	–7.1
Total		–4.9	–4.7	–5.2	–2.9	–1.0	–12.3	–5.2
DCC price index	1.00	0.95	0.91	0.86	0.83	0.83	0.72	–5.2

Source: North American Transmission Equipment Market Share and Forecast, 1999, Gartner, October 11, 1999

Notes: Narrowband—DCC equipment designed to electronically cross-connect and manage DS0s (64 Kbps); wideband—DCC equipment designed to electronically cross-connect and manage DSs or T1s; broadband—DCC equipment designed to electronically cross-connect and manage DS3s/T3s or SONET OC1 circuits.

years as competition and the supply of multiplexers in the second-hand market increased. Industry conditions in the early to mid-1990s were reportedly much more like the conditions in 1997 and 1998 than the conditions in 2000 and 2001.

The second reason why prices for fiber optic equipment didn't fall faster over the 1994–2001 period is that DWDM equipment did not make a significant presence (in terms of nominal expenditures) until 1997. As the nominal share of expenditures moved toward DWDM equipment, the decline in the overall fiber optic price index accelerates. In 2001, DWDM accounted for 37 percent of all fiber optic equipment.

The bottom of table 9.9 combines the nominal expenditures and the price data to compute indexes of real spending. All of the real expenditures are expressed in 1998 millions of dollars. Between 1994 and 2001, real expenditures on fiber optic equipment increased at an average annual rate of 36.2 percent.[20] In 1999 and 2000, real expenditures on fiber optic equip-

20. Real computer investment increased at an annual rate of 36.5 percent during this period.

Table 9.9 **Summary indexes for fiber optic equipment**

	1994	1995	1996	1997	1998	1999	2000	2001	AAGR (%)
Nominal spending ($ millions)									
Total fiber optic equipment	3,443	4,163	5,112	7,160	9,059	14,081	22,061	11,842	19.3
Percent change		20.9	22.8	40.0	26.5	55.4	56.7	–46.3	
Multiplexers	1,865	2,406	2,656	3,562	4,556	7,291	10,573	4,880	14.7
DWDM	0	0	381	1,595	1,854	3,427	6,740	4,348	41.6
DCC	1,111	1,182	1,455	1,581	2,210	2,749	3,950	1,914	8.1
Price indexes (1998 5 1.0)									
Total fiber optic equipment	1.36	1.28	1.21	1.10	1.00	0.87	0.72	0.54	–12.4
Percent change		–5.7	–5.3	–9.0	–9.3	–12.6	–17.9	–25.2	
Multiplexers	1.29	1.21	1.13	1.07	1.00	0.88	0.71	0.50	–12.7
DWDM			1.73	1.32	1.00	0.75	0.60	0.44	–17.8
DCC	1.20	1.14	1.09	1.03	1.00	0.99	0.87	0.80	–5.6
Real spending (1998 $ millions)									
Total fiber optic equipment	2,536	3,251	4,217	6,491	9,059	16,112	30,762	22,089	36.2
Percent change		28.2	29.7	53.9	39.6	77.9	90.9	–28.2	
Multiplexers	1,449	1,991	2,341	3,343	4,556	8,277	14,847	9,835	31.5
DWDM			220	1,212	1,854	4,571	11,172	9,914	72.3
DCC	928	1,037	1,340	1,535	2,210	2,777	4,550	2,396	14.5

Notes: It is assumed that prices for multiplexers fell an average of 6.1 percent in between 1994 and 1996, the same rate that was estimated for 1996 to 1998. The price index for dense wavelength division multiplexing (DWDM) equipment is assumed to fall 24 percent, the average rate from 1998 to 2001. The price index for digital cross-connects (DCC) in 2001 is assumed to fall 8.0 percent, a slightly faster rate than in previous years because of increased industry competition.

ment grew at furious paces, in part due to technological advances and the large build-out of many long-haul networks. In 2001, nominal expenditures plunged over 46 percent, but prices also fell quickly, so that in real terms, expenditures fell a little over 28 percent.

9.6 Price Indexes for Overall Communications Equipment

The previous sections presented results on the extent to which prices for various components of communications equipment changed during the 1990s. In this section, those results are used to derive three price indexes for overall communications equipment. The indexes vary by the assumptions that underlie them. The first index is based on very conservative assumptions about price changes and the third index is based on aggressive assumptions about price changes. The "truth" likely lies between the two extreme cases. The three indexes are located on the bottom of tables 9.12, 9.13, and 9.14.

Table 9.10 Communications equipment: Spending and production ($ millions)

	1994	1995	1996	1997	1998	1999	2000	1997–2000 AAGR (%)
Categories from table 9.3								
1. Total				77,444	86,344	99,000	113,855	13.7
2. Consumer				8,167	8,331	8,420	8,456	1.2
3. Business and government spending				69,277	78,013	90,581	105,399	15.0
GDP accounting								
4. Communications equipment GDP (5 + 6 + 7 + 8 + 9)	69,598	77,401	83,740	97,461	103,176	110,710	124,249	8.4
5. Equipment and software	54,743	60,019	65,609	73,700	81,200	93,300	116,800	16.6
6. Government	12,914	13,533	14,157	15,017	15,771	16,919	18,983	8.1
7. Consumer spending	4,523	4,958	5,420	8,167	8,331	8,420	8,456	1.2
8. Exports	11,237	13,762	14,469	17,683	18,209	20,008	23,284	9.6
9. Imports	13,819	14,871	15,915	17,105	20,335	27,937	43,274	36.3
Memo:								
10. Domestic spending (5 + 6 + 7)	72,180	78,510	85,186	96,883	105,302	118,639	144,239	14.2
11. (10 – 1)				27,606	27,289	28,058	38,839	12.1
ASM production information								
12. Industry shipments	48,052	58,499	68,232	82,852	86,119	97,953	119,329	12.9
13. ASM product shipments	48,440	55,431	63,968	78,142	81,932	92,715	107,921	11.4

Note: ASM = Annual Survey of Manufacturers.

9.6.1 Aggregate Spending and Production

Accurate spending figures are needed to derive aggregate deflators for communications equipment. Table 9.10 summarizes spending and production of communications equipment. The top panel of numbers in table 9.10 is from table 9.3, spending on communications equipment for certain categories I obtained largely independent of government sources. The second panel of numbers in table 9.10 shows the official numbers on communications equipment spending.[21] Using the E&S, government, and consumer spending figures, total domestic spending on communications equipment grew at an average rate of 14.2 percent between 1997 and 2000, only half a percentage point faster than the figures from table 9.3.

The bottom portion of table 9.10 shows estimates of production of com-

21. The government and consumer spending figures are not published on a regular basis and, in fact, were last published for 1992. The government expenditure figures were extrapolated to 2000 by assuming the growth rate was half that of the E&S series. The consumer spending numbers are based on those I derived in table 9.3 and on the 1992 input-output tables. Private-sector spending on communications gear likely grew much faster than government spending during the 1990s. As a result of the Telecommunications Act of 1996, a flood of entrants entered into the telecommunication service industry. Also, as stated previously, there was a surge in spending on fiber optic equipment that was tied to the build-out of privately owned long-haul fiber networks.

munications equipment, a concept similar to the GDP figures in line 4. Surprisingly, industry shipments and product shipments increased at faster rates than the GDP figures. Why this is the case is unclear.

Overall, the point to take away from table 9.10 is that several independent sources concur that domestic spending on communications equipment increased at a fairly rapid clip in the late 1990s and that production of communications equipment also increased quickly. Further, the spending estimates from table 9.3 account for a majority of all communications equipment spending.

9.6.2 Constructing Overall Communications Equipment Price Indexes

I employ a bottom-up approach to construct overall price indexes for communications equipment—the estimates of price indexes for various components of communications equipment are chain weighted. The assumptions made about prices for the conservative, moderate, and aggressive scenarios are displayed in table 9.11. Tables 9.12 through 9.14 show the results based on these assumptions.

Conservative Assumptions

Lines 1 through 6 in the top portion of table 9.12 show the price indexes used in place of the PPI for a select group of products. For the conservative assumptions, only those price indexes are used that were discussed earlier in this paper. That set of results includes previous results on cell phones, central office switching equipment, and LAN equipment. Added to these three sets of results are those that are developed in this paper—fiber optic equipment, PBXs, and modems. For all other communications equipment, the conservative approach uses the PPI for communications equipment.[22]

These price indexes in lines 1 through 6 are chain weighted using the weights in lines 7 through 12. The aggregate price index for these products, line 15, fall an average of 14.0 percent between 1994 and 2000, with the fastest price declines occurring in the later three years. In contrast, the overall PPI for communications equipment (line 19) falls at a 0.4 percent annual rate.

The price index for the special products does not include the prices for products not listed in lines 1 through 6. The conservative approach assumes that prices for all other communications equipment follow the PPI. Line 22 shows the overall price index for communications equipment under the conservative assumptions—prices fall an average of 6.4 percent, 6 percentage points faster than the PPI and 3.5 percentage points faster than BEA's communications equipment price index (line 24). Recall that the

22. Ideally, each product would be linked to its own PPI. However, the concordance between my system and the SIC was difficult to construct. Also, most PPIs within SIC 366 do not show much change over the late 1990s, so even if I were to use a more refined concordance, the overall results would not change very much.

Table 9.11 Three sets of assumptions for prices, by equipment type

Equipment type	Conservative	Moderate	Aggressive	Comments
Central office switching and transmission equipment	BEA (16.1% decline per year)	BEA	BEA	
Fiber optic equipment	Section 9.5 results	Section 9.5 results	Section 9.5 results	
Cellular phone infrastructure	PPI	–7.5% per year, half that of cellular phones	–10% per year, 2/3 that of cellular phones	There has been continuous improvement in cell phone technology over the past decade, and there has been increased competition in the base station equipment market.
Local area network (LAN) equipment	Doms and Forman	Doms and Forman	Doms and Forman	
Modems	Section 9.4 results	Section 9.4 results	Section 9.4 results	
Other data communications (WAN, ISDN, ATM, frame relay, and the like)	PPI	3/4 of Doms and Forman	3/4 of Doms and Forman	The prices for equipment in this category probably do not fall as fast as LAN equipment because the market is more dispersed and competition is not as great.
Private branch exchange (PBX)/Key telephone system (KTS)	Section 9.4 results	Section 9.4 results: –1% per year	Section 9.4 results: –2% per year	It is likely the results in section IV understate the actual price declines, so the moderate and aggressive assumptions make adjustments.

Voice processing equipment (call centers, voice mail, and the like)	PPI PBX: –1% per year	Section 9.4 results for Section 9.4 results:	–2% per year	There have been large improvements in technology in this category during the 1990s, especially in the technology used in call centers.
Wireless handsets (cell phones)	Hausman	Hausman	Hausman	
Capital equipment spending by cable television firms not covered above	PPI	Decline of 5% per year	Decline of 5% per year	There have been improvements in cable TV technology, including the widespread upgrades to digital cable.
Communications equipment not covered by above categories	PPI	PPI: –2% per year	PPI: –4% per year	The moderate and aggressive cases assume that the PPI for other categories is mismeasured. However, the largest components in this group are not the ones where technology change has been as rampant as other categories. Therefore, the aggressive case has the PPI falling less than half as fast as the aggregate price index for the above listed items.

Note: BEA = Bureau of Economic Analysis; PPI = producer price index; ISDN = integrated services digital network; ATM = asynchronous transfer mode.

Table 9.12 **Price indexes for communications equipment—Conservative assumptions (all price indexes = 1.00 in 1994, all spending figures in $ millions)**

	1994	1995	1996	1997	1998	1999	2000	AAGR (%)
Price indexes used instead of the PPI								
1. Central office switching and transmission equipment	1.00	0.84	0.70	0.59	0.50	0.42	0.35	–16.1
2. Fiber optic equipment	1.00	0.94	0.89	0.81	0.74	0.64	0.53	–10.1
3. Local area network (LAN) equipment	1.00	0.84	0.77	0.64	0.46	0.38	0.33	–17.0
4. Modems	1.00	0.83	0.72	0.51	0.41	0.29	0.20	–23.3
5. Private branch exchange (PBX)/Key telephone system (KTS)	1.00	1.03	0.96	0.90	0.86	0.79	0.75	–4.8
6. Wireless handsets (cell phones)	1.00	0.85	0.72	0.61	0.52	0.44	0.38	–15.0
Spending on the above products								
7. Central office switching and transmission equipment	9,677	9,810	11,537	12,358	13,562	14,475	15,500	8.2
8. Fiber optic equipment	3,443	4,163	5,112	7,160	9,059	14,081	22,061	36.3
9. LAN equipment	5,828	7,808	10,502	11,437	13,111	14,027	15,838	18.1
10. Modems	2,500	3,000	3,500	3,077	3,290	2,800	2,500	0.0
11. PBX/KTS	5,890	6,105	6,245	6,832	7,601	7,980	8,392	6.1
12. Wireless handsets (cell phones)	2,963	3,704	4,630	5,787	7,228	7,619	7,692	17.2
13. Spending on special products by consumers	1,481	1,852	2,315	2,894	3,614	3,810	3,846	17.2
14. Spending on special products by business and government	28,820	24,930	28,709	32,320	37,126	43,146	52,299	10.4
Aggregate price indexes for above products								
15. Total	1.00	0.89	0.79	0.67	0.56	0.48	0.40	–14.0
16. Consumer products	1.00	0.85	0.72	0.61	0.52	0.44	0.38	–15.0
17. Business and government investment	1.00	0.89	0.79	0.68	0.57	0.48	0.41	–13.9
18. Percent change		–11.3	–10.9	–14.6	–16.3	–15.3	–15.2	
Construction of business and government price index								
19. PPI for communications equipment	1.00	1.01	1.01	1.02	1.01	1.00	0.97	–0.4
20. Percent change		0.5	0.9	0.6	–0.6	–1.7	–2.3	
21. Business and government spending net of special products	38,837	48,621	51,057	56,397	59,845	67,074	83,483	13.6
22. Conservative communications equipment price index	1.00	0.96	0.92	0.87	0.80	0.74	0.67	–6.4
23. Percent change		–4.5	–3.6	–5.8	–7.7	–8.1	–8.4	
24. Bureau of Economic Analysis communications equipment price index	1.00	0.96	0.94	0.93	0.89	0.86	0.83	–3.0
25. Percent change		–4.0	–2.5	–1.0	–4.1	–3.6	–2.8	

Note: PPI = producer price index.

BEA index already makes an adjustment for two of the six product categories in lines 1 through 6—LAN equipment and central office switching and transmission equipment.

Moderate Assumptions

The next set of assumptions about prices builds upon the conservative set of assumptions. The first additional assumption made is that prices for cellular phone infrastructure fall half as fast as cell phones. There has been continuous improvement in cell phone technology over the past decade, especially as new generations of equipment have been deployed. There has been a progression from AMPS to iDEN to GSM and CDMA.[23] Each successive technology is better than the previous one, and this trend is likely to continue.

Another assumption made is that prices for "other data communication" fall about three-quarters as fast as LAN equipment. This category includes WAN equipment, frame relay, ATM, and other components needed to run large data networks. Technology in these areas has improved over the years.

Another modification made within the set of moderate assumptions is that PBX prices fall 1 percent more per year than the results in section 9.4. As stated previously, the PBX results are likely to be biased upward. Additionally, I assume that prices for voice-processing equipment follow a similar pattern. There have been large improvements in voice-processing technology, especially in the technology used by call centers.

Finally, for communications equipment not covered by the above-mentioned categories, I assume that prices fall at an average annual rate that is 2 percentage points less than the official PPI for communications equipment. In each and every instance that prices for communications equipment have been examined, it has been found that prices fall faster than the PPI. Therefore, assuming that prices fell faster than the officially published numbers by a modest amount seems reasonable.

As shown in table 9.13, under these assumptions, prices for communications equipment fell at an 8.3 percent annual rate, more than one-third as fast as the BEA computer price index and over 5 percentage points faster than the BEA communications equipment price index.

Aggressive Assumptions

Finally, table 9.14 presents results under the aggressive assumptions. The aggressive assumptions are laid out in table 9.11. The biggest difference

23. The Advanced Mobile Phone Service (AMPS) was an analog system developed by Bell Labs in the 1970s. The remaining technologies are digital. iDEN, developed by Motorola, uses time-division multiple access (TDMA) technology. The two digital technologies that are the fastest growing in the United States are code division multiple access (CDMA) and the global system for mobile (GSM) communications.

Table 9.13 **Price indexes for communications equipment—Moderate assumptions (all price indexes = 1.00 in 1994, all spending figures in $ millions)**

	1994	1995	1996	1997	1998	1999	2000	AAGR (%)
Price indexes used instead of the PPI								
Items from conversative assumptions page with adjustment for:								
1. PBX prices falling an additional 1% per year	1.00	0.88	0.79	0.67	0.56	0.47	0.40	–14.2
2. Other data communication	1.00	0.88	0.83	0.72	0.57	0.49	0.44	–12.7
3. Voice-processing equipment (call centers, voice mail, etc.)	1.00	1.03	0.96	0.90	0.86	0.79	0.75	–4.8
4. Cellular phone infrastructure	1.00	0.93	0.86	0.79	0.73	0.68	0.63	–7.5
5. Cable TV equipment	1.00	0.95	0.90	0.86	0.81	0.77	0.74	–5.0
Spending on special products								
6. Items from conversative assumptions page	28,820	24,930	28,709	32,320	37,126	43,146	52,299	10.4
7. Other data communication	4,902	6,567	8,834	9,620	11,344	13,479	15,532	21.2
8. Voice-processing equipment (call centers, voice mail, etc.)	4,279	4,435	4,537	4,963	5,626	6,215	6,743	7.9
9. Cellular phone infrastructure	4,266	4,693	5,162	5,678	4,474	4,955	4,734	1.8
10. Cable TV equipment	2,554	2,810	3,091	3,400	3,850	5,400	6,000	15.3
11. Spending on special products by business and government	44,821	43,435	50,332	55,981	62,420	73,195	85,308	11.3
Aggregate price indexes for special products								
12. Business and government investment	1.00	0.91	0.83	0.73	0.62	0.54	0.48	–11.6
13. Percent change		–9.4	–8.8	–12.0	–14.5	–12.9	–12.1	
Construction of business and government price index (assume PPI falls 2% per year faster than actual)								
14. Modified PPI for communications equipment	1.00	0.99	0.97	0.96	0.94	0.90	0.86	–2.4
15. Moderate communications equipment price index	1.00	0.94	0.88	0.81	0.73	0.66	0.60	–8.3
16. Percent change		–6.4	–5.8	–8.1	–10.2	–9.7	–9.3	
17. BEA communications equipment price index	1.00	0.96	0.94	0.93	0.89	0.86	0.83	–3.0
18. Percent change		–4.0	–2.5	–1.0	–4.1	–3.6	–2.8	
19. BEA computer price index	1.00	0.84	0.64	0.49	0.36	0.28	0.24	–21.2
20. Percent change		–16.1	–24.0	–22.5	–26.4	–23.8	–13.6	

Note: PPI = producer price index; PBX = private branch exchange; BEA = Bureau of Economic Analysis.

Table 9.14 Price indexes for communications equipment—Aggressive assumptions (all price indexes = 1.00 in 1994, all spending figures in $ millions)

	1994	1995	1996	1997	1998	1999	2000	AAGR (%)
Price indexes used instead of the PPI								
1. Central office switching and transmission equipment	1.00	0.84	0.70	0.59	0.50	0.42	0.35	–16.1
2. Fiber optic equipment	1.00	0.94	0.89	0.81	0.74	0.64	0.53	–10.1
3. Cellular phone infrastructure	1.00	0.90	0.81	0.73	0.66	0.59	0.53	–10.0
4. Local area network (LAN) equipment	1.00	0.84	0.77	0.64	0.46	0.38	0.33	–17.0
5. Modems	1.00	0.83	0.72	0.51	0.41	0.29	0.20	–23.3
6. Other data communication	1.00	0.88	0.83	0.72	0.57	0.49	0.44	–12.7
7. Private branch exchange (PBX)/Key telephone system (KTS)	1.00	1.01	0.92	0.85	0.79	0.71	0.66	–6.8
8. Voice-processing equipment (call centers, voice mail, etc.)	1.00	1.01	0.92	0.85	0.79	0.71	0.66	–6.8
9. Cellular phones	1.00	0.85	0.72	0.61	0.52	0.44	0.38	–15.0
10. Cable TV equipment	1.00	0.95	0.90	0.86	0.81	0.77	0.74	–5.0
Spending on special products								
11. Spending on special products by business and government	44,821	51,242	60,834	67,418	75,531	87,222	101,146	14.5
Aggregate price indexes for special products								
12. Business and government investment	1.00	0.90	0.81	0.71	0.60	0.51	0.44	–12.6
13. Percent change		–10.0	–9.8	–13.2	–15.5	–14.0	–13.3	
Construction of business and government price index (assume PPI falls 4 percent per year faster than actual)								
14. Modified PPI for communications equipment	1.00	0.97	0.94	0.90	0.86	0.81	0.76	–4.4
15. Aggressive communications equipment price index	1.00	0.92	0.85	0.76	0.66	0.58	0.51	–10.6
16. Percent change		–7.9	–8.0	–10.8	–13.0	–12.2	–11.6	
17. BEA communications equipment price index	1.00	0.96	0.94	0.93	0.89	0.86	0.83	–3.0
18. Percent change		–4.0	–2.5	–1.0	–4.1	–3.6	–2.8	
19. BEA computer price index	1.00	0.84	0.64	0.49	0.36	0.28	0.24	–21.2
20. Percent change		–16.1	–24.0	–22.5	–26.4	–23.8	–13.6	

Note: See table 9.13 notes.

between the aggressive and moderate assumptions is that the PPI is assumed to fall 4 percentage points faster than the official PPI. Under the aggressive assumptions, prices for communications equipment fall at a 10.6 percent annual rate, about 2 percentage points faster than the moderate assumptions.

9.7 Investment and MFP

In this section we address the implications of the mismeasurement of communications equipment prices. Specifically, we examine how growth rates in various investment aggregates would change if the alternative price indexes for communications equipment are used. The calculations are performed for investment in communications equipment, information-processing equipment, and for total nonresidential investment. One reason we might be interested in how the growth rates of real investment change as a result of new deflators is that it may alter the results on capital deepening and MFP. Later in this section we address this issue.

Basically, the real growth rates of various investment categories will increase as a result of using the price indexes in the previous section. What influences the effect of new communications equipment deflators on various aggregates is the nominal share of communications equipment of the aggregates. Roughly speaking, the effect of altering the price index for communications equipment is proportional to the nominal share of communications equipment. Between 1994 and 2000, communications equipment made up approximately 0.25 percent of all investment in information processing equipment and software and 10 percent of all nonresidential investment.

How the growth rates for real communications equipment, information-processing equipment, and total nonresidential investment are affected by the conservative, moderate, and aggressive price indexes is displayed in table 9.15. The figures in table 9.15 reflect how much the average growth rate for those series would increase under the various assumptions about communications equipment pricing.

Table 9.15 **Changes in average annual growth rates for real investment using various price indexes for communications equipment (increase in average annual growth from 1994 to 2000)**

	Communications equipment	Information processing equipment	Nonresidential investment
Conservative	4.1	0.9	0.4
Moderate	6.6	1.5	0.6
Aggressive	9.8	2.2	0.9

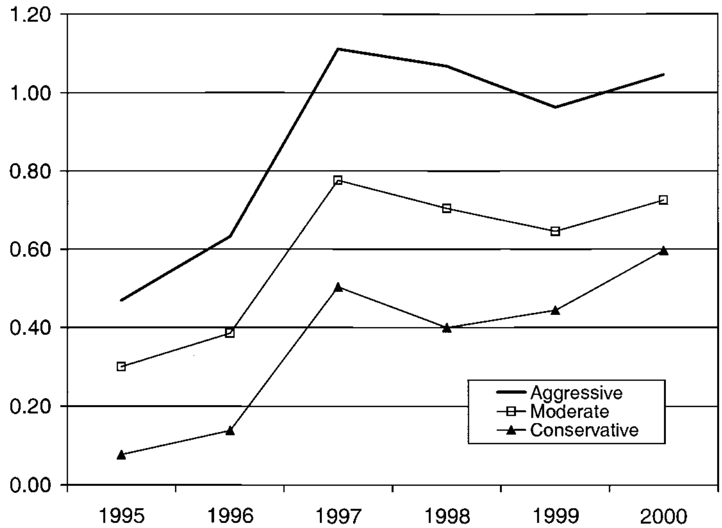

Fig. 9.6 Changes in the real growth rate in nonresidential investment under differing assumptions for communications equipment prices

As shown in the bottom left of the table, if the aggressive deflators are used, then the average annual growth rate for real investment in communications equipment increases by 9.8 percentage points between 1994 and 2000. The effects of the aggressive deflator on information-processing equipment and on nonresidential investment are smaller, but still considerable. Even if the conservative deflator is used, real nonresidential investment would be boosted by 0.4 percentage point per year.

The results in table 9.15 are averages over 1994 and 2000. Figure 9.6 shows the data on an annual basis for nonresidential investment. Each of the lines corresponds to one of the three assumptions about communications equipment prices. As shown, the changes to the deflators have the largest effects for 1997–2000, the period in which nominal spending on fiber optic equipment grew rapidly. In a nutshell, adopting deflators for communications equipment that more likely reflect actual price movements would have nontrivial effects on a variety of investment categories.

One reason the growth rate in real investment is of interest is the relationship between real investment, the capital stock, and productivity. This is especially true of the acceleration of productivity in the second half of the 1990s, when current estimates suggest that there was a significant contribution from capital deepening and a significant contribution from acceleration in MFP. One way in which the changes in the growth rate of communications equipment feed into changes in productivity is the output effect; the growth rate of overall output is increased because the growth rate of one of the parts has increased. The output effect is small given the small share of communications equipment to total output; the average share of communications equipment to total GDP between 1994 and 2000 is about 0.9 percent, and about 1.1 percent of total nonfarm business output. Even if the aggressive results are used, GDP growth would be boosted by less than 0.1 percent per year.

The other way in which the deflators affect productivity is through the contribution to the growth rate of capital services; a higher growth rate in capital services will shift some of the increase from MFP growth toward capital deepening. One way to estimate the effect changes in capital deepening is by examining the product of the capital income share of communications equipment and the change in the real growth rate in communications equipment. Daniel Sichel has estimated that the communication equipment share during the later half of the 1990s is a bit less than 2 percent. The moderate deflators for communications equipment would boost real communications equipment growth by an average of 6.5 percent, resulting in capital deepening increasing by a bit more than 0.1 percentage point per year. To put this result in some context, between 1997 and 2000, Daniel Sichel estimates that MFP grew at a 1.1 percent average rate; the moderate results in this paper on communications equipment would likely lower that estimate to closer to 1.0 percent. If the more aggressive assumptions about communications equipment prices were used, then MFP growth would be lowered to closer to 0.9 percent per year.

9.8 Conclusion

The view that statistical agencies have difficulty in measuring prices for classes of goods that exhibit rapid technological change has long been espoused. Measuring prices for such goods poses special problems, and extra effort has to be employed. For instance, there is now a large and rich literature on measuring prices for computers, and the results of this research have been folded into the national accounts.

Surprisingly, relatively little work on more accurately measuring prices has been done in the area of communications equipment, an area where nominal expenditures have been very close to those of computers and an area where certain segments have enjoyed rapid technological change. There are several reasons for this, including the large diversity of products within communications equipment and the difficulty in obtaining prices.

This paper has attempted to derive measures of prices for communications equipment by gathering information on prices for many of the individual pieces of communications equipment. Some of the price series were poached from previous research, some others were developed more fully in this paper, and some assumptions have been made about the remainder. We estimate that prices for communications equipment likely fell anywhere from 5.5 to 10.5 percent on average between 1994 and 2000, significantly faster than the PPI and the BEA deflator.

On the one hand, these results are somewhat akin to the price profiles for computers in that they show steady declines and that the declines accelerated in the late 1990s. On the other hand, the price declines for communications equipment appear to be less than half of those of computers. We did find that prices for some components of communications equipment fall very fast, especially for fiber optic equipment. However, fiber optic equipment makes up a small share of total communications equipment, and so the influence it has on the larger communications aggregate is muted.

Our results are also roughly consistent with several independent sources of information on technological change and price declines. First, Aizcorbe, Flamm, and Khurshid find that the prices for semiconductors that go into communications equipment do not fall as quickly as prices of chips that go into computers. Further, semiconductor content in computers is higher. Second, figure 9.2 showed that the number of patents awarded to communications equipment was much less than the number awarded for computers in the late 1990s.

One can speculate about other reasons that prices for communications equipment do not fall as quickly as computers, such as the fact that the communications equipment industry is much more fragmented than that for computer hardware. Achieving economies of scale or proceeding up learning curves, as are important for computers and semiconductors, do not appear to happen often within communications equipment, with the exception of cell phones and LAN cards.

The implications for the results in this paper are that real investment in certain categories was much higher than actually reported. For instance, real nonresidential investment would be from 0.5 to 1.0 percentage point higher between 1997 and 2000 if the deflators presented in this paper were used. This higher rate of real investment also feeds into higher rates of capital accumulation, resulting in shifting a small portion of the growth in MFP in the late 1990s to capital deepening.

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