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Pricing at the On-Ramp to the Internet
Price Indexes for ISPs during the 1990s

Greg Stranger and Shane Greenstein

7.1 Introduction

Prior to commercialization, the Internet was available only to researchers and educators. Less than a decade after commercialization, more than half the households in the United States were online according to the National Telecommunications Information Administration (NTIA; 2001). The Internet access industry generated 15.6 billion dollars in revenue in 2001 (U.S. Department of Commerce 2003, 733). This growth presents many challenges for measuring the contribution of the Internet to gross domestic product (GDP). In this study we consider the formulation of consumer price indexes for commercial Internet access. We focus on constructing an index for the earliest period of growth of dial-up service, when the challenges for index construction are greatest.

No simple measurement strategy will suffice for formulating price indexes for Internet activity. On average, more than two-thirds of time online is spent at so-called free sites. Many of these are simply browserware or Usenet clubs for which there is no explicit charge. Some of these are partly or fully advertising-supported sites. Households also divide time between

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activities that generate revenue directly from use. For example, most electronic retailing does not charge for browsing but does charge per transaction. Other media sites, such as pornography, newspaper archival, and some music, charge directly for participation (Goldfarb 2004).

There is one place, however, where almost every household transacts money for service. Internet service providers (ISPs) provide the point of connection for the vast majority of household users, charging for such a connection. From the outset of commercialization, most users moved away from ISPs at not-for-profit institutions, such as higher education (Clemente 1998). Far more than 90 percent of household use was affiliated with commercial providers (NTIA 2001). This continues today.

In this paper we investigate the pricing behavior at ISPs from 1993 to 1999 with the goal of generating price indexes. We begin with the earliest point when we could find data, 1993, when the commercial ISP market was still nascent. We stop in 1999 for a number of reasons. For one, the industry takes a new turn with the AOL/Time Warner merger in early 2000, an event that we believe alters strategies for accounting for qualitative change. Second, until the merger many industry sources indicate that all online providers followed the same technological trajectory. This helps us construct indexes without data on market share, which we lack. Third, and somewhat independently, broadband began to diffuse just near the end of our sample. After a few years, it connected enough households to influence Internet price indexes and would require us to alter the procedures carried out in this paper. Finally, spring 2000 marks the end of unqualified optimism about the persistence of the Internet boom. This change in mood was affiliated with restructuring of the ISP industry, potentially bringing about a marked departure in price trends.

Using a new data set about the early period, we compute a variety of price indexes under many different methods. The results show that ISP pricing has been falling rapidly over time. The bulk of the price decline is in the early years of the sample, especially between early 1995 and the spring of 1996. We also find a 20 percent decline in price per unit of ISP quality for the thirty-three-month period between late 1996 and early 1999. We assess alternative models that vary in their attention to aspects of qualitative change. We find that this attention matters. Accounting for qualitative change shapes the estimates of price declines and the recorded timing of those declines.

This paper is unique in that it is the first to investigate a large sample of U.S.-based ISPs. This setting gives rise to a combination of familiar and unique challenges for measurement. This novelty and challenge should be understood in context. There have been many papers on hedonic price indexes in electronic goods (Berndt and Griliches 1993; Berndt, Griliches, and Rappaport 1995; Berndt and Rappaport 2001) and new industries, such as automobiles (Griliches 1961; Raff and Trajtenberg 1997). We borrow many lessons learned from those settings (see Berndt [1991] for an overview). There is also another paper about prices at Canadian ISPs (see Prud'homme and Yu 1999), which has some similarities to our setting, though involving many fewer firms.

This is one of the first papers to investigate and apply these hedonic methods to estimate price indexes for a service good. In this setting, physical attributes are not key features of the service, but features of the contract for service are. These features can improve quite rapidly from one year to the next as contracting modes change, as new entrants experiment with new service models for delivery, and as technological change alters the scope of possible services available to ISPs. Our primary goal is to understand hedonic price indexes in such an evolving market.

Many, but not all, ISPs offer more than one type of contract for service. In our data there is no one-to-one association between firm and the features of service. This provides some challenges for measurement, as well as some opportunities. We compare alternative ways to control for unobserved quality at the level of the ISP. This is another novelty, albeit a small one for the results.

We view this paper as one small step in a much larger research enterprise, measuring the economic changes brought about from the diffusion of and improvement in the Internet. There is much distance between our historical exercise and an ideal cost-of-living index for the Internet (Greenstein 2002). During the time period under examination, the Internet underwent dramatic changes. The quality of what users got from the Internet skyrocketed. Said another way, what the user did with the service they got from an ISP also changed dramatically over this time period. We measure only a small piece of that dramatic change in experience.

7.2 A Brief History of Internet Service Providers in the United States

The Internet began as a defense department research project to develop networking technologies more reliable than existing daisy-chained networks. The first product of this research was the Advanced Research Projects Agency Network (ARPAnet). Stewardship was handed to the National Science Foundation (NSF) in the mid-1980s, which established NSFnet, another experimental network for universities and their research collaborators. The NSF's charter prohibited private users from using the infrastructure for commercial purposes, which was not problematic until the network grew. By 1990, the transmission control protocol/Internet protocol (TCP/IP) network had reached a scale that would shortly exceed NSF's needs. For these and related reasons, the NSF implemented a series of steps to privatize the Internet. These steps began in 1992 and were completed by 1995. Diffusion to households also began to accelerate around 1995, partly as a consequence of these steps as well as due to the commercialization and diffusion of an unanticipated innovation, the browser (Greenstein 2001).

7.2.1 The Origins of Internet Functionality and Pricing

A household employs commercial Internet providers for many services, most of which had their origins in the ARPAnet or NSFnet. The most predominant means of communications is e-mail. The e-mail equivalent of bulk mail is called a *listserv,* where messages are distributed to a wide audience of subscribers. These listservs are a form of conferencing that is based around a topic or theme. Usenet or newsgroups are the Internet equivalent of bulletin board discussion groups. Messages are posted for all to see, and readers can respond or continue the conversation with additional postings. Chat rooms serve as a forum for real-time chat. "Instant-messaging" has gained increased popularity, but the basic idea is quite old in computing science: users can communicate directly and instantaneously with other users in private chatlike sessions.

Some tools have been supplanted, but the most common are World Wide Web (WWW) browsers, gopher, telnet, file transfer protocol (ftp), archie, and wais. Browsers and content have grown in sophistication from the one-line interface designed by Tim Berners-Lee, beginning with Lynx, then Mosaic, and, more recently, Netscape Navigator, Internet Explorer, and the open-source browser, Opera. The Internet and WWW are now used for news and entertainment, commerce, messaging, research, application hosting, videoconferencing, and so on. The availability of rich content continues to grow, driving demand for greater bandwidth and broadband connectivity.

Pricing by ISPs requires a physical connection. The architecture of the Internet necessitates this physical connection. Both under the academic and commercial network, as shown in figure 7.1, the structure of the Internet is organized as a hierarchical tree. Each layer of connectivity is dependent on a layer one level above it. The connection from a computer to the Internet reaches back through the ISP to the major backbone providers. The lowest level of the Internet is the customer's computer or network. These are connected to the Internet through an ISP. An ISP will maintain their own subnetwork, connecting their points of presences (POPs) and servers with Internet protocol (IP) networks. These local access providers derive their connectivity to the wider Internet from other providers upstream, either regional or national ISPs. Regional networks connect directly to the national backbone providers. Private backbone providers connect to public (government) backbones at network access points.

7.2.2 The Emergence of Pricing and Services at Commercial Firms

An ISP is a service firm that provides its customers with access to the Internet. These are several types of "access providers." At the outset of the in-

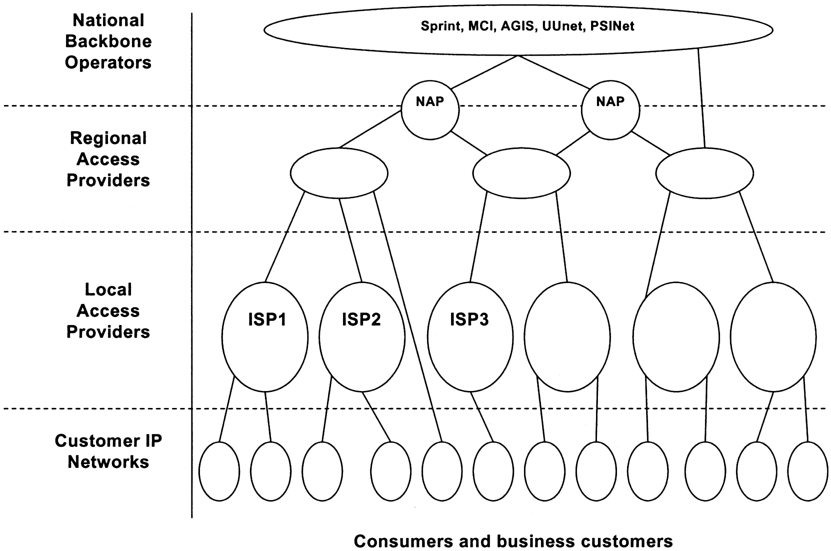

Fig. 7.1 The organization of the Internet

dustry, there was differentiation between commercial ISPs, "online service providers" (OSPs; Meeker and Dupuy 1996), and firms called "commercial online services" by Krol (1992). Internet service providers offer Internet access to individual, business, and corporate Internet users, offering a wide variety of services in addition to access, which will be discussed in the following. Most OSPs evolved into ISPs around 1995–1996, offering the connectivity of ISPs with a greater breadth of additional services and content.

Most households physically connect through dial-up service, although both cable and broadband technologies gained some use among households near the end of the millennium.[1] Dial-up connections are usually made with local toll calls or calls to a toll-free number (to avoid long-distance charges). Corporations often make the physical connection through leased lines or other direct connections. Smaller firms may connect using dial-up technology. These physical connections are made through the networks and infrastructure of competitive location exchange companies, incumbent location exchange companies (such as Regional Bell Operating Companies), and other communications firms. Large ISPs may maintain their own network for some of the data traffic and routing; the largest firms often lease their equipment to other ISPs for use by their customers. Smaller ISPs are responsible for the call handling equipment

1. Approximately 5 percent of U.S. households subscribed to a broadband connection as of 2000; see NTIA (2001).

(modems, routers, access concentrators, etc.) and their own connections to the Internet, but in some locations they may lease services for traveling customers.

Charging for access occurs at the point of access by phone. Internet service providers generally maintain POPs where banks of modems let users dial in with a local phone call to reach a digital line to the Internet. Regional or national ISPs set up POPs in many cities, so customers do not have to make a long-distance call to reach the ISP offices in another town. Commercial online services, such as America Online, have thousands of POPs across many countries that they either run themselves or lease through a third party.

Many ISPs provide services that complement the physical connection. The most important and necessary service is an address for the user's computer. All Internet packet traffic has a "from" and "to" address that allows it to be routed to the right destination. An ISP assigns each connecting user with an address from its own pool of available addresses. ISPs offer other services in addition to the network addresses. These may include e-mail servers, newsgroup servers, portal content, online account management, customer service, technical support, Internet training, file space and storage, Web-site hosting, and web development and design. Software is also provided, either privately labeled or by third parties. Some of it is a standard component of the ISP contract (Greenstein 2000b; O'Donnell 2001). Some ISPs also recommend and sell customer equipment they guarantee will be compatible with the ISP's access equipment.

Internet service providers differ in size. The national private backbone providers (i.e., MCI, Sprint, etc.) are the largest ISPs. The remaining ISPs range in size and scale from wholesale regional firms down to the local ISP handling a small number of dial-in customers. There are also many large national providers who geographically serve the entire country. Many of these are familiar names such as Earthlink/Sprint, AT&T, IBM Global Network, Mindspring, Netcom, PSINet, and so on. The majority of providers provide limited geographic coverage. A larger wholesale ISP serves all ISPs further up the connectivity chain. Local ISPs derive connectivity from regional ISPs who connect to the national private backbone providers. A large dial-up provider may have a national presence with hundreds of POPs, while a local ISP may serve a very limited geographic market.

It is difficult to describe modal pricing behavior for ISPs over time. The most likely date for the existence of the first commercial ISPs is 1991–1992, when the NSF began to allow commercialization of the Internet.[2] In one of

2. PSINet, a now bankrupt ISP, used to claim that it was the first commercial ISP, offering connection in 1991 though many others have also made a similar claim. The history is cloudy because it is unclear whether the NSF "allowed" connection or some firms connected in violation of the restrictions against commercial behavior and, needing an excuse to privatize, NSF figured out how to accommodate such behavior.

the earliest Internet handbooks, Krol (1992) lists 45 North American providers (eight have national presence). In the second edition of the same book, Krol (1994) lists 86 North American providers (10 have national presence). Marine et al. (1993) lists 28 North American ISPs and six foreign ISPs. Schneider (1996) lists 882 U.S. ISPs and 149 foreign ISPs. Meeker and Dupuy (1996) reports that there are over 3,000 ISPs, and the Fall 1996 *Boardwatch Magazine's Directory of Internet Service Providers* lists 2,934 firms in North America. This growth was accompanied by vast heterogeneity in service, access, and pricing. Descriptions of regional and wholesale connectivity (see *Boardwatch Magazine's Directory of Internet Service Providers* [1996]) imply that contracts are short term.

7.2.3 Pricing Behavior at Commercial Firms and How It Changed

Prior to the Internet, there were many bulletin boards and other private networks. The bulletin boards were primarily text-based venues where users with similar interests connected, exchanged e-mail, downloaded or uploaded files, and occasionally participated in chat rooms. The private networks or OSPs (e.g., AOL, CompuServe, Genie, and Prodigy) had similar functionality, with segregated content areas for different interests. Users could post and download files and read and post interest group messages (similar to today's Internet newsgroups, but usually moderated). These forums (as they were called on CompuServe) were often centered on a specific topic and served as a customer service venue for companies. The pricing structure of the majority of these services was a subscription change (on a monthly or yearly basis) and possibly an hourly fee for usage.

At this early stage, circa 1992–1993, most users would batch together the work they needed to do online, connect, and quickly upload and download files, e-mail, and messages. Then they would disconnect, minimizing time online. Specialized software existed to facilitate this process. When ISPs first commercialized in 1992, there were similar expectations that users would continue to use the Internet in such bursts of time.

Because much of the usage was for uploading and downloading, it was sensible to charge more for faster access. Pricing by speed is close to pricing by volume (or pricing for traffic). Consequently, many ISPs services varied the hourly charge based on the speed of the connection. In the early 1990s, speeds moved from 300 bytes per second (bps) to 1,200; 2,400; 4,800; 9,600; and eventually to 14,400 and 28,800. The latter two were the norm of the mid 1990s. 56k (or, on some lines, 43,000bps) became the norm in the latter part of the 1990s.

As speeds changed and as behavior changed, a variety of pricing plans emerged. Price plans began to offer larger amounts of hours that were included in the monthly fee and offered marginal pricing above those included hours. These plans offered traditional nonlinear pricing or quantity discounts. In these plans, the marginal hours would be priced lower than the average cost of the included hours. We will say more about this in the following.

Only later, after the ISP industry began to develop and mature, and users demonstrated preferences for a browsing behavior, pricing began to shift to unlimited usage for a fixed monthly price. These plans are commonly referred to as "flat-rate" or "unlimited" plans. These unlimited plans caused capacity issues at POPs because the marginal cost to the user was zero, and some users remained online much longer. Internet service providers reacted to this behavior by introducing plans with hourly limits and high marginal pricing above the limit. Most such plans were not particularly binding unless the user remained online for hours at a time most days of the month. Some ISPs also instituted automatic session termination when an online user remained inactive, eliminating problems arising from users who forgot to log off. However, this was perceived as poor service by some customers; consequently, many small ISPs hesitated to employ it.

7.2.4 The Structure of the ISP Market and Pricing

The ISP market began to experience explosive entry around 1995, accelerating after the commercialization of the browser around the same time. Early movers in this market had experience with the network used in higher education. Firms such as PSINet, IBM, and MCI tried to stake positions as reliable providers for business and each achieved some initial success.

A signal event in 1995–1996 was the entry of AT&T's Worldnet service, which was first aimed at business in late 1995 and then explicitly marketed at households in early 1996. It became associated with reliable e-mail and browsing as well as flat-rate pricing at $20 a month, which imposed pricing pressure on other ISPs throughout the country. This service quickly grew to over a million users within a year, though its market growth eventually stalled. Indeed, it never met forecasts from 1995 that it would dominate the market because, in effect, its competitors also grew rapidly. Growing demand for all services meant that no player achieved dominance for several years (Greenstein 2001).

The online service providers—Prodigy, Genie, CompuServe, MSN, and AOL—all began converting to Internet service around 1995, with some providing service earlier than others. All failed to gain much additional market share from this move except AOL, who used this conversion as an opportunity to alter their service's basic features. That said, AOL's conversion was not smooth. When AOL converted fully to Internet access in 1996, it experienced a difficult transition. Management underanticipated their own users' responses to the introduction of flat-rate pricing. This bad publicity also facilitated further entry by other firms looking to pick up customers who fled the busy phone lines. AOL survived the bad publicity through a series of new investments in facilities and intense marketing.

Furthermore, in 1997 it made a deal with Microsoft to use Internet Explorer, which allowed it to grow at Microsoft Network's (MSN's) expense, who had been one of its big competitors until that point (Cusumano and Yoffie 1998). Furthermore, in 1998 AOL bought CompuServe, a merger that, in retrospect, initiated it on the path toward solidifying its leadership of dial-up service.[3]

Another important change was due to consolidation, especially in 1998. AOL sold off its physical facilities in 1996. When IBM sold its facilities to AT&T in 1997, AT&T became one of the largest business providers of access in the United States. When MCI and Uunet eventually became part of WorldCom in 1998 (subject to a restructuring and sell-off of MCI's backbone, as mandated by the Department of Justice) WorldCom became the largest backbone provider in the United States and one of the largest resellers of national POPs to other firms.

Neither AT&T's entry, nor IBM's or MCI's positioning, had satisfied all new demand. After 1995, thousands of small entrepreneurial ventures also grew throughout the country and gained enough market share to sustain themselves. New entrants, such as Erols, Earthlink, Mindspring, Main One, Verio, and many others, gained large market positions. The entry (and exit) continued through 1999. Private label ISPs also emerged when associations and affiliation groups offered rebranded Internet access to their members. These groups did not own or operate an ISP. Instead, their access was being repackaged from the original ISP and rebranded.

By 1997 more than 92 percent of the U.S. population had access to a competitive market filled with a wide variety of options. Another 5 percent of the population—found in many different rural locations throughout the United States—had access to at least one firm by a local phone call (Downes and Greenstein 2002). Economies of scale and barriers to entry were quite low, so thousands of firms were able to sustain their businesses. Roughly speaking, market share was quite skewed. A couple dozen of the largest firms accounted for 75 percent of market share and a couple hundred for 90 percent of market share, but there was so much turnover and fluctuation that estimates more precise than this were difficult to develop.

Just prior to the AOL/Time Warner Merger in 1999–2000, the ISP market remained in flux. Broadband connections (digital subscriber line [DSL] or cable) began to become available in select places—primarily urban areas, offering these home users a faster and possibly richer experience. The so-called free-ISP model also emerged in late 1998 and grew rapidly in 1999, offering free Internet access in exchange for advertisements placed on the users' screen. These firms eventually signed up several million households. The scope of service also continued to differ among ISPs, with

3. In 1999, AOL bought Netscape, well after the browser wars. The merger with Time Warner was proposed in 2000.

no emergence of a norm for what constituted minimal or maximal service. Some ISPs offered simple service for low prices, while other ISPs offered many additional services, charging for some of these services and bundling other services in standard contracts.

Stated succinctly, over a six-year period there were many changes in the modal contract form and user behavior. Variations in the delivery of services and changes in user expectations resulted in numerous qualitative changes in the basic service experienced by all users. All players were buffeted by many of the same competitive forces.

7.2.5 Turbulent Times and Price Indexes

In a market as turbulent as this one, we are quite skeptical of traditional price-index construction using only measured prices weighted by market share, unaltered for qualitative change and competitive conditions. Our working hypotheses are simple: (a) it will be difficult to execute matched-model methods; (b) not accounting for quality will lead to problematic indicators of the true state of the market. Why are these hypotheses our starting point?

First, large improvement in the quality of service occurred and went unmeasured. These changes were widespread and not unique to any particular firm. They happened too frequently to be measured. Every surviving firm, whether big or small, had to experiment often with alternative modes for delivery and different features in the service.

Second, market share was frequently in flux, and such changes were likely to fall below the radar screen of any government price record. Experimentation enabled many new entrants to succeed in growing market share well after commercialization began. Yet data on market share normally is collected by government agencies at a frequency of two or three years at most. This only coarsely reflects the rapid addition of new users over time.

Third, marketwide experimentation imposed competitive pressure on incumbent behavior, even when these were very large firms. Behaving as if they were "paranoid," the most nimble largest firms of this era, such as AOL and Earthlink, did not stand still.[4] Incumbent ISPs were compelled to make frequent releases of upgrades to their software, to spend lavishly on marketing, to add new features constantly, and to keep prices low by not charging for extras—to prevent the growing young firms from cutting into the incumbents' leads. Yet most of these competitive outcomes, except nominal prices, were not measured. In short, while it is often satisfactory to ignore the behavior of small fringe firms, that omission (or de-emphasis) could lead us to throw away useful information. If the large and small acted

4. This paranoia appeared justified as the least nimble firms, such as AT&T WorldNet, did not keep up and, consequently, did not prosper (after a spectacular start in 1995–1996).

as if they were close substitutes, the small firms provide information about the unmeasured activities of the large.

In summary, quality changed so rapidly that market share bounced around, and the large firms acted as if they were afraid of losing market share to the small. These observations will push us to examine the behavior of all firms in this market and not just the top dozen.[5]

7.3 Data Set Description

The data set used in this paper is compiled chiefly from issues of *Boardwatch Magazine's Directory of Internet Service Providers* (1996–1999). The directory debuted in 1996 and continued to be published through 1999. Since 1998, the same publisher has maintained a list of ISPs at http://www.thelist.com. Before the directory was published, *Boardwatch Magazine* published lists of Internet service providers in its regular magazine. These issues date from November 1993 until July 1995. Another handful of observations in the data set were collected from the contemporaneous "how-to" Internet books that are listed in the references.

The sample covers the time period from November 1993 until January 1999, approximately a six-year period. The sample is an unbalanced panel, tracking a total of 5,948 firms with a total of 19,217 price-plan observations.[6] The data set consists of demographic information about the ISP (name, location, phone, and Web address). In each year there are a variety of other characteristics of the ISP that are measured, including whether they are a national provider, how many area codes they serve, presence of upstream bandwidth, and their total number of ports. There is additional data from a survey/test done by *Boardwatch,* tallying the percentage of calls completed and the average speed of actual connections for the national providers in 1998, though we will only partially use this data in this paper.

Each ISP is associated with one or more price plans from a given time period. Each price plan observation includes the connection speed, monthly fee, and whether the plan offers limited or unlimited access. If access is limited, then there is information on the hourly limit threshold and

5. We could also appeal to precedent. A fair number of hedonic studies for PC software and hardware have used unweighted sales data for their estimation of quality-adjusted price indexes. For example, see Berndt and Rappaport (2001) on PC hardware, or Pakes (2002), or Berndt (1991) more generally.

6. This data does not represent all firms in the industry. Two or three price plans generally listed by *Boardwatch* for any given provider at one specific time represent most, but not all, plans available from that ISP. Greenstein (2000b) confirms that the *Boardwatch* data was incomplete in terms of the number of plans actually offered by an ISP. However, *Boardwatch* does state that the plans represent "the majority of users at an ISP or the most frequently chosen plans." As table 7.1, documents, 25 observations are drawn from November 1993; 47 from January 1995; 1,283 from May 1996; 2,822 from August 1996; 3,813 from March 1997; 5,659 from January 1998; and 5,568 from January 1999.

Table 7.1 ISP price dataset: Counts of firms and observations, by year

	11/1993	1/1995	5/1996	8/1996	3/1997	1/1998	1/1999	Total
Directory firms[a]	24	35		2,934	3,535	4,167	4,511	
Sample firms[b]			710					
Total observations	25	47	1,283	2,822	3,813	5,659	5,568	
Speeds[c]								
14.4k	25	42						67
28.8k		5	702	2,822	3,367	3,972	2,562	13,430
56k					446	1,564	3,006	5,016
ISDN 64k			299			54		353
ISDN 128k			282					282
T1 1.544mb						69		69
Limited hours	13	22	303	996	1,024	1,130	581	
Unlimited	12	25	980	1,826	2,789	4,529	4,987	
% Limited	52	47	24	35	27	20	10	
28.8k speed								
Limited hours		2	303	996	1,024	1,130	581	
Unlimited		3	399	1,826	2,343	2,842	1,981	
% Limited		40	43	35	30	28	23	

Note: The data set comprises all data published by the data sources listed in the references. The sole exception is the 5/1996 data, which represents a random sample of 710 firms from a total population of ~2,050 firms. The overall results presented in this paper are insensitive to the inclusion or exclusion of this subset of observations.

[a]Some firms disappear from the published data, and others continue to be listed without price plan information. We are not sure of the fate of these firms, though it is likely that the ones that disappear have either been consolidated or failed. Firms that continue to appear without price data provide evidence that *Boardwatch* did in fact continue to monitor and update the pricing in their listings. This eliminates some bias in the results that would have occurred if the prices were not up to date.

[b]Some firms listed in the data sources did not have price plan information. That is why there are few firms represented in the data sample.

[c]Number of observations at each speed by year.

the cost of additional hours. In a given year, there may be multiple price-plan records for a given firm because they offer a variety of plans at different connection speeds. The published information generally gives pricing for 28.8k access as well as higher-speed access.[7]

Table 7.1 summarizes the number of observations in the panel. Four observations from the first two years were dropped due to the fact that they were extreme outliers. They certainly were unpopular, but because we lack market share, they had an overwhelming and undue impact on the early

7. *Boardwatch* mildly changed its formats from one year to the next. Depending on the year, this higher-speed plan could be for 64k or 128k ISDN access or for 56k access. It should be noted that the price plans for these higher speeds included no information about hourly limitations or marginal prices. We have chosen to treat them as unlimited plans. The other choice would be to attribute the same hourly limitations as the slower plan from the same firm in the same year, but we have no basis for doing so.

price-index results. No other cleaning of the data has been done, apart from simple verification and correction of data entry. As table 7.1 shows, the latter part of the sample period produces the greatest number of observations. This is one indication of how fast this industry was growing.[8]

Approximately 21 percent of the observed plans have an hourly limit, and the majority of those are accompanied by a marginal price for usage over that limit. Over time the universe of firms and plans grows, and the speeds offered increases. At the start of the sample, prices are only given for 14.4k connections. By the end of the data, 28.8k and 56k have been introduced, and there are price observations at 64k and 128k integrated services digital network (ISDN) speeds as well as a small number of observations of T1 connection prices.[9] For limited plans, the hours included in the plans continue to increase over time. The number of plans with limitations is decreasing over time as a proportion of the sample. The pattern in the mean of monthly prices is not easy to discern.

Greenstein (2000b) uses a more comprehensive source of data with a different format and examines contracting practices for only 1998. In that data, approximately 59 percent of firms quote only one price schedule, approximately 24 percent quote two price schedules, and 17 percent quote three or more. Of the single price quotes, approximately 26 percent are for limited prices. In this data set, 71 percent of the observations are firms quoting only one price, 26 percent quote two prices, and the remainder quote three or more prices. This is also highlighted in table 7.1, where the average is 1.2 price-plan observations per firm. The difference between the data here and in Greenstein (2000b) seems to be that here we have more firms who quote only one plan and fewer firms that quote more than two plans. We conclude that the data set represents a subset of the plans offered by each provider because the publishing format limited the variety of plans that an ISP could list.

One of the weaknesses of this data set is the lack of quantity measures of subscribers and usage. Without usage data, there is no way to weight the price observations in the calculation of an ideal price index. At the same time, as noted previously, we would be quite skeptical of an outcome using such weighting. We discuss this further in the following.

We construct our index assuming that most firms were responsive to the same technological trends. We are confident that qualitative change found

8. Consider the publishing pattern of ISP information in *Boardwatch.* In 1993–1995, the list of ISPs is relatively short and is included in the magazine, but by 1996 the market is growing rapidly and the listings are published in a separate directory that is updated quarterly. By 1998, changes in the market have slowed enough that the directory is only updated and published semiannually. By 1999, the directory is updated on an annual basis.

9. ISDN stands for integrated service digital network. It is a standard for transferring data over phone lines at 128k and requires both the phone line and the user to upgrade appropriately. Unlike the dial-up connections whose prices we study in this paper, a T1 line refers to a direct and fast connection, one that brings the pipe to the user's premise, usually to a business.

at one firm spread to others quickly. Another way to say this is as follows: it is as if we are assuming that the measured improvement at the small firms is informative about the unmeasured improvements at the large. In a companion paper, we partly test this assumption by examining the sensitivity of price estimates to the age of the ISP, which proxies for the durability of incumbency and stable market presence. We find it makes sense to do so (see Stranger and Greenstein 2004).

We do not think this assumption makes sense after 2000. After the consolidation of AOL's leadership and its merger with Time Warner, AOL begins to follow its own path. This is also increasingly true for MSN after the browser wars ended (in 1998) and after the entry of the free ISPs, such as NetZero, whose spectacular growth ceases after 2001. Moreover, the rate of unmeasured improvement in features of dial-up service begins to decline after the dot-com crash in spring of 2000 (though introduction of new features does not end after that, to be sure). As noted, the lack of market share is more problematic for a stable dial-up market, which, arguably, begins to emerge after 1998, and obviously emerges when adoption of the Internet slows at households, as it does by 2001 (NTIA 2001). Thus, we did not collect data after early 1999.

7.4 Elementary Price Indexes

The most elementary price index is displayed in table 7.2. It does not adjust prices for any differences of quality over time. The means of the monthly prices trace a sharp upward path from 11/1993 to 5/1996 with an even sharper fall from 5/1996 to 8/1996, followed by small increases to 1/1998 and another steep fall in 1/1999. The medians also decline over time, but the changes are discrete.

The fundamental problem with the data presented in table 7.2 is that the observations in each time period reflect very different service goods. For example, the outlying mean of prices in May 1996 is due to the inclusion of high speed contracts. Table 7.1 shows that more than 581 contracts from

Table 7.2 **Nominal price index: Mean and median of monthly price—Full sample**

Time	Mean	Median	Plans
Nov. 1993	30.84	30.00	25
Jan. 1995	38.86	30.00	47
May 1996	71.08	28.00	1,275
Aug. 1996	20.02	19.95	2,822
March 1997	21.40	19.95	3,813
Jan. 1998	39.13	19.95	5,659
Jan. 1999	19.29	19.95	5,568

Table 7.3 **Nominal price index: Mean and median of monthly price—Speed 28.8k and below**

Time	Mean	Median	Plans
Nov. 1993	30.84	30.00	25
Jan. 1995	38.86	30.00	47
May 1996	22.64	19.95	694
Aug. 1996	20.02	19.95	2,822
March 1997	19.80	19.95	3,367
Jan. 1998	19.77	19.95	3,972
Jan. 1999	19.01	19.95	2,562

May 1996 are ISDN contracts, which *Boardwatch* reports in that issue (and then never again).

Table 7.3 shows that homogenizing the sample does reduce the variation in the calculated means and medians. The price index based on the means now only rises from 11/1993 to 1/1995 and falls for the remainder of the sample period. This rise is persistent throughout the price indexes in the paper. It is discussed in more detail in a later section. The index based on the median falls early in the sample period and then remains steady for the remainder. This is indicative of the growing homogeneity across firms and plans in the later part of the sample.

7.4.1 Alternative Unweighted Matched Models

A procedure such as matched models compares products that exist in two adjacent periods. This could be an improvement, but it suffers because it ignores the introduction of new products (at least until they have existed for two periods). This method also ignores the disappearance of older or obsolete products because there is no natural comparison to the product after its last year. If quality is increasing, then matched models will overstate the period-to-period index number, biasing upward the measured price change.

Using the matched observations, it is possible to compute the values of the Dutot, Carli, and Jevons indexes (see table 7.4). Given a number of prices for matching services, represented as $P_{i,t}$,[10] these formulas are used for the indexes. More precisely, to construct the matched-model indexes, we matched price plans where firm_i, speed_j at time_t are matched with firm_i, speed_j at time_{t+1}.

Table 7.5 reports results for an analysis for this strict matching, where both firms and speeds must match for a plan to be included in the calculation.[11] The hypergrowth and turnover of the industry in the first few years

10. The i subscript designates the price plan and t subscript designates the time period.

11. Even the strict matching ignores any change in hours. We have ignored situations in which a plan switched between limited and unlimited.

Table 7.4 Dutot, Carli, and Jevons indices

Index	Formula	
Dutot I_{Dutot}	$\dfrac{\sum_i P_{i,t}}{\sum_i P_{i,t-1}}$	Mean ratio of the prices
Carli I_{Carli}	$\dfrac{\sum_i \dfrac{P_{i,t}}{P_{i,t-1}}}{N}$	Mean of the price ratios
Jevons I_{Jevons}	$\sum_i \left(\dfrac{P_{i,t}}{P_{i,t-1}}\right)^{1/N}$	Geometric mean of price ratios

Table 7.5 Matched model: Strictly matched observations

		Indices		
Date	No. of matches	Dutot	Carli	Jevons
Nov. 1993		1.00	1.00	1.00
Jan. 1995	15	1.34	1.72	1.30
May 1996	5	0.58	0.57	0.53
Aug. 1996	535	0.95	1.06	0.98
March 1997	2,599	0.99	1.03	0.99
Jan. 1998	3,561	0.97	1.01	0.99
Jan. 1999	2,691	0.94	1.02	0.96
Cumulative index		0.67	1.10	0.64

results in relatively few matches in the 1993–1996 period. In 1996, 510 plans[12] from 5/1996 are matched into the 8/1996 part of the sample. From 1996 to 1997, a similarly large proportion of plans match. Although the absolute number of matching plans remains high, the proportion of plans that are matched decreases toward the end of the sample.

It has been noted that the Carli index generally overestimates the index level, and this seems to be confirmed in the results in table 7.5 (Diewert 1987). This is because a single large or extreme value of P_1/P_0 swamps small values of P_1/P_0 when averaged. The simplest explanation is that this price ratio is unbounded above (price increases can exceed 100 percent), but the ratio is bounded below (price decreases can only be 100 percent) to zero. The Dutot index is nothing more than a comparison of the mean prices of the matched products. Because it is a simple average, the Dutot index is also

12. Of the 1,283 total plans in 5/96, only 702 can possibly match a plan in 8/1996 because the remaining 581 plans are either 64k or 128k plans that are not reported for any firms in the 8/1996 data.

susceptible to influence by large outlying data. The Jevons index is quite different. As a geometric average, the Jevons index works very efficiently in a large sample to reduce the impact of outlying observations.

The results suggest that prices are declining throughout the sample period, with especially dramatic changes arising in between January 1995 and May 1996, though the sample is quite small for that time period. The notable exception is the Carli index, which shows price increases in nearly every period except May 1996, where the sample is very small. The average annual growth rate (AAGR) for the Jevons and Dutot indexes for the entire period is –7.8 percent. In all cases, the Jevons and Dutot indexes agree on direction of price change, despite differing on the exact magnitude of the change. These results are intriguing and suggest that more precise quality controls will yield interesting insights.

7.4.2 Determinants of Price

Before proceeding to examine hedonic regressions and the associated price indexes, we motivate the selection of the hedonic price model. The speed and duration of the plan are important as are complementary service offerings. Contract length and setup costs may also be important, but they are not recorded in this data. Firm quality, experience, and the competitive environment are also potential determinants of price.

One of the key developments in ISP service offerings over the 1993–1999 time period is the move from limited and metered plans to largely flat-rate unlimited usage plans. As noted earlier, in 1993, when ISPs began to offer services to consumers, there was little need for unlimited plans. In table 7.6, we show the mean fixed monthly cost of Internet access in this sample of ISPs. In each year, the mean price for limited contracts is below the mean price for unlimited contracts. These differences are all statistically significant, with p-values less than 1 percent. The table also illustrates the shift away from limited plans over the 1993–1999 time frame. At the outset, the limited plans make up roughly 50 percent of the sample plans. By 1999, limited plans make up just over 10 percent of the plans in the sample. In 1999, limited plans are, on average, \$0.91 per month less expensive than unlimited plans.

In table 7.7, we continue to examine the effect of plan limitations on ISP pricing. The data in the table indicate that for nearly every year, there is a persistent pattern to the mean prices and the hourly limits. The lowest prices are from the contracts that include ten hours or less in the fixed price. As the hourly limits expand, so do the mean prices. This is true across all years (except for 1/1995), and the monotonic relationship is maintained until the limits exceed 100 hours. Hour limitations above 100 hours appear to have no obvious relation to price that is consistent across the observational periods in the sample.

Survey data from March 2000 report that 93.4 percent of users have monthly usage of eighty-two hours or less, and 90 percent of users have

Table 7.6 Descriptive statistics for prices of limited and unlimited plans

Prices	Limited	Unlimited
Nov. 1993		
Mean	15.15	47.83
SD	12.65	25.06
N	13	12
Jan. 1995		
Mean	27.71	48.67
SD	15.58	38.73
N	22	25
May 1996		
Mean	19.73	24.90
SD	12.72	19.26
N	303	391
Aug. 1996		
Mean	18.36	20.93
SD	7.79	6.22
N	996	1,826
March 1997		
Mean	18.29	22.54
SD	7.60	22.21
N	1,024	2,789
Jan. 1998		
Mean	18.67	21.38
SD	9.19	14.59
N	1,130	4,406
Jan. 1999		
Mean	18.48	19.39
SD	5.94	7.46
N	581	4,987

Notes: SD = standard deviation. All of the differences between means are significant at *p*-values of 1 percent or smaller.

monthly usage of sixty-five hours or less (Goldfarb 2004). Thus, it is not surprising that limitations higher than 100 hours have little effect on ISP price. Comparing the higher-limitation mean prices with the unlimited plans in table 7.6, we observe that it is clear that these high-limitation plans are not priced very differently than the unlimited plans.

Other relevant variables are in table 7.8. Connection speed is another important dimension of Internet access. Over the full sample, there are observations from price plans that range from 14.4k at the low end up to some prices for T1 speeds (1.544Mbs) at the upper end. As noted earlier, these speeds should be given a broad interpretation. The changing nature of user behavior influenced the marginal returns to faster connections.[13]

13. Of course, the other argument is that as connection speeds have improved, content providers have begun to offer richer content that uses higher transmission bandwidth.

Table 7.7 Descriptive statistics of nominal prices by hourly limitation

	Hourly limitations (hrs)								
Prices	10	20	35	50	80	100	150	250	>250
Nov. 1993									
Mean	11.25	20							
SD	4.79								
N	4	1							
Jan. 1995									
Mean	16.69	38.74	26.23	47.48			33		
SD	3.25	19.32	5.82	38.93					
N	7	4	8	2			1		
May 1996									
Mean	12.59	15.31	20.11	22.43	21.41	22.94	22.86	25.48	30.43
SD	7.85	5.31	7.03	6.31	9.17	5.72	6.42	5.14	40.29
N	70	34	28	39	24	37	32	23	18
Aug. 1996									
Mean	11.28	13.80	17.87	21.13	21.05	22.33	21.02	20.82	20.41
SD	6.52	5.34	8.71	7.51	6.27	6.89	6.08	5.08	5.62
N	163	119	105	122	122	135	122	81	43
March 1997									
Mean	10.44	13.46	17.65	19.52	20.61	21.85	20.82	21.07	19.29
SD	4.91	5.35	10.48	6.66	6.86	6.64	5.83	4.75	5.41
N	141	99	102	109	130	152	130	114	65
Jan. 1998									
Mean	10.15	13.12	15.74	19.33	20.25	22.74	20.95	21.26	20.84
SD	5.15	5.85	5.28	6.56	6.79	14.73	5.49	4.85	11.06
N	123	91	126	110	135	170	152	140	101
Jan. 1999									
Mean	9.65	10.69	16.10	15.97	18.70	21.01	20.11	20.44	19.15
SD	6.29	2.76	4.77	5.48	4.73	6.37	5.10	4.56	4.45
N	30	34	38	33	47	69	112	135	87

Notes: SD = standard deviation. Survey data from March 2000 in Goldfarb (2004) shows that 93.4 percent of users have monthly usage of 81.7 hours or less, 90 percent of users use 65 hours or less. So limitations at or above 80 hours were probably not binding at all until recently and then only for a very small percentage of users.

There are a number of other measures in the data set that could signal ISP quality. More specialized types of access services being offered by an ISP could signal the technical expertise of their staff and their reputation for quality and adoption of leading technology. While there are many different ways to proxy for quality, we, for the most part, do not employ them in our hedonic analysis.[14] In part, this is due to data limitations. More-

14. We explored using such factors as whether the ISP provided national coverage, whether they provided additional services and some coarse measures of capacity, such as ports or T1 line backbone connections. These largely did not predict as well as the factors we left in the hedonic analysis. In addition, some of these were not available in all time periods, resulting in us using nonnormalized measures of qualitative change over time.

Table 7.8 Descriptive statistics for hedonic regression explanatory variables: Full sample

Variable	No. of observations	Mean	SD	Min.	Max.
hrs10	19,217	0.028	0.165	0.000	1.000
hrs20	19,217	0.020	0.140	0.000	1.000
hrs35	19,217	0.021	0.144	0.000	1.000
hrs50	19,217	0.022	0.145	0.000	1.000
hrs80	19,217	0.024	0.153	0.000	1.000
hrs100	19,217	0.029	0.169	0.000	1.000
hrs150	19,217	0.029	0.167	0.000	1.000
hrs250	19,217	0.026	0.158	0.000	1.000
isdn	11,964	0.504	0.500	0.000	1.000
limited	19,217	0.212	0.409	0.000	1.000
price	19,209	29.163	100.845	0.000	3,200
speed	19,217	43.392	91.607	14.400	1,544
speed14	19,217	0.003	0.059	0.000	1.000
speed28	19,217	0.699	0.459	0.000	1.000
speed56	19,217	0.261	0.439	0.000	1.000
speed64	19,217	0.018	0.134	0.000	1.000
speed128	19,217	0.015	0.120	0.000	1.000
speedT1	19,217	0.004	0.060	0.000	1.000
yr93	19,217	0.001	0.036	0.000	1.000
yr95	19,217	0.002	0.049	0.000	1.000
yr96a	19,217	0.067	0.250	0.000	1.000
yr96b	19,217	0.147	0.354	0.000	1.000
yr97	19,217	0.198	0.399	0.000	1.000
yr98	19,217	0.294	0.456	0.000	1.000
yr99	19,217	0.290	0.454	0.000	1.000

over, as we show in the following, however, we employ a random-effects estimator that correlates errors at an ISP over time. This will capture a portion of any unobserved quality that is correlated at the same firm.[15]

7.4.3 Hedonic Price Indexes

Hedonic models can be used to generate predicted prices for any product (i.e., bundle of characteristics) at any given time. The first hedonic model that we will estimate is

$$(1) \quad \ln P_{ijt} = \alpha_0 + \alpha_t \text{Year}_{ijt} + \beta_1 \text{Limited}_{ijt} + \beta_{2-9} d\text{Hrly}_{ijt} \cdot \text{Limited}_{ijt} + \gamma_{1-5} d\text{Speed}_{ijt} + \varepsilon_{ijt},$$

where the subscripts designate firm i, plan j, at time t. To divide the hourly limitations into indicator variables, we examined the frequency plot of the

15. In our companion paper (Stranger and Greenstein 2004), we will control for quality with vintage and age effects. For more on measuring quality at ISPs, see Augereau and Greenstein (2001) and Greenstein (2000a,b, 2002).

Table 7.9 **Frequency counts for limited hours bins**

Variable	Hourly limitation (hrs)	Count
hrs10	0–10	538
hrs20	10–20	382
hrs35	20–35	407
hrs50	35–50	415
hrs80	50–80	458
hrs100	80–100	563
hrs150	100–150	549
hrs250	150–250	493
hrgt250	>250	314

Notes: Each hourly limitation includes the upper boundary but not the lower boundary. The limit "10–20" is the set of hours (10,20).

hourly limits. Those divisions and frequencies are shown in table 7.9. Note that the use of indicator variables provides flexibility for the coefficient estimates.

The specification in equation (1) was estimated for the whole pooled sample and for each pair of adjacent time periods. Regression results are reported in table 7.10. In all cases, the standard errors are robust standard errors with corrections for clustering. Because of the abundance of data between 1995 and 1999 and because of the similarity of pricing strategies across ISPs in a given year, we expect most of the coefficients to be tightly estimated. In general, we also expect the specifications for adjacent time periods to be superior to the pooled specification.

We observe in the data that over time ISPs offer increasingly fast connection speeds. Unlimited plans have become more prevalent over time, while the hours allowed under limited plans have increased over time. These trends also indicate increases in "quality" over time. In the adjacent period models, the time indicator variable is only being compared to the previous period. In the pooled models, each coefficient on the time indicator variables represents a difference in price relative to the omitted time period (11/1993). In the pooled model, the coefficients should all be negative, and the coefficients of each succeeding period should be more negative than the previous one because each successive coefficient estimate represents an accumulated price decline.

Limited plans should have a negative impact on prices, but that impact should be decreasing as the number of hours allowed under the plan increases. For the regression, this means that we expect the difference between the coefficients Hrs10 $\cdot$ L and Limited to be negative. Each difference should be smaller in absolute value as Limited is compared to higher-level buckets, but the differences should remain negative (or approach zero—indicating that a high-limit plan is really no different than an unlimited plan).

Table 7.10 **Regression results from estimation of eq. (0.1)**

Variable	Model full	Restricted	Adjacent period regressions					
			93/95	95/96a	96a/96b	96b/97	97/98	98/99
Constant	3.282***	3.262***	4.044***	3.586***	3.104***	3.005***	2.991***	2.981***
Year95	0.313**	0.332**	0.058					
Year96a	–0.663**	–0.643**		–0.968***				
Year96b	–0.768***	–0.748**			–0.098***			
Year97	–0.776***	–0.757**				–0.028***		
Year98	–0.803***	–0.784***					–0.035***	
Year99	–0.881***	–0.863***						–0.073***
Limited	–0.036	0.030***	–1.039***	–0.131	–0.091	–0.070	–0.010	0.017
Hrs10 · L	–0.716***	–0.782***	0.019	–0.601***	–0.642***	–0.664***	–0.738***	–0.795***
Hrs20 · L	–0.432***	–0.499***	0.746*	–0.275*	–0.356***	–0.381***	–0.454***	–0.526***
Hrs35 · L	–0.196***	–0.263***	0.562	–0.102	–0.115	–0.138	–0.229***	–0.274***
Hrs50 · L	–0.030	–0.097***	1.025	0.101	0.071	0.029	–0.060	–0.126***
Hrs80 · L	–0.005	–0.057**		–0.025	0.038	0.038	–0.019	–0.053*
Hrs100 · L	0.104***			0.130	0.136**	0.133***	0.093***	0.070**
Hrs150 · L	0.055*		0.866**	0.116	0.084	0.077	0.041	0.018
Hrs250 · L	0.087***			0.241*	0.110	0.090*	0.062*	0.048*
Speed14	omitted		–0.433*	omitted				
Speed28	0.494**	0.494*	omitted	0.490*	omitted	omitted	omitted	omitted
Speed56	0.564**	0.564**				0.253***	0.123***	0.042***
Speed64	1.446***	1.446***		1.463***	0.977***		0.877***	0.852***
Speed128	1.998***	1.998***		1.999***	1.513***			
SpeedT1	4.748***	4.749***					4.270***	4.246***
No. of observations	19,199	19,199	71	1,322	4,097	6,635	9,471	11,218
Firms	5,575	5,575	45	705	2,988	3,596	4,186	5,137
R^2	0.534	0.533	0.402	0.496	0.548	0.233	0.576	0.593

Notes: Robust standard errors were used throughout, including corrections for clustering by firm. Not too much should be made of the R^2 measures across regressions. The higher R^2s occur in the regressions with the high-speed (64, 128, and 1544) plans where there is the greatest degree of price dispersion. The high R^2 is predominantly due to the dichotomous variables on the high-speed plans.

***Significant at p-values less than 1 percent.

**Significant at p-values less than 5 percent.

*Significant at p-values less than 10 percent.

The expected sign of the estimated coefficients on the speed indicator variables varies depending on which speed variable is omitted although in all cases we expect that higher-speed plans should have higher (more positive) coefficients than lower-speed plans.

The regression results based on equation (1) appear in table 7.10. The largest hourly limitation buckets have been discarded from the full model, so we focus on the coefficients of the restricted model and the accompanying adjacent period regressions. In the restricted regression (second column), all estimated coefficients are significant predominantly at the 1 percent or 5 percent level. The coefficients on each of the speed variables confirm the previously given hypothesis. The coefficients for the higher speeds exceed the coefficients for the lower speeds, and the pattern is monotonically increasing. The differences between the hourly limitation variables coefficients and the coefficient on limited also confirm the previously given hypothesis. Specifically, plans with a limited number of hours are priced at a discount to unlimited plans, but this discount diminishes as the number of included hours increases.[16]

The coefficients on the time indicator variables agree largely with the previously given hypotheses. Apart from the period from 11/1993 to 1/1995, the estimated coefficients indicate that quality-adjusted prices were falling, and the coefficients become successively more negative as time passes, consistent with the hypothesis described earlier.

There are two anomalies regarding the time indicator variable. The difference between the coefficients on year95 and year96a is very large (indicating that 5/1996 prices are 40 percent of the level of 1/1995 prices). This dramatic large price decline needs to be investigated further, which we do in the following.

One interesting result from the regression is that prices appear to increase on a quality-adjusted basis from 11/1993 up to 1/1995. This is a recurring pattern through many of the models. It can be explained by the fact that the nature of Internet access changed during the intervening time period. In 11/1993, the connections that were offered were all unix-to-unix copy (UUCP) connections that were capable of exchanging files, newsgroups, and e-mail but had no interactive features. By 1/1995, all of the plans in the data are for serial line Internet protocol (SLIP) access, which is a more highly interactive connection that has all the capabilities of

16. After testing the coefficients for each of the hourly buckets, all but the lowest four were dropped from the model. Results from hypothesis tests (For example, testing H0: Hrs80 · L – Limited = 0) indicated that these coefficients were not significantly different from the coefficient on Limited because they added no more information than the Limited variable. In the unrestricted models (both pooled and adjacent year models), the omitted hourly · Limited indicator variable is for all hourly limits above 250 hours. The omitted speed indicator variable is for plans offering 14.4k access. The omitted time period indicator variable (year) is for 11/1993.

UUCP plus additional features (including multimedia capabilities).[17] When the quality increase is the same across all of the sample products, then it cannot be identified separately in an hedonic regression from the time period indicator variable. Thus, in 1/1995 prices are higher than in 11/1993, but it is because Internet access technology has fundamentally improved. Because all the ISPs have adopted the new type of access and quality has increased, there is no heterogeneity in the sample and no way to control for the quality change.

The final six columns in table 7.10 display results from the adjacent period regressions. The pooled model is a significant restriction. In the pooled model, intercepts may vary across time, but the slopes with regard to the characteristics are restricted to be equal across periods. The adjacent period models relax this restriction so that the slopes are restricted to be equal only across two periods in any model. In the latter years of the data, this restriction does not affect the estimated coefficients much. The restriction does matter in the early years of the data. The estimate on Limited and some of the specific hour limitations varies paired-year to paired-year. As we have an abundance of data for later years and not in early years, we lose degrees of freedom with the adjacent year regressions during the earliest part of the sample, when we most need it.

Although some of the coefficients among the adjacent period models are statistically insignificant, the majority of coefficients confirm the stated hypotheses. The hourly limitations and speeds affect price in the same way as the pooled model. The price increase in 1/1995 is indiscernible because although the coefficient has a positive sign, it is not significant. The remaining interperiod indicators are of negative sign and the steep change in price from 1/1996 to 5/1996 is still present and very significant.

The coefficients from the hedonic regression model in equation (1) lead to a calculation of the estimated price indexes. These estimates are a consequence of the form of the model, plus a correction for the bias from exponentiating estimates of equation (1).[18] The models estimated in table 7.10 lead to estimated price indexes in table 7.1, where 11/1993 is our base time period. These are easily reconverted to period-to-period indexes. The models in table 7.10 that consider adjacent time periods also lead directly to estimates of the period-to-period indexes.

17. Looking carefully at the data and the advertisements, we observed that it is clear that firms were promoting SLIP accounts as a premium service (as opposed to UUCP). The data seem to indicate that they were charging a premium for it as well. Because there is no heterogeneity among the 1/1995 plan options, it is impossible to identify this effect and separate it from the time period constant.

18. See the discussion in Berndt (1991). The correction involves adding half of the squared standard error of the regression to the simulated price, correcting for the nonzero expectation of an exponential normal error. Sometimes this correction can make a big difference to the estimate for the price index. See Pakes (2002) for such an example. In our case it did not make much difference to the estimated price index.

Table 7.11 Direct price indices calculated from hedonic specification eq. (0.1)

Model	Restricted		93/95	95/96a	96a/96b	96b/97	97/98	98/99
Regression coefficients								
Jan. 1995	0.332		0.058					
May 1996	–0.643			–0.968				
Aug. 1996	–0.748				–0.098			
March 1997	–0.757					–0.028		
Jan. 1998	–0.784						–0.035	
Jan. 1999	–0.863							–0.073
Indices	Cumulative	Period-to-period	93/95	95/96a	96a/96b	96b/97	97/98	98/99
Nov. 1993	1.000							
Jan. 1995	1.394	1.39	1.06					
May 1996	0.526	0.38		0.38				
Aug. 1996	0.473	0.90			0.91			
March 1997	0.469	0.99				0.97		
Jan. 1998	0.457	0.97					0.97	
Jan. 1999	0.422	0.92						0.93

The results are shown in table 7.11. The table shows that the cumulative quality-adjusted index declines 58 percent to 0.422 in 1/1999 when compared to 1.00 in the base period, 11/1993. The individual period-to-period indexes display large variation during the initial periods, but then moderate to a 1–10 percent decline per period thereafter.[19] The calculations from the adjacent year regressions are largely the same as the results from the restricted model. The exception is the 11/1993 to 1/1995 index, which displays a less extreme rise during the time period under the adjacent years method.

The extreme drop in the index from 1/1995 to 5/1996 is still present and deserves an explanation. Two factors produce this drop. First, there is a large difference in the number of firms. The observations from January 1995 describe a couple dozen ISPs selling connections to the Internet for purposes of using a Mosaic browser, or a beta version of the Netscape browser, and basic e-mail client. By May of 1996, most of the new entrants are small ISPs selling connections for the Netscape browser and e-mail. Second, by the spring of 1996, AT&T WorldNet has entered home service and the market is heading toward a twenty-dollar price point for basic service at 28k speeds. Even without controlling for quality, table 7.6 shows

19. It is difficult to compare all of the adjacent period indices. Each time period is of different length, so for accurate and easier comparison, it would be correct to annualize the changes.

that prices declined during this period for both unlimited and limited plans. However, table 7.6 does not control for precise levels of limits. With such raw data, it is not a surprise that estimated price declines by more than half once hedonic estimates control for the same level of limits.

This finding is consistent with popular perceptions about the growth in the Internet, usually timed to Netscape's initial public offering (IPO) in August 1995. To our surprise, the price declines do not stop after the spring of 1996. We also find a 20 percent decline in price per unit of ISP quality for the thirty-three-month period between spring 1996 and early 1999.

7.4.4 Hedonic Price Indexes with Random Effects

The data set covers very few characteristics of each plan or product, and there are undoubtedly unmeasured elements of quality that are missing from the model specified in equation (1). One concern is that unmeasured quality at an ISP is roughly the same across contracts and across years. In other words, if an ISP guaranteed high-quality service (e.g., large modem banks that rarely have busy signals) or offers the same enticements to all its customers (e.g., large e-mail accounts), then this quality will be unmeasured for contracts coming from the same firm. Because of the (unbalanced) panel nature of the data set, the firm-specific unmeasured quality can be at least partially corrected using a random-effects model, where the unmeasured error is assumed to be the same for all contracts offered by one firm.

In this case, the regression model given above in equation (1) will be changed by adding a firm-specific error term (υ_i).

$$(2) \qquad \ln P_{ijt} = \alpha_0 + \alpha_t \text{Year}_{ijt} + \beta_1 \text{Limited}_{ijt} + \beta_{2-9} d\text{Hrly}_{ijt} \cdot \text{Limited}_{ijt} + \gamma_{1-5} d\text{Speed}_{ijt} + \upsilon_i + \varepsilon_{ijt}$$

This specification will emphasize within variation in contracts in situations where we observe multiple contracts from the same firm. Because much of the data comes from small firms who do not appear often in the data set, it was difficult to predict whether this specification will change the estimates much.

We have estimated both the fixed- and random-effects specifications of model (2)—using the standard subroutines in Stata. The regression results are shown in table 7.12. The Breusche-Pagan test indicates that the hypothesis that $\text{var}(\upsilon_i) = 0$ can be rejected with better than 1 percent certainty. The Hausman specification test indicates that the random-effects specification is preferred.[20] We therefore examine the random effects results in further detail.

20. Intuitively speaking, it is easy to see why random effects is preferred in this data set. The fixed-effect model throws out all the observations where an ISP has one contract. In contrast, the random-effects specification employs the variation between these ISPs who offer only one contract, while the fixed-effect specification does not.

Table 7.12 Regression results from estimation of eq. (0.2)

				Adjacent period regressions—random effects specification					
Variable	Models full, FE	Full, RE	Restricted, RE	93/95	95/96a	96a/96b	96b/97	97/98	98/99
Constant	3.009***	3.136***	3.125***	3.964***	3.538***	3.104***	2.998***	2.986***	2.975***
Year95	0.335***	0.299***	0.309***	0.119					
Year96a	–0.428***	–0.516***	–0.505***		–0.824***				
Year96b	–0.477***	–0.586***	–0.575***			–0.097***			
Year97	–0.477***	–0.590***	–0.579***				–0.023***		
Year98	–0.499***	–0.613***	–0.603***					–0.030***	
Year99	–0.563***	–0.684***	–0.674***						–0.064*
Limited	–0.034*	–0.038**	–0.003	–0.761***	–0.031	–0.002	–0.003	0.016	0.021***
Hrs10 · *L*	–0.663***	–0.682***	–0.717***	–0.260	–0.707***	–0.731***	–0.711***	–0.645***	–0.688***
Hrs20 · *L*	–0.299***	–0.350***	–0.385***	0.597*	–0.363***	–0.446***	–0.391***	–0.396***	–0.416***
Hrs35 · *L*	–0.094***	–0.147***	–0.181***	0.204	–0.173	–0.205***	–0.172***	–0.215***	–0.229***
Hrs50 · *L*	–0.055*	–0.044*	–0.079***	0.543	–0.018	–0.019	–0.043	–0.101***	–0.124***
Hrs80 · *L*	–0.017	–0.007	–0.034*		–0.100	–0.030	0.010	–0.044*	–0.056**
Hrs100 · *L*	0.005	0.056**							
Hrs150 · *L*	0.029	0.040*							
Hrs250 · *L*	0.074***	0.079***	0.044**	omitted	0.177	0.021	0.030	0.024	0.018
Speed14	omitted	omitted	omitted	–0.401	omitted				
Speed28	0.464***	0.450***	0.450***		0.391	omitted	omitted	omitted	omitted
Speed56	0.538***	0.522***	0.523***				0.276***	0.139***	0.048***
Speed64	1.401***	1.389***	1.390***		1.367***	0.978***		0.917***	0.883***
Speed128	1.944***	1.934***	1.934***		1.897***	1.514***			
SpeedT1	4.697***	4.688***	4.689***					4.254***	4.237***
No. of observations	19,199	19,199	19,199	71	1,322	4,097	6,635	9,471	11,218
Firms	5,575	5,575	5,575	45	705	2,988	3,596	4,186	5,137
R^2	0.529	0.532	0.532	0.378	0.496	0.547	0.233	0.574	0.593

Note: See notes to table 7.10.

***Significant at less than 1 percent.

**Significant at less than 5 percent.

*Significant at less than 10 percent.

The random-effects regression results does not differ from the earlier results much except in one key place. The main difference is that the drop in prices ascribed to 1/1995 to 5/1996 period is dampened. The pattern among the time period indicator variables is maintained. The significance and pattern among the plan limitations fits with earlier hypotheses and follows the pattern of the earlier results. The estimated coefficients on the speed indicator variables also follow the pattern outlined in the preceding hypotheses and reconfirm the results from the earlier regression. Table 7.12 also reports the adjacent period regression results. They follow the same pattern of the earlier results with, again, the main difference being a dampened drop in the index from 1/1995 to 5/1996.

Using the regression results from the random-effects restricted model and the random-effects adjacent period model, we have recalculated the cumulative and period-to-period indexes in table 7.13, which are biased predictors under the stochastic specification. Even then, the results are qualitatively similar. The cumulative index drops from 1.00 in 11/1993 to 0.51 in 1/1999, imply that the quality-adjusted prices fell by 49 percent over this period. As before, the period-to-period indexes swing wildly in the initial periods but then settle to steady declines of almost 7 percent per year on average. The notable difference between the random-effects model results and the earlier results is shown in the period-to-period index from 1/1995 to 5/1996. Without random effects, the index declined to 0.38 over this single period. Taking other unmeasured elements of firm quality into ac-

Table 7.13 **Direct price indices calculated from estimation of hedonic eq. (0.2)**

Model	Restricted		93/95	95/96a	96a/96b	96b/97	97/98	98/99
Regression coefficients								
Jan. 1995	0.309		0.119					
May 1996	–0.505			–0.824				
Aug. 1996	–0.575				–0.097			
March 1997	–0.579					–0.023		
Jan. 1998	–0.603						–0.03	
Jan. 1999	–0.674							–0.064
Indices	**Cumulative**	**Period-to-period**	**93/95**	**95/96a**	**96a/96b**	**96b/97**	**97/98**	**98/99**
Nov. 1993	1.000							
Jan. 1995	1.362	1.36	1.13					
May 1996	0.604	0.44		0.44				
Aug. 1996	0.563	0.93			0.91			
March 1997	0.560	1.00				0.98		
Jan. 1998	0.547	0.98					0.97	
Jan. 1999	0.510	0.93						0.94

count dampens this drop in the price index. In table 7.13, the index only drops to 0.44. The index values calculated from the adjacent period models are all nearly the same as the single period indexes derived from the pooled model. The only difference is the 11/1993 to 1/1995 index, but this is an insignificant coefficient in the adjacent period regression.

It appears, therefore, that firm-level random effects slightly alter the quality-adjusted price index, but not by much. The basic reason is that there is so much entry and exit in the sample. With thousands of new firms each year, it is not possible to get a sufficient number of repeat observations on enough firms to measure changing quality. In more recent times, when the set of firms is so stable we would expect this correction to have a greater effect, but it does not due to the presence of many firms offering only a single contract.

We conclude that accounting for measured and unmeasured quality is a simple and useful addition to the tools for calculating price indexes. It is a further refinement of the standard hedonic techniques, and it is not difficult to implement. To be sure, in this example, it did not yield a large difference in estimates, but it was enough to raise questions about the quality of estimates early in our sample. It is worthwhile to further explore in service industries where quality of service is correlated across all services offered by one firm.

7.4.5 Analysis of Subsample with Speeds below 28.8k

Because change in modem speeds is coincident with the transition to unlimited plans, we were aware of the possibility that the preceding results could be an artifact of change in modem speeds. We assessed this empirically by examining contracts only for 28.8k service.

We have repeated the random-effects modeling (from equation [2]) with a subsample of plans that offer connection speeds at or below 28.8k. Table 7.14 presents the regression results from this subsample. The results shown for the subsample correspond well to the full sample regression. The coefficients display the same pattern as the earlier full sample regressions, supporting the preceding hypotheses. Quality-adjusted prices decline over the sample period, with the coefficient for each time period being more negative than the previous one. The apparent quality-adjusted price rise from 11/1993 to 1/1995 persists, suggesting that this pattern is not an artifact of the higher-speed plans. The plans with hourly limitations reconfirm the pattern of the full sample.

Additional limited hours are consistently more valuable, with the highest limited plans nearly indistinguishable from unlimited plans. In the pooled regression for the subsample, speed of a plan is handled using a dichotomous variable indicating whether a plan is 14.4k or 28.8k. In the regression, the 28.8k plan indicator was the omitted category. The only result in this subsample that conflicts with the earlier results is the coefficient on

Table 7.14 **Regression results from estimation of eq. (0.2): 28.8k speed plans only**

			Adjacent period regressions					
Variable	Model (0.2) full sample	28.8 (1.2) subsample	93/95	95/96a	96a/96b	96b/97	97/98	98/99
Constant	3.136***	3.110***	3.614***	3.566***	3.088***	2.997***	2.978***	2.968***
Year95	0.299***	0.305***	0.049					
Year96a	–0.516***	–0.604***		–0.937***				
Year96b	–0.586***	–0.677***			–0.073***			
Year97	–0.590***	–0.697***				–0.020***		
Year98	–0.613***	–0.704***					–0.007**	
Year99	–0.684***	–0.738***						–0.036***
Limited	–0.038**	–0.048***	–0.912***	–0.128	–0.082**	–0.095***	0.004	0.004
Hrs10 · *L*	–0.682***	–0.725***	–0.119	–0.603***	–0.680***	–0.650***	–0.743***	–0.793***
Hrs20 · *L*	–0.350***	–0.353***	0.742**	–0.279***	–0.363***	–0.296***	–0.430***	–0.477***
Hrs35 · *L*	–0.147***	–0.164***	0.364	–0.100	–0.134***	–0.103***	–0.228***	–0.252***
Hrs50 · *L*	–0.044*	–0.026	0.721	0.101	0.034	0.061*	–0.068**	–0.113***
Hrs80 · *L*	–0.007	0.002		–0.027	0.044	0.089***	–0.054**	–0.052**
Hrs100 · *L*	0.056**	0.060***		0.129	0.102**	0.153***	0.009	0.065***
Hrs150 · *L*	0.040*	0.043**	0.829	0.114	0.066	0.082**	0.028	0.014
Hrs250 · *L*	0.079***	0.082***		0.242**	0.044	0.114***	0.035	0.052**
Speed14	omitted	0.566***	0.414	0.479***				
Speed28	0.450***	omitted	omitted	omitted				
Speed56	0.522***							
Speed64	1.389***							
Speed128	1.934***							
SpeedT1	4.688***							
No. of observations	19,199	13,484	71	741	3,516	6,189	7,339	6,530
Firms	5,575	5,282	45	697	2,981	3,590	4,173	4,835
R^2	0.532	0.533	0.394	0.291[a]	0.257	0.242	0.2251	0.209

Notes: See notes to table 7.10. For estimates in 1996 and later the only available speeds are 28.8k and higher. Because all high-speed plans are dropped from the data, any speed variable is collinear with the constant term in the regression.

[a]The drop in R^2 here and in the following adjacent year regressions is due to the loss of heterogeneity in plan speeds. In this regression, only 42 14.4k plans remain. The balance of the observations are 28.8k speed.

***Significant at less than 1 percent.

**Significant at less than 5 percent.

*Significant at less than 10 percent.

14.4k speed plans. Recall the earlier argument that put forward the hypothesis that faster plans should command a price premium. To be consistent with that hypothesis, the coefficient on Speed14 should be negative (because Speed28 is the omitted dichotomous variable). However, in table 7.14, this estimated coefficient is positive and statistically significant.

Coefficient estimates from the adjacent period regressions are also shown in table 7.14. Similar to the pooled model, these regressions on the subsample largely reconfirm the results from the full sample. Prices decline over time, and larger limits are more valuable. In the 95/96a regression results, a similar positive and significant coefficient appears for Speed14. This again is unexpected and runs contrary to the preceding hypothesis. The remaining adjacent period regressions do not control for speed of plan because only 28.8k speed plans are considered in the remaining part of the subsample.

Using the regression results from the random-effects restricted model and the random-effects–adjacent-period model, we have recalculated the cumulative and period-to-period–quality-adjusted price indexes; they appear in table 7.15. The results are consistent with the results from the full sample. The cumulative index reveals that prices in this subsample drop from 1.00 in 11/1993 to 0.48 in 1/1999. This implies that the estimated quality-adjusted prices have dropped by 52 percent over the sample period. This index is consistent with the full sample cumulative index, which

Table 7.15 Direct price indices calculated from estimated coefficients in hedonic eq. (0.2): 28.8k speed plans only

Model	Restricted		93/95	95/96a	96a/96b	96b/97	97/98	98/99
Regression coefficients								
Jan. 1995	0.305		0.049					
May 1996	–0.604			–0.937				
Aug. 1996	–0.677				–0.073			
March 1997	–0.697					–0.02		
Jan. 1998	–0.704						–0.007	
Jan. 1999	–0.738							–0.036
Indices	**Cumulative**	**Period-to-period**	**93/95**	**95/96a**	**96a/96b**	**96b/97**	**97/98**	**98/99**
Nov. 1993	1.000							
Jan. 1995	1.357	1.357	1.050					
May 1996	0.547	0.403		0.392				
Aug. 1996	0.508	0.930			0.930			
March 1997	0.498	0.980				0.980		
Jan. 1998	0.495	0.993					0.993	
Jan. 1999	0.478	0.967						0.965

dropped by 49 percent over the same period. The adjacent period calculations are consistent with the full sample results. The price index increases between the first two periods, which is followed by a sharp decline and then steady annual declines of 1–7 percent thereafter.

In summary, repeating the analysis of the random-effects estimation of equation (2) on a subsample of plans with speeds at or below 28.8k yields results consistent with the full sample. This suggests that the treatment of the hourly limitations in the higher-speed plans is not significantly skewing the results for the full sample. It also suggests that although many new entrants appeared over time offering higher-speed plans, the pattern of quality-adjusted prices was not different between the "old" and "new" providers. The most important conclusion is that the unobserved limits for the high-speed plans are not affecting the overall results.

7.4.6 Weighted Hedonic Price Indexes

As noted earlier, we were skeptical of calculating a price index with market shares or revenue shares of the product or service. However, even with such skepticism, we would still prefer to calculate such an index and see what difference, if any, such weighting makes. Unfortunately, the *Boardwatch* ISP pricing data did not contain such information. Because the listings are organized by area codes served, we considered using the number of area codes served by each ISP as a coarse market share weighting. However, close inspection of this procedure reveals that it is fraught with problems.

First, even in the best of times, it would be a coarse measure because population density is not uniform across area codes and intra-area code market shares are not evenly split across population areas. Moreover, the number of potential area codes in which an ISP can offer service is capped at the maximum number of area codes in the United States, just over 200 (and growing slightly over the years of the sample). So the number only captures a difference between extremes, such as local and national ISPs. Prior to 1995, all ISPs were local, so the number does not really weight between ISPs until after 1995.

Second, the interpretation of the area code variable changes when many facilities-based firms initiated programs to rent their backbones and modem banks to others, who could in turn offer access elsewhere in the country. This is especially common in the later years of our sample (1997–1999), rendering the area code variable almost meaningless as a measure of market share. That is, the footprint of area code coverage for many firms became disconnected from ownership of facilities. Hundreds of firms advertised a national footprint in 1998 and 1999, even small ISPs with only a few customers who had just entered service.

We conclude, therefore, that the area codes provide equal weight of all ISPs prior to 1995 and a meaningless weight after 1997 and beyond. We also conclude that the area code variable does not provide a consistent interpretation over time. Hence, we have abandoned the proposal of using number of area codes as a measure of market size or share.

Another (and simpler) alternative is to weight the plans based on the connection speed offered. Such data is available from the Graphics, Visualization, and Usability (GVU) lab WWW surveys (Georgia Institute of Technology 1997). The GVU laboratory at the Georgia Institute of Technology has conducted a WWW users survey semiannually since January 1994. The surveys cover a broad range of topics but, one portion of the survey inquires about online services, Internet usage, and speed of connection to the Internet. The GVU has collected information on Internet connection speeds since 1995. Their data are shown in table 7.16.

The split of plans between 28.8k and 56k in the 1997–1999 periods of the data set roughly mirrors the data in the GVU survey. Taking 28.8k and 33.6k to be equivalent speed plans, the comparative proportions are shown in table 7.17. The only substantial difference between our data and the GVU survey occurs in 1997. It appears that in 1997, the *Boardwatch* data overrepresent the prevalence of 56k connections by about 2.5 times. It is clear that the proportions in 1998 and 1999 are roughly the same. Because 1997 was not a year of dramatic change in measured contracting behavior, such as hourly limitations, the impact on a recalculated index is minimal.[21]

We also considered different schemes that alter the index more directly as a function of whether the ISP is young, old, exiting, or innovating with a new product or service. These issues delve into questions about the interaction between the changing industrial organization of this market and the pricing of firms, a topic on which we focus in our companion paper (Stranger and Greenstein 2004).

7.5 Conclusion

Internet service providers are a necessary component of Internet infrastructure. They enable businesses and individuals to connect to the Internet. The earliest history for ISPs dates back to late 1992-early 1993. This paper investigates pricing trends in this nascent industry over the time period from 1993 to 1999, with attempts to incorporate adjustment for quality change.

Using a new data set, we have computed a variety of price indexes, ranging in sophistication from very crude averages to quality-adjusted ones based on hedonic models. The results show decisively that ISP prices have been falling rapidly over time. The bulk of the price decline is in the early years of the sample, especially the period between early 1995 and spring of 1996, but a significant and steady decline continues throughout. We con-

21. Available from the author upon request.

Table 7.16 **GVU WWW survey data: Internet connection speeds**

ISP	Date	Unknown	<14.4	14.4	28.8	33.6	56	128	1mb	4mb	10mb	45mb	Total
Jan. 1995	April 1995	517	402	2,930	810		284	83	393	138	806	84	6,447
	Oct. 1995	1,514	140	3,407	2,822		397	188	528	234	995	156	10,381
May 1996	April 1996	451	32	1,106	1,749		155	129	541	77	133	29	4,402
Aug. 1996	Oct. 1996	644	32	1,579	4,291		240	232	748	120	150	50	8,086
March 1997	April 1997	1,272	42	1,393	4,584	2,558	362	464	1,541	280	276	112	12,884
	Oct. 1997	1,471	17	324	1,368	1,753	377	201	591	102	117	44	6,365
Jan. 1998	April 1998	544	11	243	1,558	1,611	1,242	182	707	124	133	47	6,402
Jan. 1999	Oct. 1998	85	2	37	349	388	760	98	288	71	47	82	2,207

Source: Georgia Institute of Technology (1997).

Note: Data presented is extracted from surveys 3–10 and represents counts of respondents from the United States only.

Table 7.17 **Comparison of *Boardwatch* to GVU plan speeds**

Boardwatch ISP data				GVU survey data			
Date	28.8 plans	56k plans	Ratio	Date	28.8–33.6 plans	56k plans	Ratio
March 1997	3,367	446	7.55	April 1997	7,142	362	19.73
Jan. 1998	3,972	1,554	2.56	April 1998	3,169	1,242	2.55
Jan. 1999	2,562	3,006	0.85	Oct. 1998	737	760	0.97

Source: Georgia Institute of Technology (1997).

clude that ignoring aspects of quality underestimates the price declines. It also alters the timing of the measured declines.

We view this paper as only one small step in a much larger research enterprise, measuring the economic benefits from improvement in the Internet. During the latter half of the 1990s, the Internet underwent dramatic changes. The quality of what users got from the Internet skyrocketed. Over the next half decade, many users adopted the Internet who had never used it.

Constructing a cost-of-living index for the user's experience would face many challenges. Such an index would have to measure the change in the cost of living arising from the growth of the use of the Web, as well as the economic change in user experience from the rapid infusion of e-mail and browsing into everyday life. Not trivially, no price index could possibly accomplish that goal without accounting for changes in speed, changes in availability, changes in the quality of standard contract features, changes in reliability and other nonprice dimensions of use, changes in the size of the network effects, and other features of user experience.

References

Augereau, Angelique, and Shane Greenstein. 2001. The need for speed in emerging communications markets: Upgrades to advanced technology at Internet service providers. *International Journal of Industrial Organization* 19:1085–1102.

Berndt, Ernst R. 1991. *The practice of econometrics—Classic and contemporary.* Reading, MA: Addison-Wesley.

Berndt, Ernst R., and Zvi Griliches. 1993. Price indexes for microcomputers: An exploratory study. In *Price measurements and their uses,* ed. M. Foss, M. Manser, and A. Young, 63–93. Studies in Income and Wealth, vol. 57. Chicago: University of Chicago Press.

Berndt, Ernst R., Zvi Griliches, and Neal J. Rappaport. 1995. Econometric estimates of price indexes for personal computers in the 1990s. *Journal of Econometrics* 68:243–68.

Berndt, Ernst R., and Neal J. Rappaport. 2001. Price and quality of desktop and mobile personal computers: A quarter century historical overview. *American Economic Review* 91 (2): 268–73.

Boardwatch. 1996–1999. *Directory of Internet service providers.* Littleton, CO: Boardwatch.

Clemente, Peter C. 1998. *The state of the net: The new frontier.* New York: McGraw-Hill.

Cusumano, Michael, and David Yoffie. 1998. *Competing on Internet time: Lessons from Netscape and its battle with Microsoft.* New York: The Free Press.

Downes, Tom, and Shane Greenstein. 2002. Universal access and local commercial Internet markets. *Research Policy* 31:1035–52.

Diewert, Erwin. 1987. Index numbers. In *The new Palgrave: A dictionary of economics.* Vol. 2, ed. J. Eatwell, M. Milgate, and P. Newman, 767–80. London: Macmillan.

Georgia Institute of Technology. 1997. *GVU's WWW user survey: Surveys 3–10.* Graphics, Visualization and Usability Lab, Georgia Institute of Technology. http://www.cc.gatech.edu/gvu/user_surveys/.

Goldfarb, Avi. 2004. Concentration in advertising-supported online markets: An empirical approach. *Economics of Innovation and New Technology* 13 (6): 581–94.

Greenstein, Shane. 2000a. Building and developing the virtual world: The commercial Internet access market. *Journal of Industrial Economics* 48 (December): 373–90.

———. 2000b. Valuing the net: What determines prices for dial-up Internet access? Northwestern University, Working Paper.

———. 2001. Commercialization of the Internet: The interaction of public policy and private actions. In *Innovation, policy, and the economy,* ed. Adam Jaffe, Josh Lerner and Scott Stern, 151–86. Cambridge, MA: MIT Press.

———. 2002. *Is the price right? The CPI for Internet access. A report for the Bureau of Economic Analysis.* Washington, DC: Bureau of Economic Analysis.

Griliches, Zvi. 1961. Hedonic price indexes for automobiles: An econometric analysis of quality change. In *The price statistics of the federal government,* 173–96. New York: National Bureau of Economic Research.

Krol, Ed. 1992. *The whole Internet.* Sebastopol, CA: O'Reilly & Associates.

———. 1994. *The whole Internet.* 2nd ed. Sebastopol, CA: O'Reilly & Associates.

Marine, April, Susan Kilpatrick, Vivian Neou, and Carol Ward. 1993. *Internet: Getting started.* Indianapolis, IN: Prentice Hall PTR.

Meeker, Mary, and Chris Dupuy. 1996. *The Internet report.* New York: HarperCollins.

National Telecommunications Information Administration. 2001. A nation online: How Americans are expanding their use of the Internet. http://www.ntia.doc.gov/reports.html.

O'Donnell, Shawn. 2001. Broadband architectures, ISP business plans, and open access. In *Communications policy in transition: The Internet and beyond,* ed. Benjamin Compaine and Shane Greenstein, 35–58. Cambridge, MA: MIT Press.

Pakes, Ariel. 2002. A reconsideration of hedonic price indices with an application to PCs. NBER Working Paper no. 8715. Cambridge, MA: National Bureau of Economic Research.

Prud'homme, Marc, and Kam Yu. 1999. Towards an elementary price index for Internet services. Statistics Canada. Unpublished Manuscript.

Raff, Daniel M. G., and Manuel Trajtenberg. 1997. Quality-adjusted prices for the American automobile industry: 1906–1940. In *The economics of new goods,* ed.

Timothy Bresnahan and Robert Gordon, 71–108. Chicago: University of Chicago Press.
Schneider, Karen G. 1996. *The Internet access cookbook.* New York: Neal-Schuman.
Stranger, Greg, and Shane Greenstein. 2004. Pricing in the shadow of firm turnover: ISPs in the 1990s. Northwestern University. Mimeograph.
U.S. Department of Commerce. 2003. *Statistical abstract of the United States.* 123rd ed. Washington, DC: Government Printing Office.