Prices for Local Area Network Equipment

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I. Introduction

Though local area networking (LAN) equipment is seldom noticed and has received comparatively little study, the importance of such hardware is vast. LAN equipment routes information between computers and plays a part in every message sent and received over the Internet. By 1999, sales of LAN equipment in the United States totaled close to $16 billion dollars to become one of the single largest categories of communications equipment. In 1992, spending on LAN equipment was just $3 billion. The rapid growth in the power, and the reduction of price, of LAN equipment has facilitated the rapid growth in the use of personal computers and the explosion in popularity of the Internet.

This paper presents the results of an analysis of price changes for four types in LAN equipment--routers, switches, LAN cards, and hubs. Hedonic regressions were used to estimate price changes for the two largest classes of LAN equipment, routers and switches. A matched model was used for LAN cards and the prices for hubs were inferred by using an economic relationship to switches.

As a preview to our conclusions, we find that prices the four groups of LAN equipment fell at double-digit rates in the last half of the 1990s. Routers fell an average of about 14 percent between 1995 and 1999, although results vary considerably across router classes. We also find that between 1996 and 2000, the prices for switches fell faster than routers, averaging an annual decline of about 22 percent. The prices for LAN cards dropped at an annual average rate of 18.3 percent. We estimate that the prices for hubs, the smallest portion of the LAN category, fell an average of 19 percent. Between 1995 and 1999, our estimate of the price index for all LAN equipment fell an average of 17 percent--pulled down by switches and hubs but held up by routers. These results stand in sharp contrast to the PPI for communications equipment that is nearly flat over the 1990s. However, the declines in the prices for LAN equipment, although dramatic, are less than the decline in computer prices.

The rest of this introduction attempts to answer the question: Why do we examine this topic? There are three basic reasons. First, a greater share of communications equipment is being used for data instead of voice; LAN equipment is one chunk of the data communications revolution. Looking into the future, the importance of data communications is likely to grow. So, gaining a better understanding LAN equipment will give us a much better understanding of equipment that is becoming an increasing share of total communications equipment.

The second reason we explore prices for LAN equipment is that there is a widespread belief that official measures for prices in the more aggregate category of communications equipment do not accurately capture quality changes. This belief stems from several sources, including a couple of studies that examined small parts of the communications equipment spectrum previously, and the high-tech nature of communications equipment. Once we get a better handle on what has happened to prices for LAN equipment, we will then be better able to address questions on how investment in communications equipment affects output measurement, and how communications equipment investment may be related to the acceleration in aggregate productivity growth.[1]

Lastly, segments of the LAN equipment market are dominated by Cisco. We generally find that the segments where Cisco faces the greatest competition are the segments where prices fall the fastest. Although in no way do we formally test this relationship, our findings are suggestive of areas for further research.

How important is LAN equipment?

Table 1 presents estimates of communications equipment spending by end user group and type of equipment. The estimates come from a large array of sources, most of which are private firms that track portions of the communications equipment industry. The end users groups are telecommunication service providers, business and government, and other. It is surprising to see that the business and government group spent more on communications equipment then telecom service providers in three of the last four years--in 2000, telecom service providers had a large surge in spending, especially in fiber optic transmission equipment. Within the business and government group, a majority of communications equipment expenditures is on data communications equipment, the largest component being LAN equipment.

Official prices measures

Table 2 presents summaries of some official price measures for communications equipment and computers during the past decade. The table shows the average annual percent change in price for the selected series for the 1990-1995, 1995-2000, and the 1990-2000 periods. The PPI for overall communications equipment grows slightly (0.3 percent per year) over the

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1 Jorgenson and Stiroh (2000) examine the implications of falling communications equipment prices on productivity growth

1990s. The PPI does not have category for LAN equipment. However, the PPI that is most closely aligned with LAN is equipment is "other data communications equipment" that was compiled between 1995 and 2000. The prices for this category decreased at an average rate of 0.2 percent, slightly faster than the overall communications equipment aggregate. The deflator BEA uses for its PDE communications equipment category decreased by almost 2 percent on average. One reason why the BEA category actually falls is that part of their index is based on a hedonic price index for digital telephone switches developed by Bruce Grimm (1996).

In sharp contrast to the official prices indexes for communications equipment, the official prices for computers have fallen very rapidly in the 1990's. Between 1995 and 2000, the BEA measure for PDE computer prices fell an average of over 22 percent.

Why do we expect the prices for LAN equipment to fall faster than the official measures?

First, there has been a steady stream of innovations in LAN equipment and in other areas of communications equipment. Figure 1 shows patent data for high technology products that were generously provided by Manuel Trajtenberg. The share of patents granted in his communications category has increased to over 6 percent of total patents. However, computers (as measured by hardware, software, peripherals, and storage devices) and semiconductors experienced larger increases. Since communications equipment is a large consumer of semiconductors, some of the increase in the share of semiconductor patents likely benefits communications equipment. Ana Aizcorbe and Kenneth Flamm are constructing a price index for semiconductors that go into communications equipment. Their preliminary results suggest that the price of semiconductors that go into communications equipment fall less rapidly than semiconductors that go into computers.

Second, two previous studies found that central office switching equipment fell faster than the PPI. Kenneth Flamm (1989) reviewed pricing for a variety of telephone switching equipment--prices for some types of equipment fell up to low double-digit rates. Bruce Grimm (1996) found that prices for digital switches fell an average of 10.1 percent between 1985 and 1996. Unfortunately, that's about all of the work that has been done to measure prices for communications equipment.[2]

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[2] Getting price and characteristic data on communications equipment has always been difficult, and perhaps more so now that the telecom service industry is more loosely regulated than in the past.

Third, the most convincing reason is also the most difficult to quantify--throughout the communications equipment universe, significant changes have occurred in the last decade, so many changes that it is very difficult for financially hamstrung statistical agencies to keep track. As shown in this paper, LAN equipment has drastically improved.

The rest of the paper is as follows. In section II we briefly discuss the technology of computer networking. In particular, we discuss networking equipment products known as routers, switches, LAN cards, and hubs. These products act as "traffic cops", routing the flow of information through a network or through the Internet. We also discuss the history and development of the computer networking industry. In section III we discuss the construction of and regression diagnostics on hedonic price regressions for routers and switches. This section also includes the matched-model analysis of LAN cards. Section IV presents some alternative price measures based on our hedonic results for routers. Section V presents the aggregate price index for LAN equipment and some concluding thoughts.

II. Local Area Networks

II.1 Overview of LAN equipment

The basic manner in which data communications takes place is, broadly speaking, little different from the method by which voice communications takes place--a common language, or protocol, is used so that communications can be sent from a sender to a receiver. This language is translated by various means into a signal that travels over a physical medium, such as copper wire, fiber optic cable, or over the airwaves. Because of the physical impossibility of maintaining direct communications links between every possible sender and receiver of data, network traffic travels over the physical medium through a series of nodes which, like circuit switches in the telephone communications infrastructure, act to guide and regulate traffic over the network.

LAN equipment are the devices that direct traffic between computers, making possible email transmission, Internet browsing, and file sharing with co-workers. LANs are used to connect small groups of users who are usually located physically close to one another and who may often wish to utilize a shared resource such as a printer or some other peripheral. Users in a LAN are often grouped not only physically but also functionally, so that the most frequent contacts for a user within a LAN will usually be other users within the same LAN.

To make some sense of the various LAN devices, figure 2 has a simplified and partial diagram of the LAN at the Federal Reserve. When an email is sent from a computer in the

Research and Statistics Division (the bottom right of the figure), the computer breaks the message into pieces, called packets. The packets are sent through the computer's network interface card, a device that physically connects the PC to the computer network. The packets go to a switch. Switches act as filters, making simple decisions as to which packets are to be sent up to the next level and which packets should be sent to other users that share the switch. For instance, if a file is to be printed, the packets of information can stay in the local loop and not congest network traffic further up. Switches operate much like circuit switches in the public telephone network, acting as nodes that take incoming traffic and then redirect it in a direction toward its final destination. Basically, a switch is a device with multiple ports in which messages enter into one port and are then processed internally and redirected on toward another port to send the message on to its final destination. Today's switches are advanced products, often coming complete with hundreds of ports and capable of redirecting millions of packets of information a second.

The switch sends the email message up to a router that oversees the Research and Division. A router is a sophisticated device that decides where packets should be sent next, depending on traffic congestion and the packet's final destination. If the message is intended for a coworker, the router send the message back down the network. In the case of an email to someone outside the board, the message will be sent along a fiber optic loop that connects all of the divisions at the Board. The message then hits another router and sends them to the Internet. Routers are often the central "brains" behind any network. Like switches, routers work to direct packets of information across a network. However, differences in the ways in which routers and switches work have given routers some functionality that switches do not have. Routers are able to communicate with one another in a way that allows the router to optimize network traffic, determining the optimal path through which a packet of information should flow. In addition, the architecture of routers allow them to include network management and security features that switches are incapable of providing, allowing network managers to identify problems and congestion within a network with ease as well as providing protection to keep the network safe from outside intruders.

When an email is sent from one of the Federal Reserve Governors, packets of information are again sent through a computer interface card into the LAN. Packets in this case travel to a hub. Like switches, hubs are used to connect computers in a LAN, or to allow multiple computers to share a given network line. Unlike switches or routers, however, hubs do not filter packets. Instead, they simply route packets received from one port to all of the other ports, so that all segments of the LAN can see the packets. While still commonly used, hubs are much simpler devices than either routers or switches, generally lacking many of the management features as well as the filtering capabilities of those products.

Today's routers and switches are very complicated devices, carrying advanced processing devices and sometimes costing hundreds of thousands of dollars. Some are capable of handling millions of packets of information every second, redirecting them along complicated networks with seemingly limitless branches. Development of this technology over the past decade has been extraordinarily rapid. Maintaining abreast of this market was difficult for even the most informed of network managers. It is in this complicated, even bewildering, environment that the IS managers have been forced to choose equipment for their company's networks throughout the 1980s and 1990s. As we shall see, the extremely complicated nature of these products will have important implications for how we view the welfare benefits of networking equipment.

II.2 A Brief History of Computer Networking and Internetworking

II.2.1 Early History, the 1980s

The history of the development of computer networking equipment has paralleled the development of the computer. Computer networking emerged first as a means by which users could interface remotely with mainframe computers. International Business Machines (IBM) and Digital Equipment Corporation (DEC) developed communications protocols named Systems Network Architecture (SNA) and DECnet, respectively, to allow users to interact with their mainframes and minicomputers. Throughout the 1970s and 1980s, these communications protocols, and their associated network architectures, dominated the data communications landscape. With the birth of personal computers, simple LANs came into use. Small LANs that covered short distances were the most common at first since there were difficulties in transmitting data over far distances.

LANs were found to be very useful, as users were able to communicate and share files in ways that before seemed impossible. However, there was soon found to be a limit to the number of computers that could be on a given LAN. Networks require open bandwidth for information to travel, and a network that has too many users quickly becomes congested, slowing traffic on the network. To solve this problem, network managers divided their networks into sets of smaller LANs. These smaller LANs would in turn be linked together by devices known as bridges or routers, which route network traffic from one LAN segment to another. Though the tasks performed by routers and bridges were similar, they were accomplished by slightly different means. Routers were intelligent devices that were slower than bridges but had additional functionality that allowed them to determine the optimal path through which any message should travel through the network. Bridges were faster, but had no such functionality. In time, the added functionality of routers was seen to be very beneficial, and routers became the predominant form of internetworking equipment.

A trend that began in the 1980s that had important ramifications for the LAN industry was that users and manufacturers came to rely more and more on open protocols. The major set of protocols used for the Internet, TCP/IP, had been developed in the 1970s by the Department of Defense. LANs used a set of standards and protocols called ethernet that was developed at Xerox Corporation's Palo Alto Research Center in the late 1970s and early 1980s. Xerox's ethernet was an open standard. Still, the new openness of standards did not evolve into a single new, openly published protocol, but rather developers learned to use a variety of protocols already in use by manufacturers. Thus, many open protocols came into widespread acceptance--token ring, ATM, TCP/IP, ethernet--and many more. However, two standards gained the most widespread acceptance; ethernet came to be used most often for corporate networks while TCP/IP became the dominant standard in the Internet.[3]

[3] This is oversimplifying things a bit. To be precise, data communications takes place in several stages, or *layers*. Each layer must be conducted within the parameters of a specific protocol, and the protocols in use vary depending on layer. The protocols mentioned refer to the network layer of data communications, and are the standards most commonly thought of when referring to network protocols.

II.2.2 Computer Networking in the 1990s

By the early 1990's the networking business soared, boosted by the migration of information systems from mainframe to client/server (C/S) computing platforms. The advent of open standards and the continued proliferation of networking protocols used in C/S helped to make multiprotocol routers--routers that were capable of supporting a variety of differing protocols--particularly popular. The June 1991 issue of Data Communications magazine noted that "no less than 10 vendors have announced multiprotocol routers during the past 6 months." Established vendors also focused their energies on the multiprotocol router market. In 1991 IBM and DEC announced that they would begin supporting other protocols on an equal footing with their native SNA and DECnet, while in the same year both vendors brought to production their first multiprotocol routers. In the same year another major networking company, 3Com, exited their LAN operating systems business to concentrate on becoming a networking hardware company. In the early 1990s the rapid growth and changing landscape of networking left an array of bewildering choices for IS managers.

Because of the difficulty involved in maintaining abreast of the latest changes in technology and the increasing importance of network reliability, industry trade publications noted that networking professionals seemed to desire some standardization of product line. Indeed, as we discuss below, IS departments seemed to prefer some consolidation in the industry--despite fewer choices and potentially higher prices--because of the added simplicity such consolidation would bring to the network design process. Because networks and internetworking equipment had become an important part of the corporate infrastructure, networks increasingly needed to be reliable, easily maintained, and serviceable by the manufacturer.

The industry structure of the early 1990s was ill-suited to address these concerns of network buyers. The proliferation of new vendors and products, along with the accompanying concerns over lack of standardization, made network design and product choice very difficult. Many networking equipment firms did not have the products available to eliminate interoperability concerns by providing complete "network solutions" for clients. Moreover, while the technology of multiprotocol equipment such as routers was improving tremendously, levels of service provided by vendors to configure and maintain systems were not. New start-up firms had the technology to provide impressive new products, but did not have the staff or the training to provide extensive support.

The desires of users for a full product line and greater service and support, along with the strong cash flows and high stock values the acquired by firms operating in a booming industry, helped to ignite a wave of consolidation in the industry. Moreover, it was believed that "full-service" networking vendors would be able to better provide rock-solid service to the customer, as large-scale vendors would have the scale necessary for a significant service organization. Concentration in the networking market fell in the early 1990s as firms rushed to enter the growing market, but has since risen significantly.

Table 3 lists some of the major merger and acquisition transactions taking place in the early to mid 1990s in the internetworking industry. As is evident from the column labeled "description", most transactions were attempts by major players such as Cisco or 3Com to plug holes in their existing product line, or attempts by smaller firms to merge their complementary product lines and so remain competitive in the marketplace. The trend towards industry consolidation B as well as the industry practice of major players acquiring industry start-ups to fill gaps in existing product lines B was further boosted by the introduction of a new technology, switching.

Switches became popular in 1994 as a solution to increasing congestion that was plaguing corporate networks and the Internet. The technology underlying the brainy routers, although important to generating the features which had made them so successful, was judged too slow in some instances to route the increasing volume of traffic in high-speed networks. Switches in many ways resembled the bridging technology of a previous generation--fewer functions but faster processing times.

As figure 4 shows, switches have grown explosively since 1994, becoming by far the fastest growing segment of the networking industry. Such explosive growth was not lost on the major networking hardware firms, who quickly bought up switch manufacturers to fill gaps in their product line. Consolidation was so extensive that the networking equipment industry became dominated by one firm, Cisco Systems Inc. Cisco grew throughout the 1990s from a relatively small manufacturer of routers to what one industry trade journal has described as the Wal-Mart of networking. Table 4 presents the top four firms in the four major areas of LAN equipment for 1996 and 1999. Cisco's market share in routers and switches increased during this time--in 1999, Cisco had 77 percent of the router market. Cisco also has a large presence in the switch market, although not as large as that for routers. In 1996, Cisco commanded about 30 percent of LAN switch sales, and by 1999 that figure had increased to about 47 percent. Chart 4 shows worldwide spending on switches by networking standard. The chart illustrates the fantastic growth of 10 Mbps and 100 Mbps ethernet switches relative to other technologies such as ATM and Token Ring (plots of alternative technologies such as FDDI exhibit a similarly slow rate of growth).4

III. Hedonic Analysis for Routers and Switches

In this section we describe and present results from a hedonic analysis of routers and switches. The problems of using hedonics to calculate price changes while attempting to hold quality constant are well known. Trajtenberg (1989) notes that, in particular, the hedonic method may be insufficient to capture price or quality improvements for products such as routers and switches undergoing rapid technological change. When using the hedonic method there are often difficult questions over the proper right hand side variables to employ, and the regression results can often be quite sensitive to the particular specification chosen. Still, the hedonic method is well known and is one of the most common methods employed for estimating quality-adjusted price changes.

III.1 Routers

III.1.1 Data and characteristics selection

The hedonic method requires data on the prices and characteristics of the goods in question. We collected data from Cisco Systems pricing guides for the summer quarters of 1995-1998. Pricing information for 1999 was also collected directly from the firm's World Wide Web site. The information collected from these sources were list prices rather than transactions prices. The problems of using list price data is discussed in further detail below. We include data only from Cisco Systems in our hedonic price regressions, and, due to Cisco's large market share, this should provide us with a good indication of market conditions. We were unsuccessful in obtaining comparable data for routers made by other firms.

A second problem related to the particular definition of router used. Buyers often had great flexibility in choosing the features bundled with a final purchased product. In the case of multiprotocol routers, users often had the choice of over 40 interface modules that allow the

[4] Switches vary mainly by how fast they are, the languages they speak, and by the number of ports. When switches were first introduced, they were noticeably simpler and cheaper than routers. More recently, higher end switches are very complex and the distinction between switches and routers is becoming blurred.

router to support various types of protocols. Moreover, buyers could choose a number of modules to purchase with a router, in effect choosing the number of possible interfaces of the router with the network. A number of other add-ons, such as added memory or a DC power source, were also available. Given that all of these extras and add-ons could not possibly be controlled for in our hedonic price regressions, a major question became "what constitutes a router?"

We chose to work with router configurations that would ensure as much comparability across models as possible. Because the configuration of interface modules often varied across product class (i.e., some included their own processor in order to speed up the routing of data) and because the number of interface module ports varied across routers, we decided for the sake of consistency to consider only routers which were "fully loaded" with such modules. In other words, all routers in the regression were configured with as many modules as the machine had available ports.[5] In general, all routers considered were configured with a processing engine, memory, interface ports or modules, and an input/output controller. Software was generally not included because many types of software were available for routers yet we had no way of controlling for quality differences.[6] In cases in which users were able to choose the particular type of configuration used for a given component (i.e., the amount of memory included in the router or the type of interface module) we would consider models with all possible configurations. Prices were determined by summing the list prices of all components.

A third problem related to the pricing data itself. Ideally, transaction rather than list prices should be used in estimating hedonic price regressions. There is some anecdotal evidence that manufacturers such as Cisco would discount significantly off of their list prices to large accounts. However, nowhere in our study of the industry did we find any evidence or suggestion the difference between transaction prices and list prices changed significantly over time.

Following industry practice, we break our data into four major categories of routers: Small Office/Home Office (SOHO), Low End, Midrange, and High End. Small Office/Home Office routers are personal models designed primarily to connect a remote user to the corporate

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[5] Some interface modules were built so that additional modules could, in turn, be built on to them. We did not consider routers with this extra layer of "add-ons," as such further add-ons tended to be the exception.

[6] In a small number of cases, list prices included a bundled version of Cisco's Internetworking Operating System (IOS) software, thus prices by necessity included the price of software. We discuss the potential biases this will create in the data below.

network. Small branch offices of corporations, to organize traffic within the branch and to connect the office to the larger corporate network, generally use Low End models. Midrange routers are the brains behind many small to mid-size corporate networks, and High End routers are typically employed only by large multinational corporations or Internet Service Providers (ISPs). More recently, multi-gigabit routers have come onto the market, but there was not enough data on these routers to include in our analysis.

As in hedonic studies of computers, there exist two classes of characteristics that one may use for the vector of characteristics. One class of characteristics variables uses data from performance studies to measure attributes such as the speed of the device (in our case, packet throughput) or, perhaps, reliability (in the case of routers, packet loss rate). A major problem with the use of such benchmark studies is that the manufacturers themselves often sponsor them. Thus, because the measurement of product attributes such as speed will depend the particular conditions under which the test is run so that the "best" router in such studies is, not surprisingly, often found to be the one from the manufacturer sponsoring the study. A major exception is the Harvard Device Testing Lab, which until recently conducted and published benchmark tests of internetworking product performance. Unfortunately, the Harvard Lab closed down.

We instead employ primarily engineering data on the main components of the router as our characteristics variables. Table 5A lists the variables used and their mean and standard deviation by market segment. The variable *BANDWIDTH* measures the theoretical maximum bandwidth, measured in Mbps (megabits per second), that the router is capable of networking. In other words, *BANDWIDTH* represents the total amount of network data that can be sent to the router at one time, and is found by summing the theoretical maximum data throughput from the cables connected to the router. The variable is a measure of the data capacity capable of being sent to the router, however it says nothing about the speed with which that data will be processed.

The variables *MPORTS* indicates the number of ports available for network interface modules. The variable *DRAM* indicates the amount of standard DRAM memory included with the router, while *FLASH* indicates the amount of flash memory included. Both variables are measured in megabytes. The variable *PROCESS* indicates the processor speed of the router, measured in MHz. The variable *DC* is a dummy variable indicating whether the router includes a DC power source.

We also employ dummy variables to indicate the year and market segment of a particular router. Table 5B provides a list of the dummy variables and their sample means. The variables *D95-D99* are time dummies indicating model year. The variables *DSOHO*, *DLOW*, *DMID*, and *DHIGH* indicate whether the router is included in the SOHO, Low End, Midrange, or High End markets, respectively. The variables *DHE* is one if the router is in the Midrange or High End of the market and zero otherwise, and will be used to allow coefficients to vary across different parts of the product spectrum.

III.2 Hedonic estimation and results

We now turn to a discussion of the empirical methods used and our results. The hedonic method provides little guidance in the way of a priori restrictions on specification of the model. We confront three major specification issues. First, there are a variety of functional forms from which to choose. Like many other hedonic studies, we consistently found that log-log models were superior to other functional forms and only those results will be discussed. Second, there is a question as to whether the relationship between prices and characteristics is stable across the four major router product classes. Last, we ask if the valuations of product characteristics are constant through time. Given the vast technical change in these products, consumers' valuation of characteristics may have changed as product characteristics have improved.

III.2.1 Parameter stability across router classes

We expect there is likely to be some difference in consumers' valuation of product characteristics across product classes, particularly between the very high and low end groups. As noted above, the products at the top and bottom of the product spectrum serve very different purposes and target very different audiences, implying, as Triplett (1989) notes, that the contour of the hedonic surfaces are likely to be different.[7]

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[7] To see this, it may be useful to examine an example. Consider the cost of an ethernet port across the four categories in our data in 1999. In our hedonic regressions, because ethernet lines have bandwidth of 10 Mbps, this would translate into the cost of 10 Mps of *BANDWIDTH.* In the High End sample, a 6-port ethernet processor module configured for a High End Cisco 7500 router had a list price of $16,000, for an approximate cost of $2666.67 per ethernet port. Among the 7200 series routers, which are included in both the High End and Midrange samples, the cost of a 4-port ethernet module was $4500, or $1125 per port. However, in the Low End of our sample, the cost of a complete Cisco 2501 *router* which included both an ethernet and two serial ports was $995, while in the SOHO category the cost of a complete Cisco 1005 router with one ethernet and one serial port was $395. Although the conclusions one can draw from an example such as this are limited, it does suggest one should be careful about assumptions of parameter constancy.

A more systematic way of examining the hypothesis of parameter constancy is to compute F-tests. However, as Berndt, Griliches, and Rappaport (1995) note, when samples are large and standard test procedures employed (as they are in this case), F-tests may reject simplifying parameter restrictions on purely statistical grounds. We follow their procedure of applying 0.01 significance levels to F-tests and examining the change in root mean squared error (RMSE) in determining whether the hypothesis of parameter restrictions should be rejected. As in their paper, we consider cases in which (1) the p-value of F-tests is less than .01 and (2) the change in RMSE from moving to an unrestricted regression is greater than 5% as a clear rejection of the hypothesis of parameter constancy.

We divided our sample into high (consisting of High End and Midrange) and low (consisting of Low End and SOHO) groups and test for parameter constancy across the two groups. The results suggested we should allow parameters to vary across the two sample groups. We also investigated the hypothesis that the coefficients on the characteristics variables should be allowed to vary across all four product segments. Unfortunately, there was insufficient variation in the product characteristics variables within a given segment and year to allow reliable estimation for the early years of the sample in which we have fewer observations.

We chose to specify a model that allows parameters to vary between the higher (High End and Midrange) and lower (SOHO and Low End) ends of the sample but not across all product classes. This specification also fits within our knowledge of the industry. The low end sample, consisting of the SOHO and Low End segments, consist primarily of self-contained routers selling mostly for under $3,000 and which are meant to be used by branch offices or single users connecting to the corporate network. In contrast, the Midrange and High End segments are much higher priced equipment which are meant to serve as the brains behind a firm's central corporate network. We expect the relationship between parameters and price to vary across these two groups. Moreover, although there is a distinction made between the SOHO and Low End groups and the Midrange and High End groups, both within our data and the industry, the dividing line between products in each of these groups is not clear. In fact, our classification system, which is the same as that used by industry consulting group Dataquest, places some product series in two different classification groups,[8] placing the Cisco 1600 series

[8] DATAQUEST divides its product line both into product series and then models within that series. For instance, the Cisco 2501 is a particular model within the 2500 series. Models within the same series often share common characteristics, such as memory or processor speed.

and 7200 series within both the SOHO and Low End and Midrange and High End product groups, respectively. For instance, the determination of whether a 1600 series belongs in the SOHO or Low End category depends on whether the router includes an optional Wan Interface Card (WIC). Moreover, the Cisco 7202 and 7204 models, both members of the 7200 series, are included within the Midrange group, while the 7206 is classified as a High End product.

III.2.2 Parameter stability through time

There are typically three methods used to estimate hedonic regressions. First, one can estimate yearly regressions and allow parameter estimates to vary by year. Second, one can estimate pooled regressions holding coefficients constant over adjacent two-year time periods. Last, one can estimate a single pooled regression over the entire sample period. Estimating pooled regressions will, of course, have the advantage of improved efficiency if the hypothesis of parameter stability is correct.

To examine the hypothesis of parameter stability through time we again use F-tests and examine the change in RMSE by moving from the restricted to unrestricted regression estimates. There is fairly strong evidence that parameters do not remain stable over the entire sample period. Perhaps this supports the Triplett (1989) notion that pooled regressions are only appropriate if the hedonic surface remains constant over time. The comparison between our yearly and adjacent years regression models is not as clear cut; F-tests reject the hypothesis of parameter stability at the one percent level in all cases, however the improvement in RMSE is often less than the 5% level suggested by Berndt, Griliches, and Rappaport (1995). Because of this, this section will present the results from the adjacent year regressions and section IV will explore price indexes based on yearly regressions.

III.2.3 Router results

Table 6 presents the results from the adjacent year regression results used for index computation in later in this section. The variables *BWHE, MPORTSHE, FLASHHE, PROCESSHE, DRAMHE,* and *DCHE* refer to the interaction of *BW, MPORTS, FLASH, PROCESS, DRAM* and *DC* with *DHE.* These interaction terms are provided to allow for varying coefficients across the lower and higher ends of the product spectrum. In our adjacent year regressions, we include year dummies interacted with product spectrum dummies *DSOHO, DLOW, DMID,* and *DHIGH* so that we may calculate >dummy= price indexes for comparison purposes (described further below). Standard errors are in parentheses and are calculated using the White (1980) heteroskedasticity-robust procedure.

Table 7 presents the price indexes that are generated from the dummy variables reported in table 6. There are several items to note. First, there is tremendous variation across router classes in the average annual decline in prices. Second, there is tremendous variation across time. We have some stories to explain the first result, not so much the second.

Cisco is a dominant firm in the router industry, but its influence does vary by router segment. We believe that some of the variation in results across router classes Figure 5 presents Cisco's market share by router class between 1996 and 2000. The most competitive router segment is SOHO, and that is the category that has the highest average price declines. Although Cisco has a dominant presence in the high-end market, it is this end of the market that has faced the greatest threat of entry from the new multi-gigabit segment. Many firms over the years that have entered the router business have entered by offering high-end products. A surprising result in table 7 is that for Midrange routers where prices actually increased. In section 4, we discuss this result in more detail and specifically discuss how this result may be a result of improperly assuming that the coefficients are consistent across 1996 and 1998 for this class of routers.

The last lines in table 7 show our composite, chain weighted, router index based on North American sales for the four router categories. Overall, router prices fell an average of 13.6 percent between 1995 and 1999. However, these results are based on adjacent year regressions. Section IV presents results based on yearly regressions.

III.3 Switches

III.3.1 Data and Characteristics Selection for Switches

The analysis of switches closely follows that of routers, with some exceptions. The data (prices and characteristics) used in our analysis came from Datapro, a service that periodically issues reports that compares switches from a variety of vendors. The reports typically list a series of switches across columns and the rows in the reports contain information on the characteristics of the switches, such as number of ports, interfaces et cetera. We cross checked our data against Cisco product catalogues for Cisco switches and generally found that the two sources of data for Cisco switches agreed. However, we thought it important to gather data on switches from other vendors since the switch market is much more competitive than the router market, as was shown in table 4.

Several problems were encountered in collecting this data. First, not all reports contained the same information on the characteristics, and many observations had to be dropped for inadequate information on the characteristics of the switch. Second, we were not able to obtain data for 1998. Third, our sample in 1997 is small (18 observations) because many of the Datapro reports in 1997 were simply copies of the 1996 reports with no changes. Finally, the prices in the reports are list prices, like the case with routers, and not transaction prices. When all is said and done, we were able to gather usable data for a total of 366 observations from 1996 to 2000.

Table 8 presents summary statistics for the LAN switch database. Like routers, measures of performance are difficult to come by. Characteristics that we were able to gather consistently across all types of routers fell into two catergories--the number and types of ports and other capabilities. In terms of ports, the regressions control for the presence of and the log of the number of 10, 100, and 1,000 megabit ethernet ports. Additionally, the regressions controlled for the presence and number of FDDI (fiber data distributed interface) and ATM ports. Switches also vary by whether they have layer three switching capability, single mode fiber capability.

Many of the switches in our sample had a wide array of characteristics--enabling them to speak a variety of languages and operate at varying speeds. We included all of the switches into the regressions. We did try breaking the sample into various groupings, but found no clear advantage to doing so. In fact, there was no clear dividing line between switches. Additionally, the samples by year were small (especially for 1997), so dividing the sample further greatly increased the standard errors of our estimates.

III.3.2 Switch results

Table 9 presents the results from a pooled regression and from adjacent year regressions. Annual regressions were not run because of the small samples, especially in 1997. Not shown in the table is a list of firm dummy variables. The coefficients on many of the variables came in with the expected sign. Using the dummy variables from the adjacent year regressions, we found the average annual price decrease was 21.9 percent, a faster rate of decline than that for routers. The pooled regression results generate a 22.2 percent annual decline. These results are consistent with several purchasers of LAN equipment that we talked to--they felt that switch prices fell faster than routers.

III.4 LAN Cards

The third component of local area network equipment that we examine is LAN cards, the device in a computer that is physically connected to a computer network. Like routers and switches, LAN cards vary in terms of speed and interfaces. Unlike routers and switches, LAN cards have a very small set of characteristics, and the data are fairly homogenous within each LAN card category. Price and quantity data for LAN cards between 1995 and 2000 for the worldwide market is displayed in table 10. This data comes from Dataquest. We computed a chain-weighted, matched-model price index with this data. Prices for LAN cards fell an average of 18.3 percent per year between 1995 and 2000.

III.5 Hubs

The final component of LAN equipment, hubs, are also simple devices that have been replaced over the years by switches. We have not performed an analysis of hubs like that of routers and switches. Instead, we use an indirect approach. The approach examines the relationship between changes in the price per port for switches and compares that to the price per port for hubs. The reason we exploit this relationship is that we have price per port data for hubs and for switches. For each year, we have data on revenue and the number of ports shipped for hubs and switches. The price per-port measures are Fisher indexes based on data for a handful of switch and hub classes.

Figure 6 presents these data. Between 1996 and 2000, the price per-port measures for switches fell at an annual average rate of 34.7 percent whereas the price per-port measure for hubs fell 30.1 percent. We construct a price index for hubs by taking the ratio of the two Fisher per-port indexes and multiplying by the switch price index. Since the per-port index for hubs doesn't fall as fast as the per-port measure for switches, the price index for hubs doesn't fall as fast as that for switches. From 1996 to 2000, we estimate that the prices for hubs fell at an annual average rate of 19.0 percent.

IV. Yearly Regression Results for Routers

In the previous section we calculated pooled adjacent-year regressions and used the coefficients on time dummies as the basis for our price index for routers and switches. As noted by Triplett (1989), this method relies on the assumption of stability in the hedonic surface over time. Because our tests of parameter constancy across adjacent year regressions for routers were inconclusive, we calculate alternative yearly regressions and use the results to calculate imputed price indexes.

Table 11 displays the results of the yearly regressions. Once again, the variables *BWHE, MPORTSHE, FLASHHE, PROCESSHE, DRAMHE,* and *DCHE* refer to the interaction of *BW, MPORTS, FLASH, PROCESS, DRAM* and *DC* with *DHE*. These interaction terms are provided to allow for varying coefficients across the lower and higher ends of the product spectrum. Standard errors are in parentheses and are calculated using the White (1980) heteroskedasticity-robust procedure.

In this section, we utilize the results from our hedonic regressions to compute elementary price indexes. We first compute a form of imputed price indexes of the type used by Prud'homme and Yu (1999). Fitted prices may be calculated by exponentiating the results of our hedonic regressions at the observed vector of characteristics. Thus, one has

$$\hat{P}_{it} = \exp(\hat{\beta}_{0t} + \sum_{j=1}^{m} \hat{\beta}_{jt} \log X_{ijt}) \qquad (1)$$

where $\hat{P}_{it}$ refers to the imputed price of model *i* in time *t* and $\hat{\beta}_t$ refers to the estimated vector of coefficients for time *t*. In our yearly regressions, imputed prices can be calculated using the vector of estimated coefficients $\hat{\beta}_t$ both for the year in which coefficients were estimated and some other adjacent year. Thus, for example, we may calculate the imputed prices of a 1996 model *i* in 1996 and 1998 by imputing prices using $\hat{\beta}_{96}$ and $\hat{\beta}_{98}$, respectively. The same procedure can be repeated for all *i* in 1996. Moreover, we can similarly calculate the imputed price of any 1998 models *k* in 1996 and 1998. These imputed prices can be used as the basis for a bilateral price index.

Unfortunately, a lack of quantity data at the model level prevents us from computing standard quantity-weighted price indexes. Instead, we compute simple Dutot, Carli, and Jevons price indexes. These are bilateral price indexes that compute the change in prices between years *t-1* and *t* as follows:

1. Dutot

$$I_{t-1,t}^{D} = \frac{\sum_{i=1}^{n} P_i^t / N}{\sum_{i=1}^{n} P_i^{t-1} / N}$$

2. Carli

$$I^{C}_{t-1,t} = \sum_{i=1}^{n} \frac{(P_i^t / P_i^{t-1})}{N}$$

3. Jevons

$$I^{J}_{t-1,t} = \prod_{i=1}^{n} \left(\frac{P_i^t}{P_i^{t-1}} \right)^{1/N}$$

Thus, the Dutot computes the ratio of the arithmetic average of prices, while the Carli and Jevons compute the arithmetic and geometric averages of the price ratios, respectively.

We compute these indexes using base-weighted and reference-weighted version of these indexes, and as in Prud'homme and Yu (1999), we take the geometric mean of the base-weighted and comparison-weighted version of these indexes, computing a 'Fisher-type' index. A multilateral price index $I_{0,t}$ for 1995-1999 can be computed by chaining the bilateral price indexes $I_{0,t} = I_{0,1} \times I_{1,2} \times \cdots \times I_{t-1,t}$.

Table 12 displays the results of our Dutot, Carli, and Jevons indexes. The results of our previous dummy price indexes are also included for comparison purposes. Although within each router segment the four indexes produce similar results, there are some differences. In particular, for all router classes except for Midrange, the dummy price indexes show more rapid rates of price declines than any of the imputed indexes. Moreover, the disparity in results between the dummy and imputed price indexes in the Midrange segment is particularly large. One potential reason for the disparity is that the assumption of parameter stability used in the dummy regressions may be incorrect; indeed our F-tests of parameter stability for the Midrange segment reject the hypothesis of parameter constancy for this segment. In computations not reported here, we found that the index results varied substantially depending on whether we use base- or reference-period models as the basis for index construction, and that by removing new models from the computation of the imputed price index we obtained results qualitatively similar to our dummy price index. This result of index sensitivity to the use of base- or reference-period weights has been reported in other papers in the literature (e.g., Berndt, Dulberger, and Rappaport (2000)).

One can also compute Laspeyres-type price indexes by computing equation (1) using base and comparison period coefficients and calculating fitted prices at the sample mean of characteristics variables in the base period. The ratio of the reference to base period value is then the Laspeyres index

$$I_{t-1,t}^{L} = \frac{\exp(\hat{\beta}_{0t} + \sum_{j=1}^{m} \hat{\beta}_{jt} \log \overline{X}_{jt-1})}{\exp(\hat{\beta}_{0t-1} + \sum_{j=1}^{m} \hat{\beta}_{jt-1} \log \overline{X}_{jt-1})}$$

and a complete index can be obtained by 'chaining' the results. A Paasche-type index is similarly defined using comparison period characteristics values.

The Laspeyres and Paasche indexes give very different results due to the different type of weighting used, nearly bracketing the results of the Dutot, Carli, and Jevons indexes. This type of result was also found in Berndt, Griliches, and Rappaport (1995) and Prud'homme and Yu (1999).

Overall, although price declines in our alternative indexes are consistent with our result of prices for networking equipment falling slower than that of computers, the actual rate of change is somewhat sensitive to the assumption of parameter stability and the particular choice of weighting used in our imputed price indexes.

V. Conclusions

One reason for computing price indexes for the various components of LAN equipment is to help construct an index of production. We constructed estimates of production for routers, hubs and switches by using information from the Current Industrial Reports. We examined the firm level data provided to Census to see in which categories LAN equipment was being reported. We believe that LAN cards are not produced in quantity in this country, so the production price index is based only on routers, switches and hubs. Between 1995 and 1999, our estimate of the price index for LAN equipment production fell an average of 17 percent--pulled down by switches and hubs but held up by routers.

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Table 1
Spending on Telecommunications Equipment ($Millions)
By End User Group

	1997	1998	1999	2000
Business and Government Purchasers				
of Telecommunications Equipment (1)	**34,070**	**38,490**	**41,142**	**44,657**
Data Communication	**22,275**	**25,263**	**26,947**	**29,522**
LAN Equipment	**11,437**	**13,111**	**14,027**	**15,743**
Routers	2,986	3,425	4,525	5,475
LAN Switches	3,787	5,706	6,528	7,285
Hubs	1,884	1,538	761	689
LAN Cards	2,780	2,442	2,213	2,294
Other Data/Network Equipment	**10,838**	**12,152**	**12,920**	**13,779**
Asynchronous Transfer Mode (ATM)	1,117	1,557	2,048	2,528
Modems	3,077	3,290	2,800	2,500
Remote Access Devices	1,604	1,730	2,100	2,400
Frame Relay	1,277	1,530	1,722	1,846
ISDN	900	1,050	1,200	1,350
SNA Gateways and Connectivity Gear	912	940	930	940
Channel Service Unit/Data Service Unit (CSU/DSU)	803	870	895	930
Diagnostic and Test Equipment	558	610	655	720
Multiplexers	590	575	570	565
Phone Equipment	**11,795**	**13,227**	**14,195**	**15,135**
Private Branch Exchange (PBX)/Key Telephone System (KTS)	6,832	7,601	7,980	8,392
Voice Processing Equipment	4,963	5,626	6,215	6,743
Telecommunication Service Providers (2)	**26,643**	**29,138**	**35,884**	**46,752**
Central Office Switching and Transmission Equipment	**12,358**	**13,562**	**14,475**	**15,500**
Fiber Optic Transmission Equipment	**6,748**	**8,620**	**13,095**	**22,265**
Synchronous Optical Network (SONET)	3,562	4,556	7,291	10,573
Dense Wavelength Division Multiplexing (DWDM)	1,605	1,854	3,055	7,742
Digital Cross Connects	1,581	2,210	2,749	3,950
Cellular Phone Infrastructure	**5,678**	**4,474**	**4,955**	**4,734**
ATM	**723**	**1,033**	**1,395**	**1,770**
Frame Relay	**1,098**	**1,314**	**1,485**	**1,585**
Voice Over Internet Protocol (VOIP) Gateways	**14**	**100**	**440**	**820**
Electronic Bonding Gateways	**24**	**35**	**39**	**78**
Other Spending on Communication Equipment (3)	**17,860**	**19,645**	**23,029**	**24,302**
Capital Equipment Spending By Cable Television Firms	**6,800**	**7,700**	**10,800**	**12,000**
Wireless Handsets (Cell Phones)	**5,787**	**7,228**	**7,619**	**7,692**
Consumers	**5,273**	**4,717**	**4,610**	**4,610**
Cordless Telephones	2,099	2,250	2,240	2,260
Answering Machines	1,173	1,240	1,215	1,210
Home Fax Machines	1,367	655	625	620
Corded Telephones	634	572	530	520
Total Spending (1) + (2) + (3)	**78,573**	**87,273**	**100,055**	**115,711**
PDE Communications Equipment	**73,700**	**80,700**	**99,100**	**123,870**

Source: Dataquest, FCC, TIA, RHK, KMI, Authors' Estimates

Table 2: Official Price Measures for Communications Equipment and Computers (Average Annual Percent Change)

	1990-95	1995-00	1990-00
BLS PPI Communications Equipment	1.17	-0.63	0.27
BLS PPI "Other Data Communications Equipment"		-0.12	
BEA Communication Equipment	-1.49	-1.84	-1.66
BEA Computers and Peripheral Equipment	-13.44	-22.22	-17.95

Table 3: Notable Mergers and Acquisitions, LAN Equipment Manufacturers

Acquirer	Target	Year	Value	Reason
Nortel Networks	JDS Uniphase's Zurich subsidiary	2001	$2.5 billion	Optical technology (pump-laser chips)
Cisco Systems	ArrowPoint Communications	2000	$5.7 billion	Content switches that optimize delivery of web content
Lucent Technologies	Chromatis Networks	2000	$4.5 billion	Metropolitan optical networking systems
Alcatel	Xylan Corp.	1999	$2.0 billion	Xylan's switching systems
Cisco Systems	Pirelli Optical Systems	1999	$2.2 billion	Pirelli's optical systems business
Cisco Systems	Cerent Corporation	1999	$6.9 billion	Optical transport products
Cisco Systems	StratumOne Communications, Inc.	1999	$435 million	Integrated, high-performance semiconductor technology
General Electric Company, PLC (GEC)	FORE Systems	1999	$4.5 billion	ATM routers and switches
Lucent Technologies	Ascend Communications	1999	$24 billion	ATM and frame relay high-speed WAN switching, WAN
Lucent Technologies	Nexabit Networks	1999	$900 million	WAN routers and switches
Nortel Networks	Shasta Networks	1999	$340 million	IP routing switch
Ascend Communications	Stratus Computer	1998	$822 million	Obtained SS7 and OSS technology and products.
Cabletron Systems	YAGO Systems	1998	$213 million	Gigabit switch router
Cisco Systems	Summa Four Inc.	1998	$116 million	Programmable switches
Intel	Shiva	1998	$185 million	Remote access and VPN capability
Nortel Networks	Bay Networks	1998	$9.1 billion	Bay Networks entire data communications business
3Com	U.S. Robotics	1997	$7.3 billion	Modems and access servers
Ascend Communications	Cascade Communications Corp.	1997	$2.6 billion	ATM and frame relay switching technology and products.
Bay Networks	Rapid City Communications	1997	$155 million	Gigabit ethernet switch router
Cabletron Systems	Digital Equipment Corp. Network	1997	$430 million	Digital's network product business
Lucent Technologies	Livingston Enterprises	1997	$610 million	Remote access networking products
Cisco Systems	Granite Systems, Inc.	1996	$220 million	Multilayer Gigabit Ethernet switching
Cisco Systems	StrataCom, Inc.	1996	$4.7 billion	ATM and frame relay high-speed WAN switching
3Com	Chipcom Corporation	1995	$775 million	High-end chassis hubs and switching
Synoptics Communications	Welfleet Communications	1994	$1.0 billion	Synoptics and Wellfleet merger to form Bay Networks
Cisco Systems	Crescendo Communications, Inc.	1993	$97 million	High-performance workgroup solutions
3Com	Bridge Communications	1987	$240.8 million	Bridges and routers

Source: Datapro Information Services, Wheelwright and Holloway (2000), and authors' research
Acquisition values for stock acquisitions calculated at time of agreement.
All acquisition values in U.S. dollars.

Table 4
Market Share of Four Largest Firms by LAN Equipment Type

	1996		1999	
	Firm	**Market Share**	**Firm**	**Market Share**
Routers	Cisco Systems	54.6%	Cisco Systems	77.0%
	Bay Networks Inc.	10.3%	Nortel Networks	6.9%
	Ascend Communications Inc.	9.2%	Fujitsu	2.5%
	3Com	6.4%	3Com	2.4%
Switches	Cisco Systems	29.6%	Cisco Systems	46.8%
	3Com	21.2%	3Com	12.6%
	Cabletron Systems Inc.	11.0%	Nortel Networks	8.7%
	Bay Networks Inc.	9.9%	Fore Systems	6.4%
LAN Cards	3Com	33.2%	3Com	35.4%
	IBM	13.7%	Intel	23.2%
	Standard Microsystems Inc.	6.9%	IBM	4.9%
	Madge Networks	5.8%	Xircom	4.7%
Hubs	Bay Networks Inc.	24.5%	3Com	30.3%
	3Com	18.8%	Nortel Networks	16.7%
	Cabletron Systems Inc.	14.7%	D-Link Systems	7.4%
	IBM	4.8%	Intel	4.3%

Source: Dataquest

Table 5
Summary of Router Data, 1995-1996, 1998-1999

Table 5(a): Router Characteristics Data by Market Segment

Small Office/Home Office (SOHO) Data

Variable	Mean	Std. Dev.	Min	Max
PRICE	769.05	243.78	395.00	1399.00
BANDWIDTH	17.81	13.09	10.11	40.23
MPORTS	0.00	0.00	0.00	0.00
FLASH	1.34	2.36	0.00	8.00
PROCESS	27.93	5.20	16.00	33.00
DRAM	2.83	1.77	1.00	8.00
DC	0.00	0.00	0.00	0.00

Low End Data

Variable	Mean	Std. Dev.	Min	Max
PRICE	4300.99	1860.52	895.00	8195.00
BANDWIDTH	54.28	63.88	1.54	372.22
MPORTS	1.03	0.92	0.00	3.00
FLASH	6.92	1.79	2.00	8.00
PROCESS	31.74	9.92	20.00	50.00
DRAM	14.36	10.12	2.00	24.00
DC	0.43	0.50	0.00	1.00

Midrange Data

Variable	Mean	Std. Dev.	Min	Max
PRICE	41525.60	16707.19	4600.00	78550.00
BANDWIDTH	284.57	187.49	1.00	630.00
MPORTS	3.72	0.57	2.00	4.00
FLASH	14.45	6.06	4.00	20.00
PROCESS	157.31	59.20	40.00	263.00
DRAM	28.36	7.58	8.00	32.00
DC	0.12	0.33	0.00	1.00

High End Data

Variable	Mean	Std. Dev.	Min	Max
PRICE	85899.71	47704.98	38200.00	326900.00
BANDWIDTH	539.67	258.91	7.50	1460.00
MPORTS	6.17	1.62	3.00	11.00
FLASH	16.77	3.58	4.00	20.00
PROCESS	187.20	66.35	25.00	300.00
DRAM	30.77	4.27	16.00	32.00
DC	0.00	0.00	0.00	0.00

Table 5 (b)
Sample means of dummy variables

D95	0.0200	*DSOHO*	0.0077
D96	0.0567	*DLOW*	0.0692
D98	0.2545	*DMID*	0.4647
D99	0.6688	*DHIGH*	0.4584
		DHE	0.9231

Table 6
Parameter estimates for adjacent year regressions
(heterosekdasticity-robust standard errors in parentheses)

	1995-1996	1996-1998	1998-1999
DSOHO	5.2544	4.8741	8.3544
	(0.1948)	(1.3034)	(0.4466)
DLOW	6.2668	3.9190	8.5126
	(0.7183)	(1.6818)	(0.4927)
DMID	7.7547	6.3414	6.5147
	(0.1259)	(0.1249)	(0.1208)
DHIGH	9.1135	6.9860	6.6322
	(0.1681)	(0.1387)	(0.1291)
*YEARDUMMY * SOHO*	0.0126	-0.9337	-0.2556
	(0.0676)	(0.2468)	(0.1257)
*YEARDUMMY*LOW*	0.1806	-0.9951	-0.0782
	(0.0885)	(0.2213)	(0.0541)
*YEARDUMMY*MID*	0.1187	0.0050	-0.0007
	(0.0318)	(0.0424)	(0.0132)
*YEARDUMMY*HIGH*	-0.0825	-0.4448	-0.1766
	(0.0281)	(0.0398)	(0.0149)
LOG(BANDWIDTH)	0.2286	0.1894	0.0417
	(0.0477)	(0.0474)	(0.0142)
LOG(BANDWIDTHHE)	-0.0446	-0.0350	0.0983
	(0.0492)	(0.0486)	(0.0152)
LOG(MPORTS)	0.4388	0.4332	0.3676
	(0.0689)	(0.0534)	(0.0494)
LOG(MPORTSHE)	0.4815	0.5757	0.7951
	(0.0763)	(0.0723)	(0.0641)
LOG(FLASH)	-0.3632	1.0553	0.2122
	(0.3851)	(0.3592)	(0.0996)
LOG(FLASHHE)	-0.4412	-1.2131	-0.0250
	(0.3874)	(0.3619)	(0.1034)
LOG(PROCESS)	0.4832	0.3437	-0.7665
	(0.0002)	(0.3825)	(0.1220)
LOG(PROCESSHE)	-0.2405	-0.1254	1.1515
	(0.0249)	(0.3830)	(0.1229)
LOG(DRAM)	-0.5732	0.5573	0.6451
	(0.1173)	(0.0624)	(0.0444)
LOG(DRAMHE)	0.6302	-0.2076	-0.9201
	(0.1307)	(0.0871)	(0.0633)
DC	0.1391	0.1715	0.1496
	(0.0730)	(0.0582)	(0.0307)
DCHE	-0.0564	-0.2134	-0.1849
	(0.0785)	(0.0710)	(0.0435)
Number of observations	399	1595	4744
R^2	0.9802	0.9204	0.9174

Table 7
Price Indexes For Routers Based on Adjacent Year Regressions

	1995	1996	1998	1999	AAGR
SOHO (Index)	1.000	1.015	0.411	0.321	-24.72
(Percent change)		1.50	-59.48	-21.94	
Low End (Index)	1.000	1.203	0.456	0.422	-19.40
(Percent change)		20.26	-62.11	-7.39	
Midrange (Index)	1.000	1.127	1.133	1.133	3.16
(Percent change)		12.67	0.59	-0.06	
High End (Index)	1.000	0.921	0.591	0.495	-16.11
(Percent change)		-7.88	-35.85	-16.18	
All Routers (Index)	1.000	1.066	0.622	0.557	-13.62
(Percent change)		6.56	-23.57	-10.55	

Table 8: Summary Statistics for LAN Switches

Variable	Mean	Std Dev	Minimum	Maximum
1996 Dummy	0.347	0.477	0	1
1997 Dummy	0.049	0.216	0	1
1999 Dummy	0.230	0.422	0	1
2000 Dummy	0.374	0.485	0	1
10 MBPS Ethernet 1=YES 0=NO	0.791	0.407	0	1
log(number of 10 MBPS ports)	2.114	1.305	0	6.223
100 MBPS Ethernet 1=YES 0=NO	0.558	0.497	0	1
log(number of 100 MBPS ports)	0.458	1.010	0	4.382
1,000 MBPS Ethernet 1=YES 0=NO	0.228	0.420	0	1
log(number of 1,000 MBPS ports)	0.172	0.513	0	2.485
FDDI Capability 1=YES 0=NO	0.236	0.425	0	1
Number of FDDI ports	1.108	9.205	0	168
ATM Capability 1=YES 0=NO	0.149	0.357	0	1
Number of ATM Interfaces	0.125	0.639	0	10
Layer 3 Capability 1=YES 0=NO	0.379	0.486	0	1
Single Mode Fiber Capability 1=YES 0=NO	0.014	0.116	0	1

Table 9: Hedonic Regression Models for LAN Switches

	1996-2000	1996-1997	1997-1999	1999-2000
1997 Dummy	-0.180	-0.189	NA	NA
	(0.128)	(0.121)		
1999 Dummy	-0.900	NA	-0.572	NA
	(0.11)		(0.208)	
2000 Dummy	-1.005	NA	NA	-0.227
	(0.096)			(0.105)
10 MBPS Ethernet	-1.263	-0.829	-1.029	-1.665
1=YES 0=NO	(0.169)	(0.202)	(0.373)	(0.244)
log(number of 10 MBPS ports)	0.391	0.143	0.402	0.595
	(0.048)	(0.057)	(0.111)	(0.069)
100 MBPS Ethernet	-0.284	-0.302	-0.105	-0.091
1=YES 0=NO	(0.075)	(0.083)	(0.185)	(0.112)
log(number of 100 MBPS ports)	0.119	0.143	0.083	0.112
	(0.047)	(0.089)	(0.086)	(0.056)
1,000 MBPS Ethernet	0.419	NA	0.159	0.367
1=YES 0=NO	(0.113)		(0.235)	(0.126)
log(number of 1,000 MBPS ports)	0.307	NA	0.45	0.34
	(0.082)		(0.15)	(0.088)
FDDI Capability	0.192	0.091	0.219	0.329
1=YES 0=NO	(0.085)	(0.080)	(0.19)	(0.181)
Number of FDDI ports	-0.012	-0.005	-0.013	-0.028
	(0.004)	(0.003)	(0.005)	(0.021)
ATM Capability	0.047	-0.051	0.359	0.872
1=YES 0=NO	(0.108)	(0.105)	(0.309)	(0.236)
Number of ATM Interfaces	0.247	0.216	-0.394	-0.466
	(0.056)	(0.046)	(0.431)	(0.305)
Layer 3 Capability	0.529	0.339	0.554	0.694
1=YES 0=NO	(0.084)	(0.099)	(0.175)	(0.120)
Single Mode Fiber Capability	1.203	1.223	1.198	1.106
1=YES 0=NO	(0.295)	(0.452)	(0.593)	(0.421)
N	366	145	101	220
R^2	0.740	0.537	0.678	0.796

Table 10
Average Price and Revenue for Different Types of LAN Cards

	1995	1996	1997	1998	1999	2000	Average annual growth rate (percent)
10-Mbps							
Revenue ($ millions)	2,651	2,836	1,990	886	478	278	
Price ($/card)	115	101	73	51	41	37	-20.2
100-Mbps							
Revenue	142	736	1,879	2,582	2,826	3,023	
Price	199	143	110	79	66	56	-22.4
1,000-Mbps							
Revenue			2	34	70	152	
Price			2,111	850	735	681	-31.4
Token-Ring							
Revenue	1,236	1,131	1,099	843	472	350	
Price	310	283	228	196	169	174	-10.9
FDDI							
Revenue	136	160	121	84	51	26	
Price	1,123	1,069	904	838	751	731	-8.2
ATM							
Revenue	43	66	79	98	73	75	
Price	964	614	653	562	432	437	-14.7
Wireless							
Revenue			105	188	316	488	
Price			327	340	275	250	-8.6
Matched Model Price Index							
	1.00	0.87	0.66	0.49	0.41	0.36	-18.3

Reported data is for the world market.

Table 11
Parameter estimates for yearly router regressions
(heterosekdasticity-robust standard errors in parentheses)

	1995	1996	1998	1999
CONSTANT	4.5046	5.9191	5.5472	9.5174
	(0.1603)	(0.5087)	(0.9157)	(0.7570)
DHE	--	0.1361	0.4655	-1.8443
		(0.5489)	(0.9286)	(0.7878)
LOG(BANDWIDTH)	0.2090	0.2408	0.1553	0.0601
	(0.0697)	(0.0650)	(0.0581)	(0.0160)
LOG(BANDWIDTHHE)	-0.0240	-0.0403	-0.0376	0.0874
	(0.0712)	(0.0702)	(0.0593)	(0.0171)
LOG(MPORTS)	1.0097	0.4489	0.3985	0.4860
	(0.0944)	(0.0760)	(0.0773)	(0.0691)
LOG(MPORTSHE)	--	0.8242	0.8323	0.6003
		(0.0952)	(0.0862)	(0.0737)
LOG(FLASH)	0.5297	0.3843	0.4330	0.2540
	(0.0743)	(0.0853)	(0.1208)	(0.0997)
LOG(FLASHHE)	-2.0911	-0.5169	-0.1677	-0.0050
	(0.2622)	(0.1235)	(0.1344)	(0.1051)
LOG(PROCESS)	0.4833	0.1776	-0.0514	-1.2302
	(0.0003)	(0.1469)	(0.2534)	(0.2297)
LOG(PROCESSHE)	-0.1988	-0.2848	0.5349	1.5465
	(0.0401)	(0.1507)	(0.2548)	(0.2305)
LOG(DRAM)	--	-0.2936	0.5670	0.7660
		(0.0604)	(0.0905)	(0.0823)
LOG(DRAMHE)	2.0568	1.1831	-0.8818	-1.3069
	(0.0919)	(0.0949)	(0.1257)	(0.1090)
DC	0.1399	0.1418	0.1927	0.1316
	(0.1173)	(0.0933)	(0.0739)	(0.0321)
DCHE	-0.0411	-0.2778	-0.2032	-0.2042
	(0.1229)	(0.1085)	(0.0883)	(0.0494)
N	104	295	1300	3444
R^2	0.9887	0.9563	0.9092	0.9229

Note: Double dashes (--) indicate variable was dropped due to multicollinearity.

Table 12
Alternative price indexes for routers
(Percentage change in previous year in perentheses)

Table 12a: SOHO

Procedure	1995	1996	1998	1999	AAGR
Imputed Price Indexes, Yearly Regressions					
Dutot	1.0000	1.2061	0.5691	0.4550	-17.87%
		20.61%	-52.81%	-20.05%	
Carli	1.0000	1.2207	0.6477	0.5430	-14.16%
		22.07%	-46.94%	-16.17%	
Jevons	1.0000	1.1985	0.5717	0.4754	-16.97%
		19.85%	-52.30%	-16.85%	
Laspeyres	1.0000	1.0560	0.4916	0.4291	-19.06%
		5.60%	-53.45%	-12.71%	
Paasche	1.0000	1.3602	0.6649	0.5266	-14.81%
		36.02%	-51.12%	-20.79%	
Dummy Price Indexes, Adjacent Year Regressions					
	1.0000	1.0150	0.4113	0.3211	-24.72%
		1.50%	-59.48%	-21.94%	

Table 12b: Low End

Procedure	1995	1996	1998	1999	AAGR
Imputed Price Indexes, Yearly Regressions					
Dutot	1.0000	0.9551	0.7525	0.5831	-12.62%
		-4.49%	-21.21%	-22.51%	
Carli	1.0000	1.0599	0.8912	0.7321	-7.50%
		5.99%	-15.92%	-17.85%	
Jevons	1.0000	1.0217	0.8006	0.6381	-10.62%
		2.17%	-21.64%	-20.30%	
Laspeyres	1.0000	1.1977	0.6106	0.5601	-13.49%
		19.77%	-49.02%	-8.28%	
Paasche	1.0000	0.8715	1.0497	0.7270	-7.66%
		-12.85%	20.44%	-30.74%	
Dummy Price Indexes, Adjacent Year Regressions					
	1.0000	1.2026	0.4556	0.4220	-19.40%
		20.26%	-62.11%	-7.39%	

Table 12c: Midrange

Procedure	1995	1996	1998	1999	AAGR
Imputed Price Indexes, Yearly Regressions					
Dutot	1.0000	0.8078	0.6028	0.5871	-12.47%
		-19.22%	-25.37%	-2.62%	
Carli	1.0000	1.0103	0.8313	0.8159	-4.96%
		1.03%	-17.72%	-1.85%	
Jevons	1.0000	0.9331	0.7367	0.7175	-7.96%
		-6.69%	-21.05%	-2.60%	
Laspeyres	1.0000	1.1165	1.1492	1.1874	4.39%
		11.65%	2.93%	3.33%	
Paasche	1.0000	0.7799	0.4723	0.4336	-18.85%
		-22.01%	-39.44%	-8.20%	
Dummy Price Indexes, Adjacent Year Regressions					
	1.0000	1.1267	1.1333	1.1327	3.16%
		12.67%	0.59%	-0.06%	

Table 12d: High End

Procedure	1995	1996	1998	1999	AAGR
Imputed Price Indexes, Yearly Regressions					
Dutot	1.0000	1.0033	0.6392	0.5458	-14.05%
		0.33%	-36.29%	-14.61%	
Carli	1.0000	1.0456	0.6604	0.5748	-12.93%
		4.56%	-36.84%	-12.95%	
Jevons	1.0000	0.9946	0.5727	0.4975	-16.01%
		-0.54%	-42.42%	-13.13%	
Laspeyres	1.0000	0.8653	0.5274	0.4614	-17.58%
		-13.47%	-39.05%	-12.52%	
Paasche	1.0000	1.1432	0.6219	0.5366	-14.41%
		14.32%	-45.60%	-13.72%	
Dummy Price Indexes, Adjacent Year Regressions					
	1.0000	0.9212	0.5909	0.4953	-16.11%
		-7.88%	-35.85%	-16.18%	

Supplemental Table 1
Synchronous Optical Network (SONET) Equipment

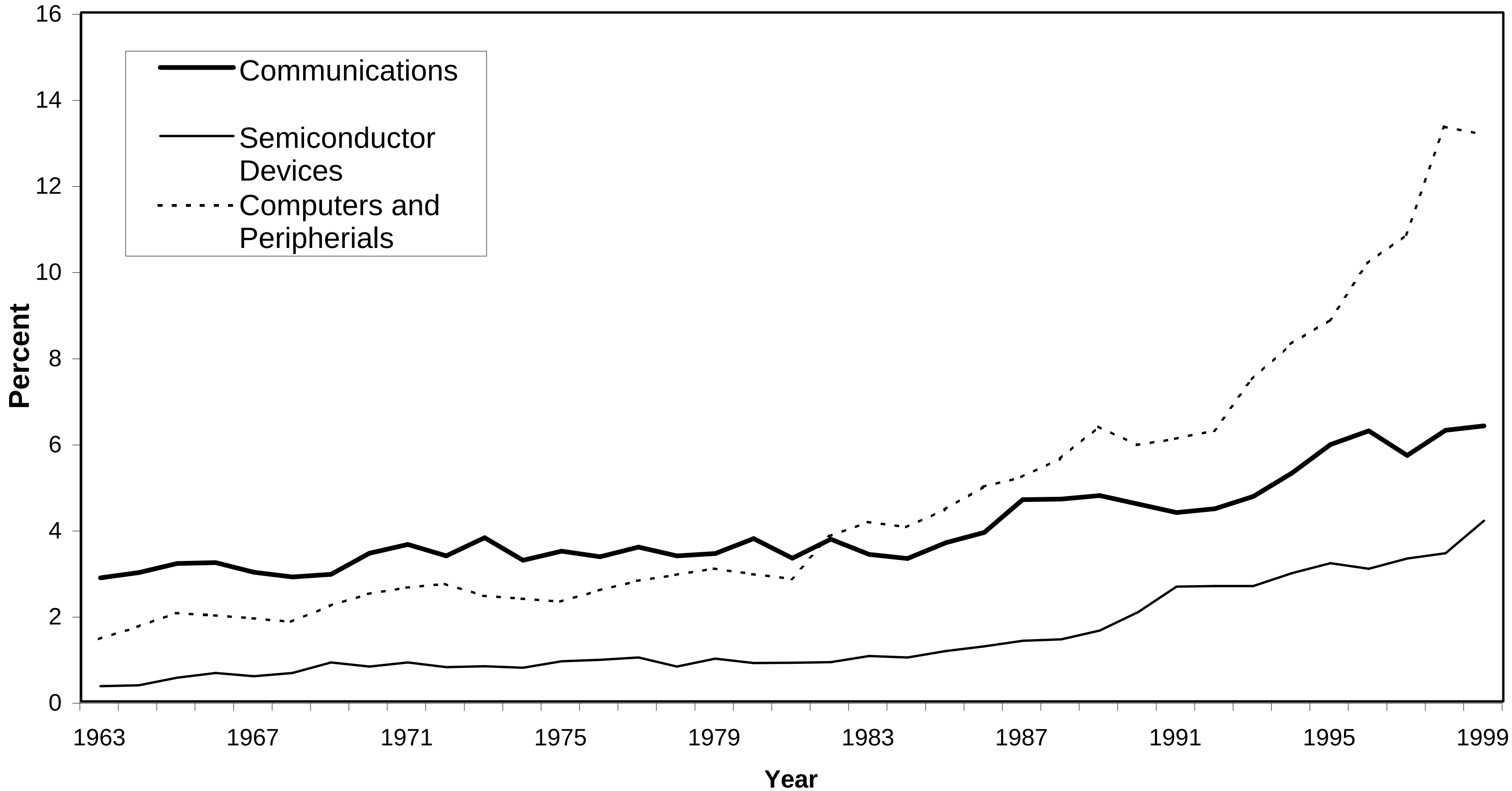
	1996	1997	1998	1999	2000	AAGR (%)
SONET Systems Units						
OC3 (155.52 megabits per second)	32,250	45,948	41,505	56,420	80,900	25.9
OC12 (622.08 megabits per second)	13,208	21,064	20,857	34,166	52,399	41.1
OC48 (2,488.32 megabits per second)	11,126	13,051	16,992	28,283	48,502	44.5
OC192 (9,953.28 megabits per second)	-	303	1,913	5,495	11,611	146.3
Total	56,584	80,366	81,269	124,365	193,411	36.0
Revenue ($ millions)						
OC3	645	827	706	846	1,092	14.1
OC12	634	843	772	1,127	1,574	25.5
OC48	1,680	1,892	2,317	3,394	4,656	29.0
OC192	-	NA	761	1,923	3,251	106.6
Total	2,959	3,562	4,556	7,291	10,573	37.5
SONET IXC ASP Pricing ($ thousands/unit)						
OC3	20	18	17	15	14	-9.4
OC12	48	40	37	33	30	-11.1
OC48	151	145	136	120	96	-10.7
OC192	-	NA	398	350	280	-16.1
Change in Prices (Percent)						
OC3	-	-10.0	-5.6	-11.8	-10.0	
OC12	-	-16.7	-7.5	-10.8	-9.0	
OC48	-	-4.0	-6.0	-12.0	-20.0	
OC192	-	-	-	-12.1	-20.0	
Matched Model Price Index	1.00	0.92	0.86	0.76	0.63	-11.0

NA=not available

Source: RHK

Note: Prices are for add/drop multiplexers, which are more expensive than standard terminals.
Pricing for each follows similar trends, but ADMs are more expensive due to added equipment to add and drop traffic.

Figure 1: Share of U.S. Patents by High-Technology Category



Source: Manuel Trajtenberg

Computers and Peripherials= Computer Hardware and Software + Computer Peripherials + Information Storage

Figure 2

A Simplified Version of the Federal Reserve Board's Local Area Network

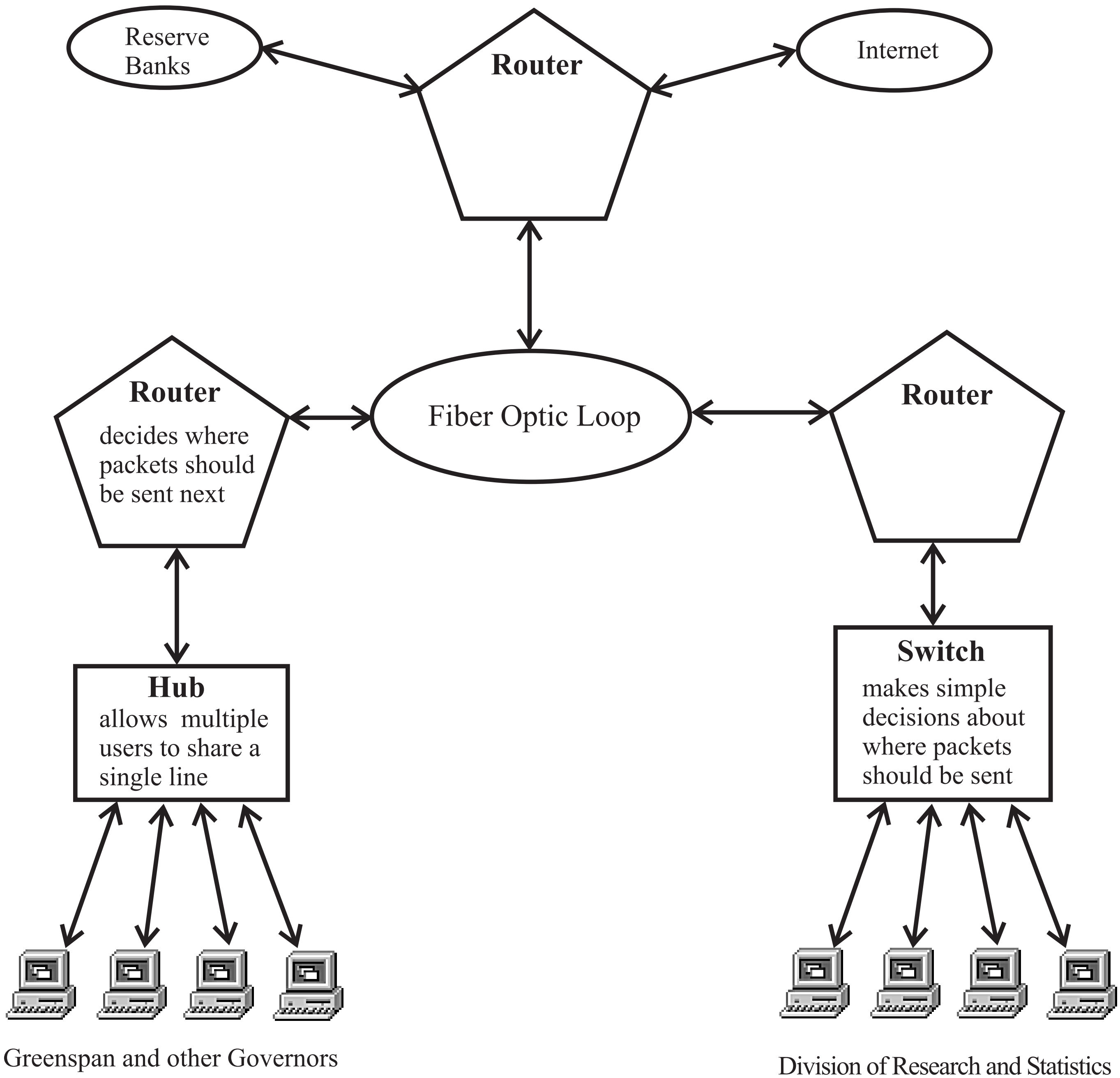


Figure 3: Manufacturer's Revenue for Switches, Worldwide

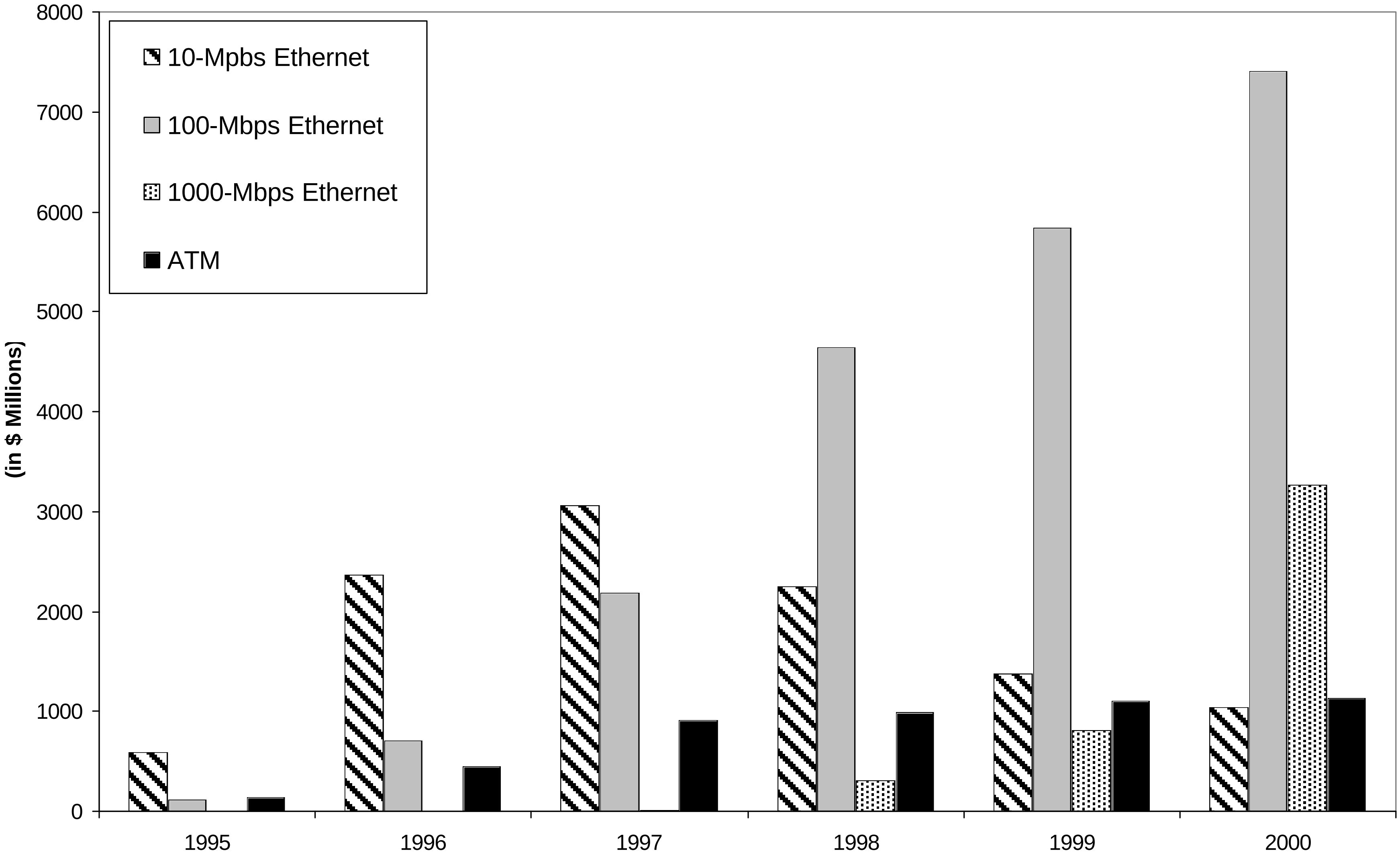


Figure 4: End User Spending on Local Area Network Equipment

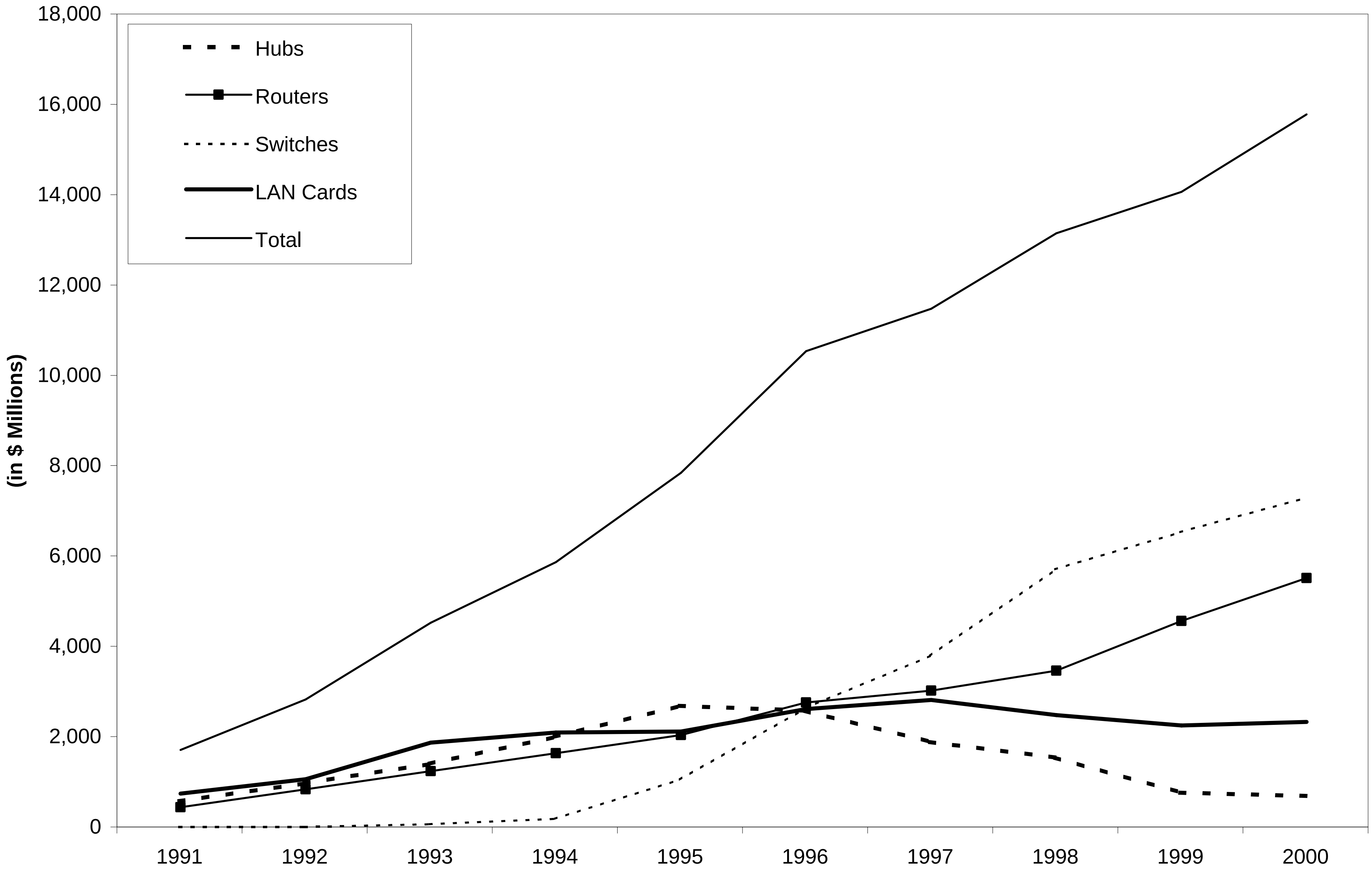


Figure 5: Cisco Market Share by Router Category

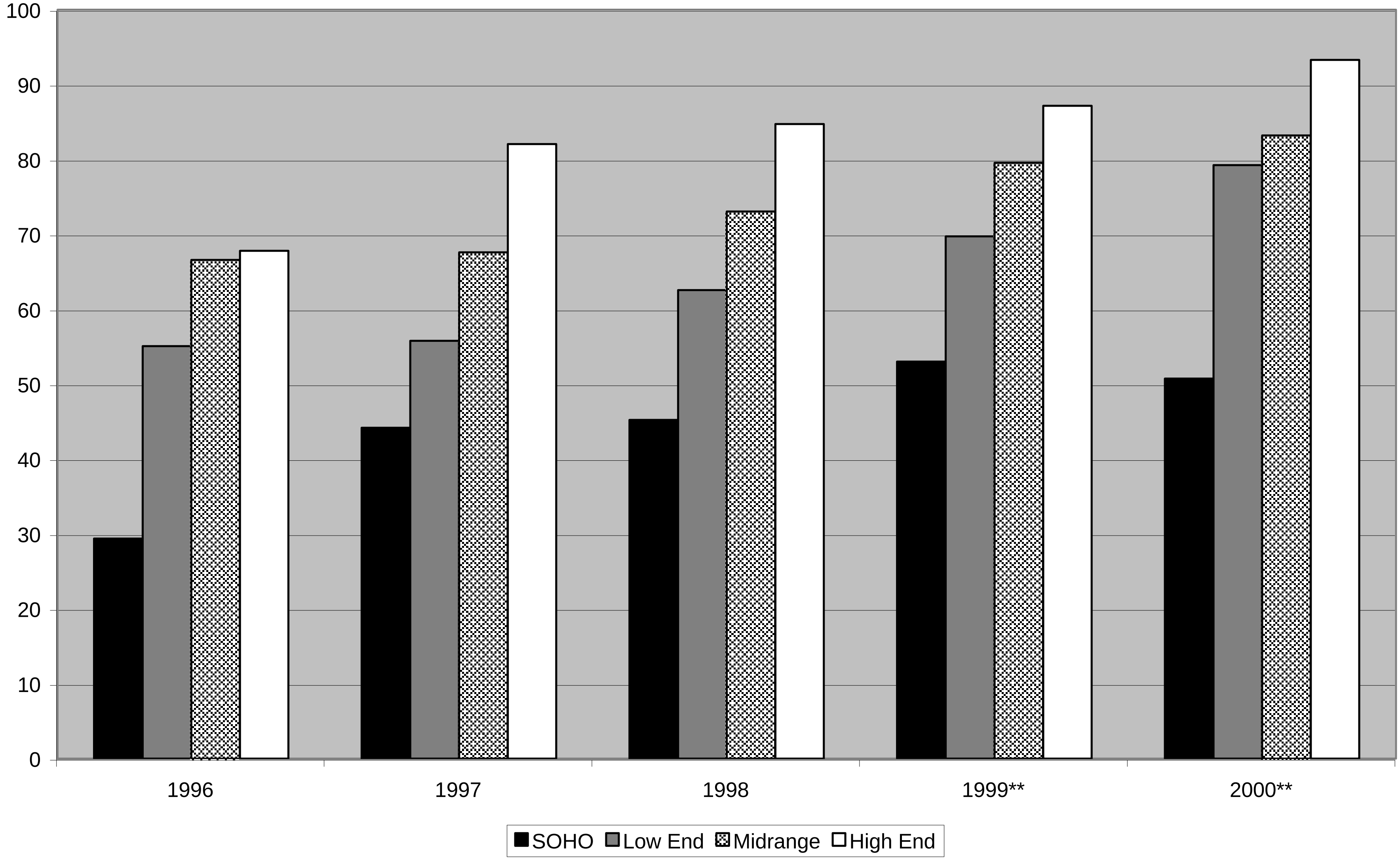


Figure 6: Price Indexes for Hubs and Switches

(Index 1996 = 100)