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Pricing at the On-ramp to the Internet: Price Indices for ISPs during the 1990s.

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Preliminary and not for quotation.
Comments Welcome.

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I. Introduction

Prior to commercialization the Internet was available for only researchers and educators. Less than a decade after commercialization, more than half the households in the US were online (NTIA, 2001). This growth presents many challenges for measuring the contribution of the Internet to GDP. This study considers the formulation of consumer price indices for commercial Internet access.

No simple measurement strategy will suffice for formulating price indices for Internet activity. On average more than two thirds of time on line is spent at so-called free sites. Many of these are simply browser-ware 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 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, 2000).

There is one place, however, where almost every household transacts money for service. Internet service providers (ISP's) 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 (Clement, 1998). Far more than 90% of household use was affiliated with commercial providers (NTIA, 2000). This continues today.

This paper investigates the pricing behavior at ISPs from 1993 to 1999 with the goal of generating price indices. 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 on line provides follow the same technological trajectory. This helps us construct indices without data on market share, which we lack. Until this merger we can test for (and correct for) the most overt potential biases, as we show below. Third, and somewhat independently, broadband began to diffuse just near the end of our sample. Though broadband has not been a huge hit (as of this writing), after a few years it did go to enough households (7-8 million) to influence Internet price indices and alter the procedures done in this paper. Finally, mid 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 dataset about the early period, we compute a variety of price indices 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, but a significant and steady decline continues throughout. We test 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 and long-term sample of U.S. based ISP's.[1] This setting gives rise to a combination of familiar and unique challenges for measurement. To be sure, there have been many papers on hedonic price indices in electronic goods and we borrow many lessons learned from those settings. However, this is one of the first papers to investigate and apply these hedonic methods to establish price indices for a service good. In this setting, the key features of the service are not necessarily physical attributes of a product, but rather features of contract for service. Moreover, the locus of qualitative change can shift quite rapidly from year to the next, as predominant contracting modes change, as new entrants experiment with new service models for delivery, and as technical change alters the scope of possible services available to ISPs.

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 test different ways to control for unobserved quality at the level of the ISP. We also assess the contribution to price changes from different distinct strategies (at the firm level) of new entrants and incumbents. We find that new firms enter the market at a small but significant price discounts to established incumbents. Related, when new products/technologies are introduced, they are priced at a significant price premium to the existing offerings. In contrast, we find that the ISPs who survive tend to have higher prices than younger firms. Early in our sample, when new entrants gain market share, prices are driven down by entry. Later in our sample, as incumbent firms manage to solidify their market shares in a growing market, the pricing of incumbent firms takes on greater importance.

[1] There is a closely related paper about prices at Canadian ISPs. See Prud'homme and Yu, 1999.

II. A history of Internet Service Providers in the US

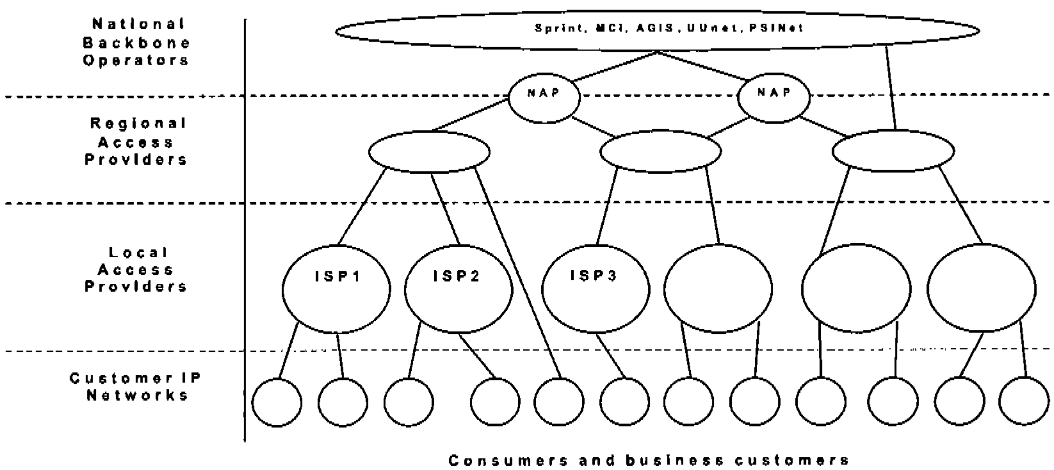
The Internet began as a defense department research project to develop networking technologies more reliable than existing daisy-chained networks. The first product of this research was ARPAnet. Later continuing research was supported by the National Science Foundation, which established NSFnet, another experimental network for universities and their research collaborators. NSF's charter prohibited private users from using the infrastructure for commercial purposes, which was not problematic until the network grew. By 1990 the TCP/IP network had reached a scale that would shortly exceed NSF's needs and, possibly, managerial reach. 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 and the commercialization of an unanticipated innovation, the browser (Greenstein, 1995).

II.1. The origins of Internet functionality and pricing.

A household uses commercial Internet provides for many services, most of which had their origins in the ARPAnet or NSFnet. The most predominant means of communications is email. The email 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 or forums. Messages are posted for all to see and readers can respond or continue the conversation with additional postings. Chat rooms and IRC 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 chat-like sessions.

Some tools have been supplanted, but the most common are WWW browsers, gopher, telnet, ftp, archie, and wais. Browsers and content have grown in sophistication from the one-line CERN interface, through Lynx and Mosaic to the most up to date versions of Netscape Navigator and Internet Explorer. The Internet and WWW are now used for news and entertainment, commerce, messaging, research, application hosting, videoconferencing, etc. The availability of rich content continues to grow, driving demand for greater bandwidth and broadband connectivity.



Pricing by Internet Service Providers requires a physical connection. The architecture of the Internet necessitates this physical connection. Both under the academic and commercial network, as shown in Figure 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 sub-network, connecting their POP's and servers with IP networks. These local access providers get their connectivity to the wider Internet from other providers further upstream, either regional or national ISP's. Regional networks connect directly to the national backbone providers. Private backbone providers connect to public (government) backbones at network access points.

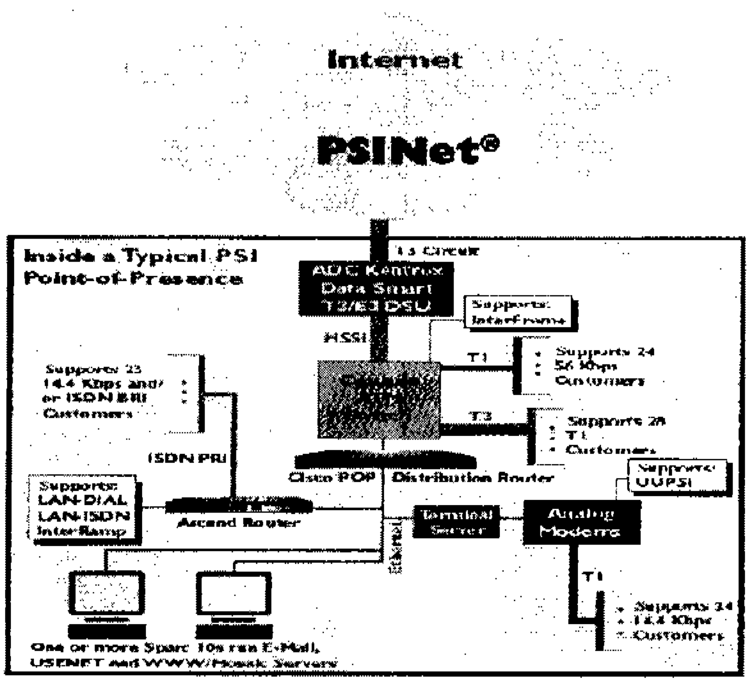
II.2. The emergence of pricing and services at commercial firms.

For purposes of this study, an ISP is a service firm that provides its subscriber customers with access to the Internet. These are several types of 'access providers. ' At the outset of the industry, there was differentiation between commercial ISP's , "online service providers," ("OSP's" - Meeker 1996) and firms called "commercial online services" by Krol (1992). . ISPs offer Internet access to individual, business and corporate Internet users, offering a wide variety of services on top of access, which will be discussed below. Most OSP's evolved into ISPs around 1995-96, offering the connectivity of ISP's with a greater breadth of additional services and content.

Most households physically connect through dial-up service, although both cable and broadband technologies gained popularity near the end of the millennium. 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 CLEC's, RBOC's, and other communications firms. Large ISP's 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 ISP's generally are responsible for the call handling equipment (modems, routers, access concentrators, etc.) and its own upstream connection to the Internet, but may lease services in some locations for traveling customers.

Charging for access occurs at the point of access by phone. Internet service providers generally maintain points of presence (or 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 don't 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.

Figure 1 – Typical PSInet point-of-presence (circa 1996)



Many ISPs provide services that compliment 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. ISP's 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, web development and design. Many larger ISP's also bundle Internet software with their subscriptions. This software is either private-labeled or provided directly by third parties. Some of it is provided as standard part of the ISP contract and some of it is not (Greenstein, 1999). Some ISP's also recommend and sell customer equipment they guarantee will be compatible with the ISP's access equipment.

There are many different types of ISP's. The national private backbone providers (i.e. MCI, Sprint, etc) are the largest "ISP's." The remaining ISP's range in size/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, etc. The majority of providers provided limited geographic coverage. A larger wholesale ISP serves all ISP's further up the connectivity chain. Local ISP's get connectivity from regional ISP's who connect to the national private backbone providers. A large dialup provider may have a national presence with hundreds of POP's, while a local ISP may have only 1 POP and serve a very limited geographic market. Ultimately ISP's are selling and servicing connectivity to the Internet. All computers that reach the Internet are connected through some form of ISP.

It is difficult to describe modal pricing behavior for ISPs because there has been so much change over time. The most likely date for the existence of the first commercial ISPs is 1991-92, when the NSF began to allow commercialization of the Internet.[2] In one of the earliest Internet "handbooks," Krol (1992) lists 45 North American providers (8 have national presence). In the second edition of the same book, Krol (1994) lists 86 North American providers (10 have national presence). Marine (1993) lists 28 North American ISP's and 6 foreign ISP's. Schneider (1996) lists 882 U.S ISP's and 149 foreign ISP's. Meeker (1996) reports that there are over 3000 ISP's, and the Fall 1996 *Boardwatch Magazine's Directory of Internet Service Providers* lists 2934 firms in North America. This rapid growth was accompanied by vast heterogeneity in service, access, and pricing. Descriptions of regional/wholesale connectivity (see of *Boardwatch Magazine's Directory of Internet Service Providers (1996)*) imply that these contracts are short-term.

II.3. Pricing behavior at commercial firms and how it changed.

Initially, the ISP pricing model mimicked what came before 'Internet access.' These services have similarities to Internet access, but they also differed from what came next. 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 email, downloaded/uploaded files and occasionally participated in 'chat' rooms. The private networks or OSP's (e.g. AOL, CompuServe, Genie, and Prodigy) had similar functionality, with segregated content areas for different interests. Users could post and download files, 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, email, 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 when much of the online time is not idle 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 1990's speeds moved from 300 bps to 1200, 2400, 4800, 9600 and eventually to 14'400 and 28'800. The latter two were the norm of the mid 1990s. 56K (or realistically, 43,000bps) became the norm in the latter part of the 1990s.

As speeds changed and as behavior changed, there were a variety of pricing plans. These changed over time. Early on price plans began to offer larger amounts of hours that were

[2] The earliest ISP's were academic institutions that offered access to students and faculty over campus networks and through dial-in servers from off-campus. PSINet, a now bankrupt ISP, used to claim that it was the first commercial

included in the monthly fee and offered marginal pricing above those included hours. These plans offered traditional non-linear 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 below.

Only later, after the ISP industry began to develop, 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 POP's because the marginal cost to the user was zero and some users remained online much longer than the companies had expected. ISP's reacted to this behavior by introducing plans with high initial hourly limits and high marginal pricing above the limit. In these plans the marginal cost of an extra hour exceeded the average cost of the included hours.

In the later part of the 1990s the pricing of contracts depended less on speed because the speed experienced by users was more dependent on customer modems than on POP equipment. The menus of plans commonly include 'unlimited' use plans for $15-$20 per month. Some ISP's also offer high limit fixed price plans with and without 'penalties' above the monthly limit. The menu usually also includes a plan aimed at infrequent or low volume users. These plans may cost $5-$10 and include 5-15 hours of online usage with marginal pricing above those limits. Some menus include intermediate plans that fall somewhere between those above.

II.4. The structure of the ISP market also influenced pricing.

The ISP market began to experience explosive entry around 1994-95, accelerating after the commercialization of the browser around the same time (Greenstein, 2001). Early movers in

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ISP, offering connection in 1991, though we have never found precise documentation for this claim this market all 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 success over the next few years. When MCI and Uunet eventually became part of WorldCom in 1998 they became the largest backbone providers in the US and one of the largest resellers of national POPs to other firms. When IBM sold its facilities to AT&T in 1997, it became one of the largest business providers of access in the US.

A signal event in 1995-96 was the entry of AT&T's Worldnet service, which was explicitly marketed at households. It became associated with reliable email and browsing, as well as flat rate pricing at $20 a month. This service eventually 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 meant that no player achieved dominance for several years.

The on-line 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 excuse to alter their service's basic features. When AOL converted fully to Internet access in 1996 it experienced quite a difficult transition because management under-anticipated their own user's response 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 MSN's expense, who had been one of its main competitors until that point (Cusumano and Yoffie. 1999). In 1998 AOL bought CompuServe, a merger that, in retrospect, initiated it on the path towards solidifying its leadership.

To be sure, this was not a self-evident outcome until the end of the Millenium. Neither AT&T's entry, nor IBM's or MCI's positioning, had satisfied all new demand. 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. Some of these positions were sustained and others were not. Private label ISPs also emerged when associations and affiliation groups offered re-branded 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 re-branded by the association. These firms could survive on relatively low market shares, though, to be sure, they were not very profitable either.

By 1997 more than 92% of the US population had access to a competitive market filled with a wide variety of options, with another 5% of the population – found in many different rural locations throughout the US -- having access to at least one firm by a local phone call (Downes and Greenstein, 2001). 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 80% of market share and a couple hundred for 95% of market share, but there was so much turnover and fluctuation that estimates more precise than this were hard to come by (Forrester report, 1999?).

Just prior to the AOL/Time Warner Merger in 1999-2000, the ISP market remained in flux. Broadband connections (DSL or cable) began to become available in select places, 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 between ISPs, with 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 and bundling others within standard contracts.

II.5. A turbulent six years.

Altogether, these conditions provide numerous challenges for price index construction. Over a six year period there were many changes in the modal contract form and user behavior. Changes in the delivery of services and changes in user expectations resulted in numerous qualitative changes in the basic service experienced by all users. The structure of the industry also fluctuated and no dominant providers emerged until the end of millennium. Until then, all players were buffeted by many of the same competitive forces.

III. Dataset Description

The dataset used in this paper is compiled chiefly from issues of *Boardwatch Magazine's Directory of Internet Service Providers*. The directory debuted in 1996 and continued to be published through 1999. Since 1998 the same publisher has maintained a list of ISP's 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 dataset were collected from the contemporaneous 'how-to' Internet books that are listed in the references below.

The sample covers the time period from November 1993 until January 1999, approximately a 6-year period. The sample is an unbalanced panel, tracking a total of 5948 firms with a total of 19217 price plan observations.[3] The dataset consists of demographic information about the ISP (name, location, phone, and web address). In each year there are also a variety of other characteristics of the ISP that are measured. These include additional service offerings such as dedicated access, ISDN access, web hosting and the price for web hosting, cable/broadband access, and wireless access. Other ISP characteristics include whether they are a national provider, and if so, how many area codes they serve, upstream bandwidth, and total number of ports. There is additional data from a survey/test done by *Boardwatch* and the results give the percentage of calls completed and the average speed of actual connections for the national providers in 1998.

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 the cost of additional hours. In a given year, there may be multiple price plan records for a

[3]This data does not represent all firms in the industry. It is also clear that the two or three price plans generally listed by *Boardwatch* for any given provider at one specific time do not necessarily represent all plans available from that ISP. Greenstein (2000) 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." This offers some comfort that the sample represents a majority of the plans offered by ISP's and chosen by consumers.

given firm because they offer a variety of plans at different connection speeds. The published information generally gives pricing for 28.8 access as well as higher speed access.[4]

Table 1 below summarizes the number of observations in the panel. The data has been left largely unchanged from its published form. Four observations from the first 2 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 price index results. No other cleaning of the data has been done, apart from simple verification and correction of data entry. As Table 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.[5]

Approximately 21% of the observed plans have a hourly limit, and the majority of those are accompanied by a marginal price for usage over that limit. As time progresses, the universe of firms/plans grows and the speeds offered continue to increase. At the start of the sample, prices are only given for 14.4 k connections. By the end of the data, 28.8k and 56k have been introduced, and there are price observations at 64k and 128k ISDN speeds as well as a small number of observations of T1 connection prices. For limited plans, the hours included in the plans continues to increase over time. The number of plans with limitations is decreasing over

[4] 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. I 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 I have no basis for doing so.

[5] Another measure of the rapid growth and evolution of this market is evidenced by the publishing pattern of ISP information in *Boardwatch*. In 1993-95, the list of ISP's is relatively short and is included in the magazine, but by 1996 the market is growing rapidly and the listing 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 semi-annually. Finally, by 1999 the directory is only published and updated on an annual basis.

time as a proportion of the sample. The pattern in the mean of monthly prices is not easy to discern.

Greenstein (2000) uses another source of data and examines contracting practices for 1998. In that data approximately 59% of firms quote only one price schedule, approximately 24% quote two price schedules and 17% quote 3 or more. Of the single price quotes, approximately 26% are for limited prices.[6] In this dataset, 71% of the observations are firms quoting only one price, 26% quote two prices and the remainder quote three or more prices. This is also highlighted in Table 1, where the average is 1.2 price plan observations per firm. The difference between the data here and in Greenstein (2000) seems to be that we have more firms who quote only one plan and fewer firms that quote more than two plans.[7] It appears that the data from the *Boardwatch* directories does not include all plans offered by each provider, particularly when an ISP offers 3 or more options. Boardwatch appears to track well ISPs who offer two or fewer options. We conclude that the dataset 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 dataset is the lack of quantity measures of subscribers and usage. Without usage data, there is no way to properly weight the price observations in the calculation of an ideal price index. However, during this period plenty of press indicates that most firms were responsive to the same technological trends. Hence, we are confident that qualitative change found at one firm spread to others quickly. We can be reasonably confident that indices about price/qualitative change would not be very sensitive to the use of weighting by

[6] Greenstein (2000) p.20.
[7] See footnote 3

market share. We test this assumption later in the paper when we examine the sensitivity of price estimates to the age of the ISP.

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 and the free ISPs, such as NetZero. Hence, the lack of market share become more problematic in principal. As we show below, prices also begin to become sensitive to incumbency by the last year of our sample. Thus, we stopped collecting data in early 1999.

IV. Elementary price indices

The most elementary price index has already been displayed in Table 2. The means of the monthly prices trace a sharp upward path from 11/93-5/96 with an even sharper fall from 5/96-8/96, followed by small increases to 1/98 and another steep fall in 1/99. The medians also decline over time, but the changes are discrete.

The fundamental problem with the data presented in Table 2 is that the observations in each time period reflect very different service goods. Table 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 11/93 to 1/95 and falls for the remainder of the sample period. This rise is persistent throughout the price indices in the paper. It is discussed in more detail in a later section below. 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.

IV.1. Matched models.

A procedure such as "matched models" compares products that exist in 2 adjacent periods. This could be an improvement over aggregating all products for comparison, but it also suffers because it ignores the introduction of new products (at least until they have existed for 2 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 higher the measured price change.

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}	$\dfrac{\sum_i \frac{P_{i,t}}{P_{i,t-1}}}{N}$	Mean of the price ratios
Jevons	I_{Jevons}	$\prod_i \left(\dfrac{P_{i,t}}{P_{i,t-1}} \right)^{\frac{1}{N}}$	Geometric mean of price ratios

Using the matched observations, it is possible to compute the values of Dutot, Carli and Jevons indices. Briefly, given a number of prices for matching services – designated by $P_{i,t}$ [8],

[8] The i subscript designates the price plan and t subscript designates the time period.

the following formulas are used to calculate the indices. To construct the "matched model" indices, we matched price plans from the sample where $firm_i$, $speed_j$ at $time_t$ are matched with $firm_i$, $speed_j$ at $time_{t+1}$

In

Table 4, we show the analysis for this 'strict' matching, where both firms and speeds must match for a plan to be included in the calculation.[9] The hypergrowth and turnover of the industry in the first few years results in relatively few matches in the 1993-1996 period. In 1996, 510 plans[10] from 5/96 are matched into the 8/96 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 4. This is because a single large or extreme value of $\frac{P_1}{P_0}$ swamps small values of $\frac{P_1}{P_0}$ when averaged. The simplest explanation is that this price ratio is unbounded above – price increases can exceed 100%, but the ratio is bounded below – price decreases can only be 100% - 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 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.

[9] Even the strict matching is ignoring any change in hours. We have ignored if a plan switched between limited and unlimited.

The results shown in suggest that prices are declining throughout the sample period. The notable exception is the Carli index, which shows price increases in nearly every period except May-96, where the sample is very small. The average AAGR for Jevons and Dutot indices for the entire period is –7.8%. In all cases, the Jevons and Dutot indices agree on direction of price change, despite differing on the exact magnitude of the change.

IV.2. Determinants of Price

Before proceeding to examine hedonic regressions and the associated price indices, we motivate the selection of the hedonic price model. The speed and duration of the plan are important as are complimentary service offerings. Contract length and set-up 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 ISP's begin to offer services to consumers, there was little need for unlimited plans. In Table 5, we show the mean fixed monthly cost of Internet access in this sample of ISP's. In each year, the mean price for limited contracts is below the mean price for unlimited contracts. These differences are all statistically significant at 1%. 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% of the sample plans. By 1999, limited plans make up just

[10] Of the 1283 total plans in 5/96, only 702 can possibly match a plan in 8/96 because the remain 581 plans are either 64k or 128k plans which are not reported for any firms in the 8/96 data.

over 10% of the plans in the sample. In 1999, limited plans are on average $0.91 per month less expensive than unlimited plans.

In Table 6, we continue to examine the effect of plan limitations on ISP pricing. The data in the table show 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 10 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 1/95) and the monotonic relationship is maintained until the limits exceed 100 hours. Hour limitations above 100 hours seem to have no obvious relation to price that is consistent across the observational periods in the sample.

Survey data from March 2000 show that 93.4% of users have monthly usage of 82 hours or less and 90% of users have monthly usage of 65 hours or less. 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 5, it is clear that these high limitation plans are not priced very differently than the unlimited plans.

Other relevant variables are in Table 7. 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 (1.544 Mbs) 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.[11]

[11] 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.

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 largely do not explicitly employ them in our hedonic analysis.[12] As we show below, however, we can use a random effects estimator which correlates errors at an ISP over time. In part this will capture any unobserved quality that is correlated at the same firm. We will also try to control for quality with vintage and age effects. See more below. [13]

IV.3. Hedonic Price Indices

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 I will estimate is:

$$\ln P_{ijt} = \alpha_0 + \alpha_t Year_{ijt} + \beta_1 Limited_{ijt} + \beta_{2-9} dHrly_{ijt} * Limited_{ijt} + \gamma_{1-5} dSpeed_{ijt} + \varepsilon_{ijt} \qquad (1.1)$$

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 hourly limits. We divided hourly limits into different dummy variables. This will provide flexibility to coefficient estimates. Those divisions and frequencies are shown in Table.

[12] 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 any better than well (or 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 non-normalized measures of qualitative change over time.

[13] For more on measuring quality at ISPs, see Augereau and Greenstein, 2001, Greenstein, 2000, or 2001.

The specification in (1.1) was estimated for the whole pooled sample and for each pair of adjacent time periods. Regression results are in Table 9. After testing the coefficients for each of the hourly buckets, all but the lowest four were dropped from the model. The tests[14] showed 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 11/93.

The trend over time is that ISP's offer increasingly fast connection speeds. Unlimited plans have become more prevalent over time and 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 11/93. 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 the coefficient 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 I expect the difference between the coefficients **Hrs10*L** and **Limited** to be negative. Each difference should be smaller in absolute value as **Limited** is compared to higher-level

[14] For example testing H0: **Hrs80*L – limited** = 0

buckets, but the differences should remain negative (or approach zero – indicating that a high limit plan is really no different than an unlimited plan).

Depending on which speed is omitted, the implication for the sign of the estimated coefficients on the **speed** indicator variables varies. It does imply that higher speed plans should have higher (more positive) coefficients than lower speed plans.

The regression results from model (1.1) appear in Table 9. The largest hourly limitation buckets have been discarded from the full model, so I will focus on the coefficients of the restricted model and the accompanying adjacent period regressions. In the restricted regression (2^{nd} column), all estimated coefficients are significant predominantly at the 1% or 5% level. The coefficients on each of the **speed** variables confirm the hypothesis given above. 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 hypothesis given above. Plans with a limited number of hours are priced at a discount to unlimited plans and this discount diminishes as the number of included hours increases.

The coefficients on the **time** indicator variables agree largely with the hypothesis given above. Apart from the period from 11/93-1/95, the coefficients indicate that quality-adjusted prices were falling, and the coefficients become more negative as the hypothesis described. There are two interesting anomalies regarding the **time** indicator variable. The difference between the coefficients on **year95** and **year96a** is very large (indicating that 5/96 prices are 40% of the level of 1/95 prices). This dramatic large price decline needs to be investigated further. The second interesting result from the regression is that prices appear to increase on a quality-adjusted basis from 11/93-1/95. This is a recurring pattern through many of the models. It is explained by the fact that the nature of Internet access changed during the intervening time period. In 11/93 the connections that were offered were all UUCP (unix-to-unix copy) connections that were capable of exchanging files, newsgroups and email, but had no interactive features. By 1/95, all of the plans in the data are for SLIP (serial line internet protocol) access.

This is a more highly interactive connection that has all the capabilities of UUCP plus other additional features (including multimedia capabilities).[15] When the quality increase is the same across all of the sample products, then it cannot be identified separately in a hedonic regression from the time period indicator variable. Thus in 1/95 prices are higher than in 11/93, but it is because Internet access technology has fundamentally changed. Because all the ISP's 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. More to the point, this problem is especially pronounced here; there is massive entry of new web services over time, but all the ISPs provide similar access, so this entry is not identifiably different than the time dummy.

The right side of Table 9 displays the results from the adjacent period regressions. The pooled model is a significant restriction on the data. In the pooled model, intercepts may vary across time, but the slopes with regard to the characteristics are restricted to be equal across periods.[16] The adjacent period models relax this restriction so that the slopes are restricted to be equal only across two periods in any model. Although some of the coefficients among the

[15] Looking carefully at the data and the advertisements, it's clear that firms are promoting "slip" accounts as a premium service (as opposed to UUCP). The data seem to indicate that they are charging a premium for it as well. Because there is no heterogeneity among the 1/95 plan options, it is impossible to identitify this effect and separate it from the time period constant.

[16] I have not yet tested for parameter stability (i.e. tested to see if this restriction is valid).

adjacent period models are statistically insignificant, the majority confirm the hypotheses given above. The hourly limitations and speeds affect price in the same way as the pooled model.[17] The price increase in 1/95 is indiscernible because although the coefficient has a positive sign, it is not significant. The remaining inter-period indicators are of negative sign and the steep change in price from 1/96 to 5/96 is still present and very significant.

The coefficients from the hedonic regression model in (1.1) lead directly to a calculation of the estimated price indices. These estimates are a consequence of the form of the model. By exponentiating both sides of (1.1), it is clear that each parameter affects price in multiplicative fashion. This aspect of the model, combined with indicator variables, simplifies the interpretation of the regression coefficients. An adjacent year model[18] is the simplest case. The column marked 93/95 in Table 9 displays the results for an adjacent period regression pooling only the data from the 11/93 and 1/95 time periods. The first variable listed after the constant term is Year95 which is an indicator variable for all plans that are from the 1/95 time period. The estimated coefficient on the variable Year95 is 0.058 (from Table 9). The direct method to calculate a price index uses this estimated coefficient. For this model, the hedonic price index would be $e^{0.058} = 1.0597$ at the time period 1/95 (relative to a base value of 1.00 at the 11/93) time period.

By using this method, the models estimated in Table 9 lead directly to estimated price indices. These are shown in Table 1. By exponentiating the estimated coefficients of the yearly

[17] The coefficients on the hourly limitations and speeds appear to be of the same magnitude across the differing time periods. While that suggests parameter stability over time and argues for the pooled model, I have not tested the restriction formally.
[18] Refer to Table 9.

dummies, I can calculate the price indices directly. In the model covering, the whole sample period, the calculated index will be cumulative (i.e. $\exp(\alpha_t) = \frac{Index_t}{Index_{\text{base year}}}$). These are easily reconverted to period-to-period indices. The models in Table 9 that consider adjacent time periods also lead directly to estimates of the period-to-period indices. These are calculated in the same manner.

The results of these calculations are shown in Table 1. The table shows that the cumulative "quality adjusted" index declines 58% to 0.422 in 1/99 when compared to 1.00 in the base period, 11/93. The individual period-to-period indices display large variation during the initial periods, but then moderate to a 1-10% decline per period.[19] The calculations from the adjacent year regressions are largely the same as the results from the restricted model. The exception is the 11/93 to 1/95 index which displays a less extreme rise during the time period under the adjacent years method. The extreme drop in the index from 1/95 to 5/96 is still present and remains an open question to be further explored.

IV.4. Hedonic Price Indices with random effects

The dataset covers very few characteristics of each plan/product, and there are undoubtedly unmeasured elements of quality that are missing from model (1.1). Because of the panel nature of the dataset, the firm-specific unmeasured quality can be corrected using a

[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.

random-effects model.[20] In this case the regression model given above in (1.1) will be changed by adding a firm specific error term (υ_i).

$$\ln P_{ijt} = \alpha_0 + \alpha_t Year_{ijt} + \beta_1 Limited_{ijt} + \beta_{2-9} dHrly_{ijt} * Limited_{ijt} + \gamma_{1-5} dSpeed_{ijt} + \upsilon_i + \varepsilon_{ijt} \quad (1.2)$$

We have estimated both the fixed and random effects specifications of model (1.2). The regression results are shown in Table 2. The Breusche-Pagan test indicates that the hypothesis that var(υ_i) = 0 can be rejected with better than 1% certainty. The Hausman specification test also indicates that the random effects specification is preferred to the fixed effects model. The random effects regression results differ from the earlier results. The main difference is that the drop in prices ascribed to 1/95 to 5/96 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 coefficients on the speed indicator variables also follow the pattern outlined in the hypotheses above and reconfirm the results from the earlier regression. Table 2 also shows the adjacent period regression results. They also follow the pattern of the earlier results with again the main difference being a dampened drop in the index from 1/95 to 5/96.

Using the regression results from the random effects "restricted" model and the random effects adjacent period models, we have recalculated the cumulative and period-to-period indices in Table 3 The cumulative index drops from 1.00 in 11/93 to 0.51 in 1/99. This shows that "quality" adjusted prices fell by 49% over this period. As before, the period to period indices

[20] Of course the 'omitted variable bias' question arises here. Unless the omitted variable is correlated with one of the year dummies, then the direct index parameter estimates will be unaffected. I have not been able to find an example of a omitted characteristic of a dial-up plan that is correlated with time (or with any of the other variables).

swing wildly in the initial periods, but then settle to steady declines of 0-7% per period. The striking difference between the random effects model results and the earlier results is shown in the period-to-period index from 1/95 to 5/96. Without random effects the index declined to 0.38 over this single period. Taking other unmeasured elements of firm quality into account dampens this drop in the price index. In Table 3, 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 indices derived from the pooled model. The only inconsistency is the 11/93 to 1/95 index, but this is an insignificant coefficient in the adjacent period regression.

Firm level random effects changes the index. It is unclear what aspect of changing quality is unmeasured. We conclude that accounting for measured and unmeasured quality is a simple and useful addition to the tools for calculating price indices. It is a further refinement of the standard hedonic techniques, but it is not difficult to implement. The results and statistical significances are easily interpreted.

IV.4. Analysis of sub-sample with speeds below 28.8

We were concerned that the results could be an artifact of change in modem speeds, which is coincident with the transition to unlimited plans. We tested this by examining contracts only for 28.8 service.

We have repeated the random effects modeling (model (1.2)) with a sub-sample of plans that offer connection speeds at or below 28.8k.[21] Table 4 shows the regression results from this sub-sample. The results shown for the sub-sample correspond well to the full sample regression.

The coefficients display the same pattern as the earlier full-sample regressions, supporting the hypotheses given above. Quality adjusted prices decline over the sample period, with the coefficient for each time period being more negative than the last. The apparent quality adjusted price rise from 11/93 to 1/95 persists, showing 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, speed of a plan is handled using a dichotomous variable indicating whether a plan is 14.4k or 28.8k. In the regression, 28.8k plan indicator was the omitted category. The only result in this sub-sample that conflicts with the earlier results is the coefficient on 14.4k speed plans. Recall the earlier argument presented above 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). In Table 4, this coefficient is positive and statistically significant.[22]

The adjacent period regressions are also shown in Table 4. Similar to the pooled model, these regressions on the sub-sample 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 hypothesis given above. The remaining adjacent period regressions do not control

[21] Although 56k connections are available during this period, the data in Table 15 suggests that dialup connections were dominated by lower speed until the spring of 1998.
[22] I do not currently have a "good" possible explanation for this apparently contradictory result. There may be an interaction of variables which is leading to this result, but I have yet to identify the problem.

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 models, we have recalculated the cumulative and period-to-period indices in Table 14. The results are consistent with the results from the full sample. The cumulative index show that prices in this sub-sample drop from 1.00 in 11/93 to 0.48 in 1/99. This shows that "quality adjusted" prices have dropped by 52% over the sample period. This index in consistent with the full sample cumulative index which dropped by 49% over the same period. The single period calculations are consistent with the full sample results. Price increases between the first two periods, followed by a sharp decline, and then steady declines of 1-7% thereafter.

Repeating the analysis of model (1.2) on a sub-sample of plans with speeds at or below 28.8k gives results that are very consistent with the analysis of 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.[23] The most important conclusion is that the unobserved limits for the high speed plans are not affecting the overall results.

IV.5. Weighted Hedonic Price Indices

To calculate an 'ideal' price index, data is needed on the market shares or revenue shares of the product or service. The *Boardwatch* ISP pricing data did not contain such information.

[23] The best test of this would be interaction terms for the time period x speed. This would explicitly allow investigation of the price paths within speed segments.

Because the listings are organized by area codes served, we could use the number of area codes served by each ISP as a crude market share weighting. It would be a crude measure because of population density is not uniform across area codes and intra-area code market shares are not evenly split. Another simpler alternative is to weight the plans based on the connection speed offered. Such data is available from the GVU lab www surveys.

The Graphics, Visualization and Usability lab at the Georgia Institute of Technology has conducted a WWW users survey semi-annually 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. GVU has collected information on Internet connection speeds since 1995. The data are shown in Table 15.

The split of plans between 28.8k and 56k in the 1997-1999 periods of the dataset 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 16. The only sizable difference between my data and the GVU survey occurs in 1997. It appears that in 1997, the *Boardwatch* data over-represent the prevalence of 56k connections by about 2.5 times. It is not clear what effect a reweighing would have on the calculation of the price index (effectively increasing the weighting of the 28.8 prices relative to the 56k prices). However it is clear that the proportions in 1998 and 1999 are roughly the same. The impact of re-calculating the index relative to the effort would be minimal.

V. ISP Pricing Strategies and the Sources of Price change

In this section of the paper, we investigate the sources of prices change. In particular, we examine the prices choices of entrants and incumbents in the sample, finding that entrants priced at a discount to incumbents. We also examine the pricing decision of ISP when new products are introduced (higher speed access). New products command a price premium initially, and this is competed away over time. This section also examines firm age and tenure. As noted, age is a good proxy for quality. Firms who have been in business longer generally command a price premium. This effect echoes the results given for firm vintage. Firms that enter in earlier years tend to maintain price premiums over time. Lastly, we examine the pricing decisions of firms that exit the sample. Firms who leave the sample offer higher prices in the period before they leave.

V.1. Entrants

Numerous firms enter the dataset during each period. An open question is what were entrants' pricing strategies as they came into this market. Did entrants differentiate their service in some meaningful dimension so that they could price at or above incumbents' prices? Using the hedonic regression techniques described above, it can be determined that the entrants do price at a discount to incumbents and that there are no vintage effects.

This new model incorporates random effects and two new sets of regressors.

$$\begin{aligned} \ln P_{ijt} = {} & \alpha_0 + \alpha_t Year_{ijt} + \beta_1 Limited_{ijt} + \beta_{2-9} dHrly_{ijt} * Limited_{ijt} + \gamma_{1-5} dSpeed_{ijt} + \\ & \delta Entrant + \delta_t Newfirm_{year} + \phi_t Vintage_{year} + \upsilon_i + \varepsilon_{ijt} \end{aligned} \quad (1.3)$$

The new regressors are ***entrant***, ***newfirm***$_{(year)}$, and ***vintage***$_{(year)}$. In Table 17, the number of price plans by entrants and incumbents is shown. The regressor ***entrant*** is a dichotomous variable that denotes a firm that has entered the dataset for the first time. The regressor ***newfirm***$_{(year)}$ is also a dichotomous variable that more closely identifies new firms specific to given years. This is the same idea presented above when limited plans were considered. Firms are either an entrant or an incumbent, and if they are entrants they enter at a particular time period. In Table 18, the number of price plans is shown for each vintage in the dataset. The regressors ***vintage***$_{(year)}$ allow tracking of firms that enter and remain in the sample. For instance, the regressor ***Vintage97*** is a dichotomous variable that marks every price plan for firms that entered the dataset in March-97. This vintage is marked for all further price plans from these firms as they remain in the sample.

Table 19 displays the regression results about entrants, incumbents and firm vintage. The regression results demonstrate that new entrants offer discounted pricing as they entered the market. This is effect is largest and most significant in 1996 and 1999. The regression results also demonstrate that new entrants not only offered discounted pricing upon entry, but tended to continue discounted pricing over time.

The first regression shown in the left column of Table 19, is a restricted version of model, including only the dichotomous variable **entrant**. In this regression, the coefficient on the entrant variable is negative and significant at the 1% level. This indicates that entrants offered roughly a 1.7% price discount when compared to their incumbent peers.

The regression shown in the second column of Table 19 is another less restricted version of model (1.3), encompassing a variable for entry (**entrant**) and a set of interaction variables indicating when an entrant entered (e.g. **new*96a, new*96b**). These entry dates coincide with the first appearance of the firm and its service plans in the dataset. Similar to the variables that cover limited plans, the sum of the coefficients on **entrant** and **new*96a** are the estimate for the discounts offered by entrants at each particular observation period. It is the sum of these coefficients that is tested for significance. The sum of the entry coefficients is negative for each of the periods in the dataset. However, only the coefficients for firms that entered in May 1996 and January 1999 are significant at 1%.

The regression in the third column of Table 19 is another version of model (1.3). This model includes dichotomous variables that mark the vintage of the firm and its price plans (e.g. **vintage95, vintage99**). The coefficients on these vintage variables are relative to the omitted vintage, 1993. The coefficients for each vintage are negative and significant in all cases except 1995. There is also a pattern among the coefficients. The coefficient on each subsequent vintage is generally more negative than the coefficient on the preceding vintage. This indicates that entrants priced lower on entry and that firms of the same vintage continued to keep prices lower than firms that had entered at previous times. Tests of the differences show that all are significant at various levels except the difference from 1997 to 1998, which does not indicate a price decline.

The regression in the rightmost column of Table 19 is the unrestricted version of model (1.3). This model incorporates all of the entrant variables as well as all of the vintage variables.[24] The results of this model re-affirm the restricted models described above. The summed coefficients on the new entrant variables are all negative except for 1997. The only sums that show statistical significance are again May 1996 and January 1999 at the 1% level. The coefficients on the vintage variables follow the same pattern of increasing discounted prices with each set of new entrants. The significance of the differences between vintages is weaker than in

[24] **vintage99** is omitted from the unrestricted model because it is the same as the interaction variable **new*99**.

the unrestricted model in the third column because two of the four differences are statistically significant. Those differences are between vintages 96a and 96b and vintages 97 and 98.

In each of the regression results shown in Table 19, the coefficients on time, limited plans, and speeds are consistent with the earlier results. The coefficients on the observation period (time) are also consistent in magnitude in the first regression shown in the left column of the table. These coefficients are less consistent in magnitude across the other restricted regressions in Table 19, because the time coefficient is also partly accounted for in the coefficient on the **entrant*year** variables. To a lesser degree this is also true of the **vintage** variables.

These results on entrants support the hypothesis that competition between ISP's was partly fought through pricing. The regressions support the general notion that entrants came into the market at a discount to the incumbents. This discount only amounts to perhaps $0.25 /month on average, but it is a significant and persistent. Looking more carefully at individual points in time, the results show that entrants in May 1996 and January 1999 were more aggressive and offered prices significantly below the incumbents. These effects are re-affirmed when examining the vintage effects. Subsequent classes of entrants offer lower and lower prices. It also appears that these differences in price among entrants of varying years are persistent over time.[25]

Altogether, the results support the view that entrants used price as a competitive weapon to gain entry to this market. However, the estimated size of the discounts is not as large as might be imagined. The results may also support the idea that subsequent entrants 'learned' this behavior as the 'accepted' mode of competition in this market and priced lower on entry as a consequence. These results also suggest that a price index that under-sampled successful new entrants would be baised upward.

V.2. New Product/Technology

When new technology is introduced among ISPs, there are capital investments and technological hurdles. The size of these hurdles and the demand for the new technology determines the rate of adoption. The introduction of higher speed access by ISP's involved the adoption of new modem technology for both the ISP and the customer. When new modem technologies have been introduced in the past, adoption has been gradual. [26] This leaves the early adopters with temporarily increased market power. It is an open question whether exploiting that market power is in the long run best interest of the ISP, but in the short run, there is room to price the new, higher speed service at a premium.

The effect of new products can be tested within the hedonic regression framework. To understand the effect of new product introductions, we estimate the following model

$$\begin{aligned} \ln P_{ijt} &= \alpha_0 + \alpha_t Year_{ijt} + \beta_1 Limited_{ijt} + \beta_{2-9} dHrly_{ijt} * Limited_{ijt} + \gamma_{1-5} dSpeed_{ijt} + \\ &\quad \delta Entrant + \lambda New56 + \phi NewBoth + \upsilon_i + \varepsilon_{ijt} \end{aligned} \qquad (1.4)$$

Model (1.4) shows two dichotomous variables. **new56** indicates 56k plans that are introduced in March 1997. **newboth** indicates 28.8 speed plans when they are introduced into

[25] This 'vintage' effect may be actually be masquerading as a combination of firm age and survivorship bias. If older, surviving firms signal quality and a loyal customer base, they would have higher prices. See the analysis of firm age in the section below.

the sample in January 1995 and 56k plans introduced in 1997. The model cannot use a dichotomous variable to represent the introduction of 28.8 speed plans alone because it would be equivalent to the linear combination of the Speed28 and Year95 variables. Rolling the new products into one dichotomous variable imposes a restriction that the coefficient on each new product variable (**new28** and **new56**) is the same.

In January 1995, the first plans to offer 28.8 kbps dial-up access appear in the data. 11% of the plans in the dataset (5/47) in 1995 were the first 28.8 plans to appear. The remainder of the plans in the 1995 data is 14.4 kbps plans. When 56 kbps plans first appear in the data in March 1997, they represent 12% of the plans in that portion of the data (446/3813). The remaining plans in the 1997 data are 28.8 kbps speed plans.

Table 2020 displays the regression results for full and restricted versions of model (1.4). As mentioned above, there are no results with a distinct estimation of the coefficient on **new28**. In the model in the left column ('NewProducts'), a restricted version of the (1.4) model is estimated using the combined newproduct variable **newboth**. The results show that the estimated coefficient on the **newboth** variable is positive and significant at better than the 1% level. In the model in the center column, the regression estimates the effect of the introduction of 56k plans that first appear in the dataset in March 1997. The results show that the estimated coefficient on the **new56** variable is positive and significant at better than the 1% level. The results shown in the right column are for the unrestricted version of **model** (1.4). This version of the model incorporates the combined new product variable **newboth** and the **newfirm** variable used in the entrant/incumbent analysis above. These results show that the estimated coefficient

[26] See Augereau (1999) for an account of the battle over the 56k modem standard and the effects on adoption.

on the **newboth** variable is positive and significant at better than the 1% level. The estimated coefficient on the **newfirm** variable is positive and significant at the 1% level and also consistent in magnitude with the results from the earlier section.

In each of the results in Table 2021, the estimated coefficient on the new product variables is approximately the same magnitude. The estimated coefficients imply that new products were introduced at approximately a 24% price premium. This is consistent with the hypothesis given above that ISPs would exploit temporary market power when they introduced new higher speed plans.

The other results in Table 20 are mostly consistent with the results in earlier sections. The coefficients on the variables for limited plans and the speed of connections are all consistent with the earlier results. The coefficients on each of the time variables do vary significantly in the regressions that contain the **newboth** variable. The coefficients on the time variables in the center column indicate a pattern for the price index that is consistent with earlier results.

However, the results shown in the left and right columns of the table are much different than the earlier results. The main difference is in the coefficient on the variable **Year96a**. The estimated coefficient for this variable is higher (less negative) than in the earlier hedonic price index results. This is important because the coefficient represents a cumulative decline since the 11/93 start of the dataset. One possible explanation of this different result is that the price premium given to the 28.8 speed plans in 1/95 was fleeting and if unaccounted for, the price index would appear to fall even more quickly from 1/95 to 5/96. If the new 28.8 plans in 1/95 are isolated and given a fixed price premium of 22%, then when they are not "new products" in the next time period, the price does not seem to have fallen as much over that time period. This is because much of the price drop can be attributed to scarcity of 28.8 speed plans and the market power and premium pricing that was attached to them in 1/95. In the subsequent time periods, inter-period declines in quality-adjusted prices are consistent with the results given in the earlier hedonic regressions above. This implies that instead of dropping 49% overall price index only declines to 0.615 or a drop of 38.5%. Moreover, the pattern of price declines is largely the same except from 1/95 to 5/96, where the price index declines much less rapidly than before, dropping from 1.33 to 0.73.

When ISP's first had the capability to offer new higher speed plans, some did. The results show that they exploited their temporary market power and charged an estimated premium of 24% above the expected quality adjusted price.

V.3. Firm age/tenure

Finally, following the example of Berndt et al, 1994, we next calculated hedonic estimates with a full array of age and vintage effects. The length of time a firm is in the sample may signal a number of effects. It is unclear from looking at the simple averages that there is an easy answer. There are reasonable arguments to expect that increased tenure in the sample would have a positive effect on pricing, namely as a signal of quality and as a signal of management competence. There could also be lock-in and loyalty effects that would sustain higher prices for older firms. But there are also reasonable arguments that would suggest a negative effect such as a lower cost position gained through accumulated learning.

In this context age is the number of times a firm has shown up in the data with at least one price plan. At the beginning of the sample, the industry has just started and all firms are of the same age. As the industry grows and matures from 1993-1999, many firms enter, some firms exit and some firms consolidate. By the end of the observational period there is quite a dispersion of the age of firms. The are several firms that have been in the sample at every period and others who are new in 1/99. The majority fall somewhere in between.

There are many possible effects here. One effect concerns survivorship bias and is akin to the quality signals that were discussed above in the section concerning the provision of technically complex services. Firms that have survived the growth and transitions in this industry must be successfully providing value to their customers. This quality effect would argue that "older" ISP's can charge premium prices because they offer higher quality.

The second effect concerns loyal customers, lock-in and switching costs. For some types of customers, the technical challenge of getting service from another ISP may raise some switching costs. Network effects from content and communications platforms that are proprietary to the ISP may help with customer lock-in. If older ISP's are more likely to have loyal customers with some degree of switching costs and lock-in, then these 'older' ISP's to be able to charge a price premium versus their less experienced, less established competitors.

A third possible effect is that older firms have 'produced' more Internet service in the time they have been in business. If there are learning curve effects, such as the optimal customer/port/bandwidth ratios, then older firms may have a knowledge and cost advantage over younger firms. This effect would argue for lower prices from older firms due to potential cost advantages.

We have created a variable **age** that counts the number of months that a firm is observed in the sample. The minimum age of any firm is 0 if they are a new entrant. The next shortest would be 3 months if they enter in 5/96, reappear in 8/96 and subsequently disappear. The longest life for a firm would be 62 months if it entered the sample in 11/93 and continued to appear through the last data point at 1/99. At each time point in the data, the age of the firm is recalculated back to its entry and this age is attached to the price plans from that set of observations.[27] To determine the effects of firm age, the hedonic regression framework is again employed to estimate the following model.

$$\ln P_{ijt} = \alpha_0 + \alpha_t Year_{ijt} + \beta_1 Limited_{ijt} + \beta_{2-9} dHrly_{ijt} * Limited_{ijt} + \gamma_{1-5} dSpeed_{ijt} + \delta FirmAge + \phi NewBoth + \upsilon_i + \varepsilon_{ijt} \quad (1.5)$$

Table 21 shows the regression results. The two models shown are the hedonic random-effects model (1.2) and the estimation of model (1.5) with the variables **firmage** and **newboth** from the previous section. The results show that the estimated coefficient on the variable **firmage** is positive and significant at better than the 1% level. The **firmage** variable is constructed as a continuous variable. Table uses the estimated coefficient on **firmage** to estimate the price premium attributed to older firms. This price premium ranges from 2.1% for a 1-year-old firm to 11.0% for a five-year-old firm.

The hypotheses given above argued that firm age could have both positive and negative effects on pricing. The results in Table 21 show that older firms can maintain a price premium. Price premiums could be realized when age is a signal of quality or when switching costs build a base of loyal customers. Accumulated experience can translate to cost advantages and lower pricing by older firms. The results from model (1.5) show that older firms have maintained a significant price premium. While this does not refute the hypothesis that accumulated learning

[27] To be clear, a firm that survives from the start of the data until the end will have plans at every date point in the dataset. Those plans would each be associated with a cumulated age (i.e. age path of plans would be 0, 14, 30, 33, 40, 50, 62)

could lower costs and prices, it does show that the quality and loyalty effects overwhelm this effect.

The consequences for estimated price indices are most pronounced at the end of the sample. The estimated hedonic coefficients would yield an even faster rate of change than estimated in previous tables. However, that effect would be counter balanced by price benefits going to established firms whose market dominance is unmeasured. More precisely, most firms in 1999 were still less than five years old, most were under 3 years old. Yet, industry sources indicate that the market shares for established firms, such as AOL and Earthlink, began to stabilize by late 1998 and even grow by early 1999.[28] To be sure, the most successful new entrant in 1999, NetZero, charged nothing for their service and accumulated an installed base in the millions. However, unlike earlier experiences, most industry reports indicated that established incumbents did not *lose* market share to these entrants. The magnitude of these premiums, combined with the observation that the prices of biggest established firms were significantly higher by as much as 6%, suggests that the lack of data on market share is increasingly a liability. We conclude that it makes these estimates are increasingly difficult to use beyond the end of this time period.

V.4. Exiting firms

In this dataset, firms that exist with price plans in one period are often still in the sample in subsequent periods. However, there are many firms that do disappear from the sample and there is no way to know why they have disappeared. Firms may have failed, they may have merged with another firm, or they may have simply changed names or locations in such a way that it was impossible to tie them to their identity in an earlier part of the sample. The variety of possible reasons for exit means that it is important to understand each of them and their effects on pricing.

We found that a mildly high residual does predict exit, but the effect is rather small. In other words, firms which are about to exit (in the next period) have prices that are roughly $0.25 higher. Price indices decline over time because of the exit of contracts coming from the high priced firms. However, the contribution from entrants and qualitative change is much larger than the contribution from exit during this time period, so we did not pursue the point further.

VI. Conclusion

Internet service providers are a necessary component of the Internet infrastructure. They enable businesses and individuals to connect to the Internet. The earliest history for ISP's dates back to late 1992 -early 1993. This paper investigated the pricing behavior and strategies in this nascent industry over the time period from 1993 to 1999.

Using a new dataset this paper computed a variety of price indices, ranging in sophistication from very crude averages to quality adjusted hedonic models. The results show decisively that ISP pricing has been falling rapidly over time. The bulk of the price decline is in the early years of the sample, but a significant and steady decline continues throughout. We conclude that ignoring

[28] Recall, however, that AOL only began to provide Internet service in 1996, CompuServe and AT&T in 1995 and so on. Our measure of age is not a measure of the age of the firm, but a measure of the age of Internet Service.

aspects of quality underestimate the price declines. It also alters the timing of the declines that they do measure.

We found that new firms enter the market at a small but significant price discount to established incumbents. When new products/technologies are introduced,[29] they are priced at a significant price premium to the existing offerings. Incumbent firms maintain relative price premiums, and these grow as firms survive.

This paper is unique in that it is the first to investigate a large and long-term sample of U.S. based ISP's. This paper is also the first to investigate and apply these hedonic methods to establish price indices for a service good. The results demonstrate the value of hedonic methods for calculating price indices. The paper suggests a modification to standard methods for this market.

These price indices are valuable from both a public policy standpoint and from a business strategy standpoint. The rapid evolution of pricing in the ISP industry has parallels in history of other industries and may help those trying to understand and explain the development of pricing policies in other new and very dynamic industries.

[29] Namely the availability of 28.8k and 56k access service.

Table 1: ISP Price Dataset – Counts of Firms and Observations[30]

Years	11/93	1/95	5/96	8/96	3/97	1/98	1/99	
Directory Firms[31]	24	35		2934	35354167		4511	
Sample Firms[32]			710					
Total obs	25	47	12832822		38135659		5568	
Speeds	Number of observations at each speed by year							Total
14.4k	25	42						67
28.8k		5	702	2822	33673972		256213430	
56k					446	1564	30065016	
ISDN 64k			299			54		353
ISDN 128k			282					282
T1 1.544mb						69		69
Limited Hours	13	22	303	996	1024113	0	581	
Unlimited	12	25	980	1826	27894529		4987	
% Limited	52%	47%	24%	35%	27%	20%	10%	
28.8k speed								
Limited Hours		2	303	996	10241130		581	
Unlimited		3	399	1826	23432842		1981	
% Limited		40%	43%	35%	30%	28%	23%	

Table 2: Price Index – Mean & median of Monthly Price – Full Sample

[30] Note that the dataset is comprised of all data published by the data sources listed in the references. The sole exception is the 5/96 data which represents a random sample of 710 firms from a total population of ~2050 firms. The overall results presented in this paper are insensitive to the inclusion or exclusion of this subset of observations.

[31] Some firms disappear from the published data and others continue to be listed without price plan information. I am 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 is evidence that *Boardwatch* did 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. An example of firms disappearing and new entry comes from the 1999 directory, "...adding 1001 new companies to the list. This is up 223 overall from *Boardwatch's* last directory." The remarks indicate that in the six months since the last directory 1001 entrants have listed information and 778 have exited the market out of a total of approximately 4500 firms.

[32] 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.

Time	Mean	Median	Plans
Nov-93	30.84	30.00	25
Jan-95	38.86	30.00	47
May-96	71.08	28.00	1275
Aug-96	20.02	19.95	2822
Mar-97	21.40	19.95	3813
Jan-98	39.13	19.95	5659
Jan-99	19.29	19.95	5568

Table 3:Price Index –Mean & median of Monthly Price – Speed 28.8 and below

Time	Mean	Median	Plans
Nov-93	30.84	30.00	25
Jan-95	38.86	30.00	47
May-96	22.64	19.95	694
Aug-96	20.02	19.95	2822
Mar-97	19.80	19.95	3367
Jan-98	19.77	19.95	3972
Jan-99	19.01	19.95	2562

Table 4: Matched Model - Strictly Matched Observations

		Indices		
Date	# of Matches	Dutot	Carli	Jevons
Nov-93		1.00	1.00	1.00
Jan-95	15	1.34	1.72	1.30
May-96	5	0.58	0.57	0.53
Aug-96	535	0.95	1.06	0.98
Mar-97	2599	0.99	1.03	0.99
Jan-98	3561	0.97	1.01	0.99
Jan-99	2691	0.94	1.02	0.96
Cumulative Index		0.67	1.10	0.64

Table 5: Mean prices for Limited and Unlimited Plans[33]

Prices		Limited	Unlimited
Nov-93	Mean	15.15	47.83
	sdev	12.65	25.06
	N	13	12
Jan-95	Mean	27.714	8.67
	sdev	15.58	38.73
	N	22	25
May-96	Mean	19.73	24.90
	sdev	12.72	19.26
	N	303	391
Aug-96	Mean	18.36	20.93
	sdev	7.79	6.22
	N	996	1,826
Mar-97	Mean	18.29	22.54
	sdev	7.60	22.21
	N	1,024	2,789
Jan-98	Mean	18.67	21.38
	sdev	9.19	14.59
	N	1,130	4,406
Jan-99	Mean	18.48	19.39
	sdev	5.94	7.46
	N	581	4,987

[33] All of the differences between means are significant at 1% or better level.

Table 6: Mean Prices by Hourly Limitation[34]

Prices		Hourly Limitations 10 hrs	20 hrs	35 hrs	50 hrs	80 hrs	100 hrs	150 hrs	250 hrs	>250
Nov-93	Mean	11.25	20							
	sdev	4.79								
	N	4	1							
Jan-95	Mean	16.69	38.74	26.23	47.48			33		
	sdev	3.25	19.32	5.82	38.93					
	N	7	4	8	2			1		
May-96	Mean	12.59	15.31	20.11	22.43	21.41	22.94	22.86	25.48	30.43
	sdev	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-96	Mean	11.28	13.80	17.87	21.13	21.05	22.33	21.02	20.82	20.41
	sdev	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
Mar-97	Mean	10.44	13.46	17.65	19.52	20.61	21.85	20.82	21.07	19.29
	sdev	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-98	Mean	10.15	13.12	15.74	19.33	20.25	22.74	20.95	21.26	20.84
	sdev	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-99	Mean	9.65	10.69	16.10	15.97	18.70	21.01	20.11	20.44	19.15
	sdev	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

[34] Survey data from March 2000 in Goldfarb (2000) shows that 93.4% of users have monthly usage of 81.7 hours or less, 90% of users use 65 hrs or less. So limitations at or above 80 hrs were probably not binding at all until recently and then only for a very small percentage of users. [data appear in Greenstein (2000) (table 1)]

Table 7: Covariates data for Hedonic regression – full sample[35]

Variable	Obs	Mean	Std. Dev.	Min	Max
age	19217	2.171	1.155	1.000	7.000
avg_speed	246	32956.380	3635.247	25790.000	45780
bandwdth	13774	8.448	18.270	0.000	512.000
cable	5568	0.087	0.283	0.000	1.000
call_com	246	88.003	7.551	63.660	97.850
dedd	17644	0.581	0.493	0.000	1.000
hrs10	19217	0.028	0.165	0.000	1.000
hrs20	19217	0.020	0.140	0.000	1.000
hrs35	19217	0.021	0.144	0.000	1.000
hrs50	19217	0.022	0.145	0.000	1.000
hrs80	19217	0.024	0.153	0.000	1.000
hrs100	19217	0.029	0.169	0.000	1.000
hrs150	19217	0.029	0.167	0.000	1.000
hrs250	19217	0.026	0.158	0.000	1.000
isdn	11964	0.504	0.500	0.000	1.000
limited	19217	0.212	0.409	0.000	1.000
nat_pops	1170	99.643	49.807	25.000	253.000
natdum	12582	0.101	0.301	0.000	1.000
newfirm	19217	0.382	0.486	0.000	1.000
newprod[36]	19217	0.060	0.237	0.000	1.000
ports	9702	777.719	4223.533	0.000	80000
price	19209	29.163	100.845	0.000	3200
speed	19217	43.392	91.607	14.400	1544
speed14	19217	0.003	0.059	0.000	1.000
speed28	19217	0.699	0.459	0.000	1.000
speed56	19217	0.261	0.439	0.000	1.000
speed64	19217	0.018	0.134	0.000	1.000
speed128	19217	0.015	0.120	0.000	1.000
speedT1	19217	0.004	0.060	0.000	1.000
yr93	19217	0.001	0.036	0.000	1.000
yr95	19217	0.002	0.049	0.000	1.000
yr96a	19217	0.067	0.250	0.000	1.000
yr96b	19217	0.147	0.354	0.000	1.000
yr97	19217	0.198	0.399	0.000	1.000
yr98	19217	0.294	0.456	0.000	1.000
yr99	19217	0.290	0.454	0.000	1.000

[35] Note here what variables are available and when. Also note what variables I would like to see used for this type of exercise and why.

[36] Somewhere when I use newfirm or newproduct, I need to note the co-linearity with the "year" constant that upsets the parameter estimates of the price change.

Table 8: Frequency counts for limited hours bins

Variable	Hourly limitation[37]	Count
hrs10	0-10 hours	538
hrs20	10-20 hours	382
hrs35	20-35 hours	407
hrs50	35-50 hours	415
hrs80	50-80 hours	458
hrs100	80-100 hours	563
hrs150	100-150 hours	549
hrs250	150-250 hours	493
hrgt250	>250 hours	314

[37] Each limitation includes the upper boundary but not the lower boundary. The limit "10-20" is the set of hours (10,20].

Table 9: Regression results from estimation of model (1.1)

Variable	Model Full	Restricted	Adjacent period regressions 93/95	95/96a	96a/96b	96b/97	97/98	98/99
Constant	3.282[a]	3.262[a]	4.044[a]	3.586[a]	3.104[a]	3.005[a]	2.991[a]	2.981[a]
Year95	0.313[b]	0.332[b]	0.058					
Year96a	-0.663[b]	-0.643[b]		-0.968[a]				
Year96b	-0.768[a]	-0.748[b]			-0.098[a]			
Year97	-0.776[a]	-0.757[b]				-0.028[a]		
Year98	-0.803[a]	-0.784[a]					-0.035[a]	
Year99	-0.881[a]	-0.863[a]						-0.073[a]
Limited	-0.036	0.030[a]	-1.039[a]	-0.131	-0.091	-0.070	-0.010	0.017
Hrs10*L	-0.716[a]	-0.782[a]	0.019	-0.601[a]	-0.642[a]	-0.664[a]	-0.738[a]	-0.795[a]
Hrs20*L	-0.432[a]	-0.499[a]	0.746[c]	-0.275[c]	-0.356[a]	-0.381[a]	-0.454[a]	-0.526[a]
Hrs35*L	-0.196[a]	-0.263[a]	0.562	-0.102	-0.115	-0.138	-0.229[a]	-0.274[a]
Hrs50*L	-0.030	-0.097[a]	1.025	0.101	0.071	0.029	-0.060	-0.126[a]
Hrs80*L	-0.005	-0.057[b]		-0.025	0.038	0.038	-0.019	-0.053[c]
Hrs100*L	0.104[a]			0.130	0.136[b]	0.133[a]	0.093[a]	0.070[b]
Hrs150*L	0.055[c]		0.866[b]	0.116	0.084	0.077	0.041	0.018
Hrs250*L	0.087[a]			0.241[c]	0.110	0.090[c]	0.062[c]	0.048[c]
Speed14	omitted		-0.433[c]	omitted				
Speed28	0.494[b]	0.494[c]	omitted	0.490[c]	omitted	omitted	omitted	omitted
Speed56	0.564[b]	0.564[b]				0.253[a]	0.123[a]	0.042[a]
Speed64	1.446[a]	1.446[a]		1.463[a]	0.977[a]		0.877[a]	0.852[a]
Speed128	1.998[a]	1.998[a]		1.999[a]	1.513[a]			
SpeedT1	4.748[a]	4.749[a]					4.270[a]	4.246[a]
Observations	19199	19199	71	1322	4097	6635	9471	11218
Firms	5575	5575	45	705	2988	3596	4186	5137
R^2 [38]	0.534	0.533	0.402	0.496	0.548	0.233	0.576	0.593

a - significant at <1%, b - significant at < 5%, c - significant at <10%
(robust standard errors were used throughout, including corrections for clustering by firm)

[38] Not too much should be made of the R^2 measures across regressions. The higher R^2's occur in the regressions with the high-speed (64, 128 &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.

Table 1: Direct Price Indices Calculated from Hedonic model (1.1)

Model	Restricted		93/95	95/96a	96a/96b	96b/97	97/98	98/99
Regression Coefficients								
Jan-95	0.332		0.058					
May-96	-0.643			-0.968				
Aug-96	-0.748				-0.098			
Mar-97	-0.757					-0.028		
Jan-98	-0.784						-0.035	
Jan-99	-0.863							-0.073
Indices	Cumulative	Period-to-Period						
Nov-93	1.000							
Jan-95	1.394	1.39	1.06					
May-96	0.526	0.38		0.38				
Aug-96	0.473	0.90			0.91			
Mar-97	0.469	0.99				0.97		
Jan-98	0.457	0.97					0.97	
Jan-99	0.422	0.92						0.93

Table 2: Regression results from estimation of model (1.2)

Variable	Models Full, FE	Full, RE	Restricted, RE	Adjacent period regressions – random effects specification 93/95	95/96a	96a/96b	96b/97	97/98	98/99
Constant	3.009[a]	3.136[a]	3.125[a]	3.964[a]	3.538[a]	3.104[a]	2.998[a]	2.986[a]	2.975[a]
Year95	0.335[a]	0.299[a]	0.309[a]	0.119					
Year96a	-0.428[a]	-0.516[a]	-0.505[a]		-0.824[a]				
Year96b	-0.477[a]	-0.586[a]	-0.575[a]			-0.097[a]			
Year97	-0.477[a]	-0.590[a]	-0.579[a]				-0.023[a]		
Year98	-0.499[a]	-0.613[a]	-0.603[a]					-0.030[a]	
Year99	-0.563[a]	-0.684[a]	-0.674[a]						-0.064[c]
Limited	-0.034[c]	-0.038[b]	-0.003	-0.761[a]	-0.031	-0.002	-0.003	0.016	0.021[a]
Hrs10*L	-0.663[a]	-0.682[a]	-0.717[a]	-0.260	-0.707[a]	-0.731[a]	-0.711[a]	-0.645[a]	-0.688[a]
Hrs20*L	-0.299[a]	-0.350[a]	-0.385[a]	0.597[c]	-0.363[a]	-0.446[a]	-0.391[a]	-0.396[a]	-0.416[a]
Hrs35*L	-0.094[a]	-0.147[a]	-0.181[a]	0.204	-0.173	-0.205[a]	-0.172[a]	-0.215[a]	-0.229[a]
Hrs50*L	-0.055[c]	-0.044[c]	-0.079[a]	0.543	-0.018	-0.019	-0.043	-0.101[a]	-0.124[a]
Hrs80*L	-0.017	-0.007	-0.034[c]		-0.100	-0.030	0.010	-0.044[c]	-0.056[b]
Hrs100*L	0.005	0.056[b]							
Hrs150*L	0.029	0.040[c]							
Hrs250*L	0.074[a]	0.079[a]	0.044[b]	omitted	0.177	0.021	0.030	0.024	0.018
Speed14	omitted	omitted	omitted	-0.401	omitted				
Speed28	0.464[a]	0.450[a]	0.450[a]		0.391	omitted	omitted	omitted	omitted
Speed56	0.538[a]	0.522[a]	0.523[a]				0.276[a]	0.139[a]	0.048[a]
Speed64	1.401[a]	1.389[a]	1.390[a]		1.367[a]	0.978[a]		0.917[a]	0.883[a]
Speed128	1.944[a]	1.934[a]	1.934[a]		1.897[a]	1.514[a]			
SpeedT1	4.697[a]	4.688[a]	4.689[a]					4.254[a]	4.237[a]
Observations	19199	19199	19199	71	1322	4097	6635	9471	11218
Firms	5575	5575	5575	45	705	2988	3596	4186	5137
R^2	0.529	0.532	0.532	0.378	0.496	0.547	0.233	0.574	0.593

a - significant at <1%, b - significant at < 5%, c - significant at <10%

Table 3: Direct Price Indices Calculated from Hedonic model (1.2)

Model	Restricted		93/95	95/96a	96a/96b	96b/97	97/98	98/99
Regression Coefficients								
Jan-95	0.309		0.119					
May-96	-0.505			-0.824				
Aug-96	-0.575				-0.097			
Mar-97	-0.579					-0.023		
Jan-98	-0.603						-0.03	
Jan-99	-0.674							-0.064
Indices	Cumulative	Period-to-Period						
Nov-93	1.000							
Jan-95	1.362	1.36	1.13					
May-96	0.604	0.44		0.44				
Aug-96	0.563	0.93			0.91			
Mar-97	0.560	1.00				0.98		
Jan-98	0.547	0.98					0.97	
Jan-99	0.510	0.93						0.94

Table 4: Regression results from estimation of model (1.2) - 28.8k Speed Plans only

Variable	Model (1.2) Full Sample	28.8 (1.2) Sub sample	Adjacent period regressions 93/95	95/96a	96a/96b	96b/97	97/98	98/99
Constant	3.136 [a]	3.110[a]	3.614[a]	3.566[a]	3.088[a]	2.997[a]	2.978[a]	2.968[a]
Year95	0.299 [a]	0.305[a]	0.049					
Year96a	-0.516 [a]	-0.604 [a]		-0.937[a]				
Year96b	-0.586 [a]	-0.677 [a]			-0.073[a]			
Year97	-0.590 [a]	-0.697 [a]				-0.020[a]		
Year98	-0.613 [a]	-0.704 [a]					-0.007[b]	
Year99	-0.684 [a]	-0.738 [a]						-0.036[a]
Limited	-0.038 [b]	-0.048 [a]	-0.912[a]	-0.128	-0.082[b]	-0.095[a]	0.004	0.004
Hrs10*L	-0.682 [a]	-0.725 [a]	-0.119	-0.603[a]	-0.680[a]	-0.650[a]	-0.743[a]	-0.793[a]
Hrs20*L	-0.350 [a]	-0.353 [a]	0.742[b]	-0.279[a]	-0.363[a]	-0.296[a]	-0.430[a]	-0.477[a]
Hrs35*L	-0.147 [a]	-0.164 [a]	0.364	-0.100	-0.134[a]	-0.103[a]	-0.228[a]	-0.252[a]
Hrs50*L	-0.044 [c]	-0.026	0.721	0.101	0.034	0.061[c]	-0.068[b]	-0.113[a]
Hrs80*L	-0.007	0.002		-0.027	0.044	0.089[a]	-0.054[b]	-0.052[b]
Hrs100*L	0.056 [b]	0.060[a]		0.129	0.102[b]	0.153[a]	0.009	0.065[a]
Hrs150*L	0.040 [c]	0.043[b]	0.829	0.114	0.066	0.082[b]	0.028	0.014
Hrs250*L	0.079 [a]	0.082[a]		0.242[b]	0.044	0.114[a]	0.035	0.052[b]
Speed14	omitted	[redacted]	[redacted]	[redacted]	–	–	–	–
Speed28	0.450 [a]	omitted	omitted	omitted	–*	–*	–*	–*
Speed56	0.522 [a]	–	–	–	–	–	–	–
Speed64	1.389 [a]	–	–	–	–	–	–	–
Speed128	1.934 [a]	–	–	–	–	–	–	–
SpeedT1	4.688 [a]	–	–	–	–	–	–	–
Obs	19199	13484	71	741	3516	6189	7339	6530
Firms	5575	5282	45	697	2981	3590	4173	4835
R^2 [39]	0.532	0.533	0.394	0.291[40]	0.257	0.242	0.2251	0.209

a - significant at <1%, b - significant at < 5%, c - significant at <10%

[*] For these time periods, the only available speeds are 28.8 and higher. Because all high-speed plans are dropped from the data, any speed variable is collinear with the constant term in the regression.

[39] Not too much should be made of the R^2 measures across regressions. The higher R^2's occur in the regressions with the high speed (64, 128 &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.

[40] 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 14.4 plans remain. The balance of the observations are 28.8 speed.

Table 14: Direct Price Indices Calculated from Hedonic model (1.2)
28.8k Speed plans only

Model	Restricted		93/95	95/96a	96a/96b	96b/97	97/98	98/99
Regression Coefficients								
Jan-95	0.305		0.049					
May-96	-0.604			-0.937				
Aug-96	-0.677				-0.073			
Mar-97	-0.697					-0.02		
Jan-98	-0.704						-0.007	
Jan-99	-0.738							-0.036
Indices	Cumulative	Period-to-Period						
Nov-93	1.000							
Jan-95	1.357	1.357	1.050					
May-96	0.547	0.403		0.392				
Aug-96	0.508	0.930			0.930			
Mar-97	0.498	0.980				0.980		
Jan-98	0.495	0.993					0.993	
Jan-99	0.478	0.967						0.965

Table 15: GVU WWW Survey data - Internet connection speeds[41]

ISP	Date	Unknown	<14.4	14.4	28.8	33.6	56	128	1mb	4mb	10mb	45mb	Total
Jan-95	Apr-95	517	402	2930	810		284	83	393	138	806	84	6447
	Oct-95	1514	140	3407	2822		397	188	528	234	995	156	10381
May-96	Apr-96	451	32	1106	1749		155	129	541	77	133	29	4402
Aug-96	Oct-96	644	32	1579	4291		240	232	748	120	150	50	8086
Mar-97	Apr-97	1272	42	1393	4584	2558	362	464	1541	280	276	112	12884
	Oct-97	1471	17	324	1368	1753	377	201	591	102	117	44	6365
Jan-98	Apr-98	544	11	243	1558	1611	1242	182	707	124	133	47	6402
Jan-99	Oct-98	85	2	37	349	388	760	98	288	71	47	82	2207

Table 16: Comparison of *Boardwatch* to GVU plan speeds

Boardwatch ISP Data				GVU Survey Data			
Date	28.8 plans	56k plans	ratio	Date	28.8-33.6plans	56k plans	ratio
Mar-97	3367	446	7.55	Apr-97	7142	362	19.73
Jan-98	3972	1554	2.56	Apr-98	3169	1242	2.55
Jan-99	2562	3006	0.85	Oct-98	737	760	0.97

[41] Data presented is extracted from surveys 3-10 and represents counts of respondents from the U.S. only.

Table 17: Counts of price plans by entrants and incumbents over time

	Observation date						
Price plans (N)	Nov-93	Jan-95M	ay-96	Aug-96	Mar-97	Jan-98J	an-99
Incumbent	0	17	81	536	2,942	4,557	3,747
Entrant	25	30	1,202	2,286	871	1,102	1,821

Table 18: Counts of price plans by vintages and time

	Observation date						
Price plans (N)	Nov-93	Jan-95M	ay-96	Aug-96	Mar-97	Jan-98J	an-99
Vintage93	25	17	38	16	18	26	12
Vintage95		30	43	13	14	20	15
Vintage96a			1,202	507	556	669	460
Vintage96b				2,286	2,354	2,848	1,914
Vintage97					871	994	634
Vintage98						1,102	712
Vintage99							1,821

Table 19: Regression results from estimation of model (1.3) that includes Entrants and vintages

Variable	Models Entrant	Entrants/Year	Vintages	Entrants/Vintage
Constant	3.164[a]	3.045[a]	3.293[a]	3.149[a]
Year95	0.293[a]	0.367[a]	0.325[a]	0.401[a]
Year96a	-0.524[a]	-0.251	-0.470[a]	-0.210
Year96b	-0.599[a]	-0.457[b]	-0.528[a]	-0.387[b]
Year97	-0.614[a]	-0.473[a]	-0.529[a]	-0.391[b]
Year98	-0.639[a]	-0.497[a]	-0.553[a]	-0.412[b]
Year99	-0.710[a]	-0.562[a]	-0.618[a]	-0.476[a]
Limited	-0.038[b]	-0.038[b]	-0.038[b]	-0.038[b]
Hrs10*L	-0.683[a]	-0.683[a]	-0.683[a]	-0.683[a]
Hrs20*L	-0.351[a]	-0.350[a]	-0.351[a]	-0.350[a]
Hrs35*L	-0.147[a]	-0.148[a]	-0.148[a]	-0.149[a]
Hrs50*L	-0.045[c]	-0.044[c]	-0.045[c]	-0.045[c]
Hrs80*L	-0.008	-0.007	-0.007	-0.006
Hrs100*L	0.055[a]	0.055[b]	0.055[b]	0.054[b]
Hrs150*L	0.039[b]	0.040[c]	0.039[c]	0.040[c]
Hrs250*L	0.079[a]	0.079[a]	0.078[a]	0.078[a]
Speed14	omitted	omitted	omitted	omitted
Speed28	0.453[a]	0.429[a]	0.464[a]	0.438[a]
Speed56	0.526[a]	0.502[a]	0.536[a]	0.510[a]
Speed64	1.392[a]	1.367[a]	1.403[a]	1.375[a]
Speed128	1.937[a]	1.910[a]	1.947[a]	1.919[a]
SpeedT1	4.692[a]	4.669[a]	4.700[a]	4.675[a]
Entrant	-0.017[a]	0.124		0.144
New*96a		-0.280[a]		-0.270[a]
New*96b		-0.141		-0.145
New*97		-0.127		-0.133
New*98		-0.124		-0.141
New*99		-0.162[c]		-0.379[a]
Vintage95			-0.059	-0.097
Vintage96a			-0.189[a]	-0.156[b]
Vintage96b			-0.230[a]	-0.200[a]
Vintage97			-0.251[a]	-0.226[a]
Vintage98			-0.229[a]	-0.202[a]
Vintage99			-0.264[a]	
Observations	19199	19199	19199	19199
Firms	5575	5575	5575	5575
R^2	0.533	0.533	0.534	0.534

a - significant at <1%, b - significant at < 5%, c - significant at <10%

Table 20: Regression results from model (1.4)
(includes new products and entrants)

Variable	Models NewProducts	New56k	NewProducts w/Entrants
Constant	3.135	3.135	3.166
Year95	0.297	0.297	0.290
Year96a	-0.305	-0.519	-0.314
Year96b	-0.376	-0.590	-0.390
Year97	-0.398	-0.612	-0.424
Year98	-0.394	-0.608	-0.422
Year99	-0.458	-0.672	-0.486
Limited	-0.040	-0.040	-0.041
Hrs10*L	-0.676	-0.676	-0.677
Hrs20*L	-0.343	-0.343	-0.344
Hrs35*L	-0.141	-0.141	-0.141
Hrs50*L	-0.038	-0.038	-0.039
Hrs80*L	0.000	0.000	-0.001
Hrs100*L	0.060	0.060	0.060
Hrs150*L	0.042	0.042	0.042
Hrs250*L	0.081	0.081	0.080
Speed14	omitted	omitted	omitted
Speed28	0.239	0.453	0.241
Speed56	0.286	0.499	0.288
Speed64	1.179	1.392	1.181
Speed128	1.724	1.938	1.726
SpeedT1	4.471	4.684	4.473
New56		0.214	
NewBoth	0.214		0.215
Entrant			-0.019
Observations	19199	19199	19199
Firms	5575	5575	5575
R^2	0.535	0.535	0.536

a - significant at <1%, b - significant at < 5%, c - significant at <10%

Table 21: Regression results from model (1.5)
(includes firm age and new products)

Variable	Models Standard RE Model (1.2)	Firm Age w/new products
Constant	3.136[a]	3.176
Year95	0.299[a]	0.286
Year96a	-0.516[a]	-0.333
Year96b	-0.586[a]	-0.406
Year97	-0.590[a]	-0.439
Year98	-0.613[a]	-0.450
Year99	-0.684[a]	-0.528
Limited	-0.038[b]	-0.041
Hrs10*L	-0.682[a]	-0.677
Hrs20*L	-0.350[a]	-0.344
Hrs35*L	-0.147[a]	-0.142
Hrs50*L	-0.044[c]	-0.039
Hrs80*L	-0.007	-0.001
Hrs100*L	0.056[b]	0.060
Hrs150*L	0.040[c]	0.042
Hrs250*L	0.079[a]	0.081
Speed14	omitted	omitted
Speed28	0.450[a]	0.236
Speed56	0.522[a]	0.283
Speed64	1.389[a]	1.176
Speed128	1.934[a]	1.721
SpeedT1	4.688[a]	4.468
FirmAge		0.002
NewBoth		0.214
Observations	19199	19199
Firms	5575	5575
R^2	0.532	0.536

a - significant at <1%, b - significant at < 5%, c - significant at <10%

Table 22: Estimated price premiums by firm age

Firm Age	Beta*FirmAge	Price Premium
1 Year	0.021	2.1%
2 Years	0.042	4.3%
3 Years	0.062	6.4%
4 Years	0.083	8.7%
5 Years	0.104	11.0%

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