NORTHWESTERN UNIVERSITY

Hedonic Price Indices In Rapidly Changing Markets: Studies Of Pricing In The Internet Service Provider And DVD Markets

A DISSERTATION

SUBMITTED TO THE GRADUATE SCHOOL
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

for the degree

DOCTOR OF PHILOSOPHY

Field of Managerial Economics and Strategy

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EVANSTON, ILLINOIS
December 2007

ABSTRACT

Hedonic Price Indices In Rapidly Changing Markets: Studies of ISP pricing and behavior and pricing in the DVD market

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This dissertation considers price indices in the context of two rapidly growing markets. The first is the emerging market for Internet Service Providers in the mid-1990s. The second is the emergence and growth of the DVD hardware market. In both, we examine indices ranging from the most rudimentary to quality adjusted hedonic models. In the context of the ISPs, we also use this framework to study firm behavior and the development of industry structure.

The results show decisively that ISP prices have been falling rapidly over time. The bulk of the price decline is in the early years of the sample, especially the period between early 1995 and spring of 1996, but a significant and steady decline continues throughout. We conclude that ignoring aspects of quality underestimates the price declines. It also alters the timing of the measured declines. The results also show that there are links between changes in market structure and ISP pricing. Entry lowered prices, and later entrants entered with differentially lower prices than earlier entrants. Both of these facts are consistent with positive sorting through entry. We also conclude that ignoring aspects of quality underestimate the price declines. It also alters the timing of the measured declines.

In the DVD hardware market, this study shows that prices have been falling at a ~24% compounded annual rate since the product's introduction in the marketplace. This is significantly faster than the results garnered from elementary price indices or matched models

methods with the same data sample. The paper shows that the hedonic framework is suitable for such rapidly growing and changing product markets. This paper demonstrates that it is the easily discernable high level features of DVD hardware that drive most of the variability in price. Brand also impacts price but the impact has less explanatory power than the high level features of the DVD hardware itself. The hedonic pricing results and the pricing indices created are extremely robust to various specifications. The results on qualitative measures of quality suggest that they are not significant determinants of the price in the hedonic model used here.

ACKNOWLEDGEMENTS

I thank Pat Bajari, Ernst Berndt, David Dranove, Chris Forman, Barbara Fraumeni, Avi Goldfarb, Zvi Griliches, Brent Moulton, Mark Roberts, Scott Stern, Manuel Trajtenberg, Jack Triplett and several anonymous reviewers for comments and suggestions. I also thank my dissertation committee, David Dranove, Mike Mazzeo and Eric Anderson for their guidance, assistance and patience. Above all, I thank my PhD advisor Shane Greenstein for his efforts and inspiration to help me to bring this project to fruition.

I received funding from the National Science Foundation, the Bureau of Economic Analysis, Northwestern University and the Kellogg School of Management. All errors are my own responsibility.

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Chapter 1 - Introduction

This dissertation considers price indices in the context of two rapidly growing markets. The first is the emerging market for Internet Service Providers in the mid-1990s. The second is the emergence and growth of the DVD hardware market. In both, we examine indices ranging from the most rudimentary to quality adjusted hedonic models. In the context of the ISPs, we also use this framework to study firm behavior and the development of industry structure.

In this paper we investigate 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 providers followed the same technological trajectory. This helps us construct indices without data on market share, which we lack. Third, and somewhat independently, broadband began to diffuse just near the end of our sample. After a few years it connected enough households to influence Internet price indices and would require us to alter the procedures carried out in this paper. Finally, Spring 2000 marks the end of unqualified optimism about the persistence of the Internet boom. This change in mood was affiliated with restructuring of the ISP industry, potentially bringing about a marked departure in price trends.

Along the way, we are able to evaluate determinants of ISP pricing in the hedonic model framework and demonstrate usefulness of the hedonic framework for a service good – using features of contracts instead of physical attributes. The various specifications allow us to

compare price indices and demonstrate the impact of quality adjustments on price trajectories and investigate the impact of various specifications on the hedonic model and the price indices.

Using this new dataset, we computed a variety of price indices, ranging in sophistication from very crude averages to quality adjusted ones based on hedonic models. The results show decisively that ISP prices have been falling rapidly over time. The bulk of the price decline is in the early years of the sample, especially the period between early 1995 and spring of 1996, but a significant and steady decline continues throughout. We conclude that ignoring aspects of quality underestimates the price declines. It also alters the timing of the measured declines.

The next section of this dissertation investigates the relationship between pricing and the introduction of new services and/or entry of new firms. Using a new dataset about the earliest period of this industry, we compute a variety of hedonic price indices under many different methods. We then consider how this index changes when we compare continuing firms with entrants, or firms providing existing services with those providing new services, such as faster modem speeds. We begin with the earliest point when we could find data, 1993, when the commercial ISP market was still nascent. We stop in 1999, after a long period of demand growth, firm entry and instability.

One of our primary goals is to understand how introduction of new services, entry, and exit shapes prices. This is part of a broad agenda to understand the relationship between evolution in market structure and firm pricing in young markets. Specifically, the ISP market is a spatially segregated industry with growing demand, comparatively small fixed costs, and fast paced technology change. Many, but not all, ISPs offer more than one type of contract for service. Physical attributes are not key features of the service, but features of the contract for service are. These

features can improve 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.

Using the same ISP dataset this study computed the sensitivity of a variety of price indices to the entry and exit of firms. New firms enter the market at a small but significant price discount to established incumbents. The introduction of new products/technologies also are priced at a significant price premium to the existing offerings, but the premium decline quite rapidly. ISPs who survive tend to have higher prices than younger firms. This bias interacts with the evolution of the market. When new entrants gain market share, prices are driven down by entry. As incumbent firms solidify their market shares in a growing market, the pricing of incumbent firms does not decline as much when new entrants appear. Lastly, we find that exit plays a small role in shaping pricing in comparison to entry.

The results show decisively that there are links between changes in market structure and ISP pricing. Entry lowered prices, and later entrants entered with differentially lower prices than earlier entrants. Both of these facts are consistent with positive sorting through entry. We also conclude that ignoring aspects of quality underestimate the price declines. It also alters the timing of the measured declines.

The goal of this study is to use a new dataset to extend the existing literature on hedonic models for DVD hardware and construct a quality adjusted price index covering the time period from the introduction of the DVD through September 2005. This paper addresses the determinants of DVD hardware prices in the hedonic model context. It examines the impact of high level capabilities, characteristics and features, brand impact and combinations of these

factors on DVD hardware prices. In parallel, the paper examines the impact of those various specifications on the estimates of the hedonic model and the price indices. Using review data from *Consumer Reports*, this paper also examines the impact of qualitative measures of quality on the prices of DVD hardware and how those qualitative factors impact the price index.

The hedonic price indices constructed in this paper show that DVD hardware prices have been falling at a ~24% compounded annual rate since the product's introduction in the marketplace and through the eight years of the sample data. This is significantly faster than the results garnered from elementary price indices or matched models methods with the same data sample. The paper shows that the hedonic framework is suitable for such rapidly growing and changing product markets and is an improvement over typical BLS methods. This paper demonstrates that it is the easily discernable high level features of DVD hardware (i.e. multiple discs, recorder, portable, combo DVD/VCR, progressive scan) that drive most of the variability in price. Lesser known, more esoteric or features largely common to most DVD hardware do not appear to have a significant impact on price. Brand is another easily observerable characteristic of DVD hardware. This paper finds that brand impacts price but the impact has less explanatory power than the high level features of the DVD hardware itself. The hedonic pricing results and the pricing indices created are extremely robust to various specifications. The results on qualitative measures of quality suggest that they are not significant determinants of the price in the hedonic model used here. There is no way to reach a conclusion as to whether this is a feature of this dataset or if quality differences among DVD hardware are truly too difficult to discern.

This dissertation has made many unique contributions to the hedonic literature and the literature on the evolution of rapidly growing markets. In this study we have developed two new substantial datasets on pricing during the early history of ISP and DVD markets and established benchmark hedonic price indices for the early history of the ISP and DVD markets. In both markets we demonstrated determinants of pricing and demonstrated the substantial differences between price indices with hedonic quality adjustments and other methodologies. This dissertation claims other unique additions to the literature. It is the first study to extend the hedonic literature to a service good (ISP). It is the first study to employ the hedonic framework to investigate interaction between market evolution and firm pricing behavior (ISP). It also the first to evaluate impact of qualitative reviews in a hedonic framework for a durable good (DVD). Each of these accomplishments is an advancement and the whole of the study stretches and extends the literature on hedonic pricing and the evolution of rapidly growing markets.

Chapter 2 - Price Indices: Review of previous research

Price indices have a long intellectual history. Along with that history, a economic literature has developed in which considers many aspects of the measurement of prices. These papers on price indices range from mainly theoretical works on index numbers to more recent empirical work, calculating and comparing different price indices. I will focus largely on the empirical branch of the literature, which was revived by Griliches' (1961) paper on hedonic price indices for automobiles. The range of goods treated in the literature ranges from asparagus to various types of computers, and semiconductors to warships. In all cases, the empirical literature has only considered physical goods; no examination of service goods has yet been completed. In this section, I will summarize the developments and issues raised in the earliest work and show more recent examples of the developments and applications in this literature.

The most pressing issue in all of the empirical literature is how to account for changing quality within the calculation of price indices. The basic argument is that in an economy where the "quality" of goods and services is largely increasing, tracking prices without taking those changes in "quality" into account will result in price indices that are fundamentally flawed. The traditional argument goes further and states that the flaw will result in an upward bias in the calculation of traditional price indices and an overstatement of inflation. This flaw and possible mismeasurement of price indices is agnostic as to whether the product is a durable good or a service. Griliches (1961) opens the debate by addressing this problem with an investigation of the feasibility and usefulness of hedonic price indices for automobiles.

Griliches' (1961) main question in his paper was to consider whether it was feasible and worthwhile to adjust for quality changes when calculating price indices. The reasoning was that

since newer models of goods often had higher quality or more desired characteristics, the difference between the prices of the newer and the older models should not be entirely attributed to inflation (as it was by the traditional government indices). Griliches also noted that if we build our price indices entirely from inter-period price comparisons of goods sold in both periods, and never compare "old" to "new" goods directly, we will never capture the effect that switching to new goods has on welfare, and this will bias price index calculations upward. Griliches suggests estimating a model which relates prices to characteristics, and then using the estimated model to obtain estimates of "quality adjusted" price changes for products with given sets of characteristics. This is known as the hedonic price index method.

Griliches studies auto prices and quality with data from 1937, 1950, 1954-1960. He notes that some changes in quality have explicit prices because they were previously offered as optional equipment and priced as an extra. The example he refers to is the automatic transmission. If this is the quality change, then price indices can readily be adjusted because we know the "value" of the quality that has been added to the automobile in one year that was not present before. However in the cases of weight, length, engine size, etc. there is no price set specifically for the differing equipment, so the adjustment cannot be made. He notes that regression techniques can help to overcome this difficulty and find implicit prices for quality changes. His goal is to use these techniques to investigate and illustrate the quality adjusted price indices for automobiles using data from 1937, 1950, and 1954-1960.

Griliches argues that hedonic regression methods can be used to calculate predicted prices $\hat{P}$ based on the characteristics of the good. Using the empirical model of one year and the goods and characteristics of an adjacent year allows the calculation of the predicted price of the

good in an adjacent period. If the level of characteristics has changed, the model will predict a different price. This change between these two prices is the quality adjusted price shift. This only works with characteristics that exist in both years. New characteristics cannot be encompassed in the model during their first year, but some degree of quality adjustment is better than none at all.

Griliches uses the log-linear regression form, with some characteristics represented as continuous variables and some characteristics represented as dichotomous variables. The importance of any one dimension of quality (a particular characteristic) is an empirical question, and Griliches emphasizes that the model itself calculates those characteristics where minor changes in quality can be ignored. (Because the implicit price is not meaningfully different from zero). As such, he emphasizes using quantifiable characteristics even if they themselves are not a desired characteristic of the product. They may represent an unmeasured or unmeasurable quality. Similarly, the dichotomous variables do not necessarily measure the consequence of the presence or absence of any particular feature. The dichotomous variables stratify the sample based on the measured feature and other correlated characteristics that may be difficult or impossible to measure. Griliches seems to ignore the problem. This is because the focus is not on the implicit prices themselves, so omitted variable bias is not an issue and nor is its affect on the parameter estimates for the coefficients of the characteristics. It is unclear that this is any less problematic than it would be in other settings.

Using the regression model, Griliches demonstrates the calculation of price indices from adjacent regressions with a dichotomous variable marking the 2nd time period. In this model with the log-linear form, the price change from year to year is obtained by exponentiating the

estimated parameter of the "year" dichotomous variable. Using the adjacent years method is equivalent to restricting the price-characteristic relationship to be the same in both years, but allowing the intercept to vary by year. Griliches notes that this is more likely to be valid (and the parameter estimates stable) when the time periods are adjacent. If models span many years, it is possible that the marginal value of certain characteristics may change and then the model would be overly restrictive. Griliches does also calculate an index based on a single regression across the entire sample period, using a dichotomous variable for each year except the base year. The method to calculate the index is exactly the same as in the adjacent year case.

Griliches also calculates regression models using a cross-section of the data from each single year. Using these yearly regressions, he computes $\hat{P}_0(X_0)/\hat{P}_0(X_1)$ where $\hat{P}_0$ is calculated from the base period regression equation, f_0. This is calculating the new estimated price of goods from the next adjacent period as if their characteristics were valued according to the model from the base period. This is similar to the Laspeyres index.

Griliches notes that ideally his indices would weight different models by volume produced/sold, but he lacks the data. Griliches states that using equal weights for all model observations causes overweighting of certain products (versus market share weightings), which can bias the results. In his results, he states that he is giving too much weight to high and medium priced cars. The direction of the bias in the price index is unclear.

When Griliches discusses the calculation of the auto portion of the CPI, he struggles to explain why the BLS results are closer to the quality-adjusted prices than their methods allow. He speculates that instead of using "exact" matches of autos from year to year, BLS personnel

may have used the prices for very similar models (in terms of features and design) that occupied similar positions in a manufacturer's product line. Doing so would violate the strict matching of the BLS method and would allow new goods and changing quality to enter the price index. This may explain why the BLS results seem to correspond to the hedonic results and are lower than the price indices calculated by others at the time.

Many of the results in Griliches (1961) are relatively surprising. Firstly, the majority of the dispersion in automobile prices can be modeled using a reasonably small number of characteristics of the good. Secondly, in traditional indices the period from 1954-60 showed substantial increases in car prices. Griliches' results indicate that those increases are readily explained by quality improvements and that hedonic quality adjusted prices actual fell over the period. The work validated the use of hedonic price functions to account for "quality change" when computing price indices for rapidly changing goods.

As I stated earlier, these surprising and provocative results spurred further empirical investigation into the effects of quality changes and new goods on price indices. In a pattern that repeats itself later with computers, Tripplett (1969) continues the work of Griliches and investigates the affect on price indices of quality change among automobiles.

Triplett revisits many of the questions and conclusions of Griliches while pointing out some less than desirable properties of the hedonic method. Triplett begins by repeating Griliches' analysis on a similar sample of automobiles (4 door sedans) from a different observational period (1960-65). Triplett shows that in this period there is little or no quality improvement in automobiles. There is also little evidence for any bias that resulting from using the "matched model" method to calculate the CPI. The paper explains that the hedonic method

itself may impart certain biases to the measurement of price indices and care must be taken when using it.

Triplett begins by repeating Griliches method and analysis on a similar sample of automobiles from 1960-1965. His regressions show that again much of the variation in prices is explained by a relatively small set of characteristics of the automobiles. Using the same adjacent year regression methods, he then computes hedonic price indices and compares them to the CPI index. Surprisingly, the hedonic index shows prices increasing over the time period whereas the CPI index shows them decreasing. This is exactly in opposition to the commonly held belief about the nature of bias in traditional methods and the outcome should hedonic methods be used to correct it. Triplett's results show that there appears to be no upward quality bias to the CPI calculations in 1960-1965 and that Griliches' results from the earlier sample (1954-1960) cannot be extrapolated outside that timeframe or necessarily to other goods or components of the CPI.

In light of the Griliches results, Triplett finding the opposite difference between BLS and hedonic results seems surprising. Triplett disposes of two possible sources of bias by testing his results on the same sample as the BLS. He finds the same results and also confirms that the results are not an artifact of the regression methodology (using the exponentiated coefficients of the dichotomous variables for time of the log-linear model to calculate the price index) nor an artifact of the differing samples. Remarkably, what is happening is that actual prices are staying relatively constant, but the quality as measured by the hedonic model is actually decreasing. This results in the increase of quality-adjusted prices.

Triplett investigates these results more deeply because they seem to be contradicting other available evidence. According to the paper, it was quite clear that the quality of

automobiles and the quantity of valuable features were increasing throughout the observational period. Triplett shows that weight is the one characteristic of the cars that is driving the majority of the regression results. In fact, weight is highly correlated with almost all measurable and unmeasurable aspects of quality in automobiles. Triplett shows convincingly that the traditional "omitted variable bias" is at work here. Over this time period, because of manufacturing and design breakthroughs, the weight of cars is decreasing. With weights decreasing but quality increasing, the coefficient on the yearly dichotomous variable is biased upward and results in the apparent increasing quality adjusted prices. Triplett further explains that this is simply a drawback of the hedonic approach. Triplett also notes that the hedonic approach cannot account for a quality shift that is common across all products. A contemporary example might be mandatory airbags. When introduced in all models simultaneously, the change in quality is econometrically unidentifiable. Any change in price due to the airbag is attributed to the dichotomous time variable and all else equal, there will be no difference between the quality adjusted and unadjusted price indices. While Griliches emphasized focusing on the measurable characteristics of the product, Triplett responds that without the ability to focus on characteristics that are actually desirable, the hedonic method may create biases rather than adjust for them.

A more recent account of the hedonic method, its origins and its applications can be found in Berndt (1991). In chapter 4 of this text, Berndt develops the concepts of price indices and the hedonic approach. He uses the example of a price index for computers, which is the subject of Bernt & Griliches (1993) and Bernt, Griliches & Rappaport (1995), both of which are described below.

Bernt notes that the greatest difficulty facing price indices is for goods whose specifications and characteristics are changing rapidly over time. This is an even more general statement of the "quality" problem. Even if "quality" were constant, but characteristics are changing, the traditional price index computation methods (primarily matching the exact good or service across time periods) are infeasible. Thus hedonic methods are not aimed solely at improving price index measurement, but in some cases making it feasible at all.

Berndt first explains the traditional method for calculating price indices. To control for the effects of quality change over time, economists and statisticians have traditionally used a "matched model" approach. With this method, the only prices used in calculating an index are those for which the good has exactly the same specifications from one period to the next. Bernt points out that this method has its flaws. It is possible that the method suffers from a version of a 'selection' bias. If the price trend for goods that are equivalent in adjacent periods is different than the price trend for the remaining sphere of goods, then the price index will be biased. A second bias may result when goods are "matched" but actually differ on unmeasured features or characteristics. These two errors are substitutes. The more 'exact' the match, the smaller sample of goods that will appear in the index. With less 'exact' matching the sample is smaller, but the control for the effect of quality change is enhanced. Berndt suggests that regression analysis and the hedonic method can lessen these tradeoffs while adjusting for quality change and avoiding the difficulties mentioned above.

Berndt recounts some of the early empirical literature that was concerned estimating the price-quality relationship. Waugh (1927) was the first to try and estimate the price-quality relationship in a cross-sectional analysis of asparagus. Court (1939) faced the question of

quality-adjusted prices in his research study linking price and sales for GM automobiles. Berndt mentions (as did Griliches) that Court developed what is now called "the hedonic method." (modeling prices and characteristics with regression analysis) Court was also the first to estimate the price-quality relationship in a panel dataset. His results showed that auto prices had been significantly declining on a "quality-adjusted" basis over the time period of his observations (1925-1927). Modern economists have modified Court's derivation and principles, but his framework formed the basis for Griliches (1961) and most other hedonic price investigations. I should note briefly that the common citation for hedonic theory is Rosen (1974).

Bernt also describes the early work of Chow (1967) on price indices for computers. In his paper, Chow takes the same hedonic framework and applies it to prices for computers for the time period 1960-1965. Chow finds that quality adjusted prices for computers are falling at an average rate of 20% per year. Government price indices for computers remained unchanged over the same time period. Chow's work built on Griliches' and showed that BLS/BEA methods can be very inadequate. Chow's paper was important because it confirmed Griliches main argument for the hedonic framework by using a different industry and a different time period. Bernt notes that Chow's work begins a long stream of studies that examine price indices for computers. Many of these works are summarized by Triplett (1989), but also include the work done by Berndt himself in the papers summarized below.

Berndt notes that several econometric issues complicate the use of the hedonic framework. Like many problems in regression, hedonic price analysis often suffers from heteroskedasticity of the error term. Using weighted least squares can correct for this problem in the linear model. Another difficulty is the choice of a parametric functional form. The work

described by Court, Griliches and Chow all used a log-linear model, but Berndt explains that nearly every possible functional form has been used in the literature, partly because the underlying theory imposes no restrictions on the functional form of the regression model. Berndt mentions that one statistical approach is to use the Box-Cox transformation to test a variety of different specifications. Berndt also repeats some of the commentary given by Triplett above concerning the choice of characteristics, the omitted variable problem and the consequences for parameter estimation. Berndt does note that these are standard econometric problems and that solutions from other settings are being applied in the current hedonic literature.

As I mentioned above, outside of his textbook, Berndt has also contributed directly to the Hedonic Price Index literature. In two separate papers, Bernt & Griliches (1993) and Bernt, Griliches & Rappaport (1995), Bernt and his colleagues estimate hedonic indices for personal computers and laptops.[1] In the next section, I will describe their methods and results as extensions of the earlier hedonic literature.

BG (1993)[2] focuses on estimating a hedonic price index for personal computers. Although many studies had been completed on price indices for computers, all the existing studies were concerned with mainframe computers.[3] In this paper, the authors consider price and characteristics data on personal computers from 1982-1988. They have data for list prices for

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[1] Hereafter I will refer to Bernt and Griliches (1993) as BG (1993) and Berndt, Griliches and Rappaport (1995) as BGR (1995).

[2] Cole's commentary on this work attacks the use of processor speed as a characteristic, saying that actual working speed (benchmarked speed incorporating memory and disk-access) would be more appropriate. This echoes the issue with modem speed in the ISP price plans. Actual speeds achieved are not only unmeasured, but also vary among providers and customers depending on equipment and line conditions.

[3] See the work of Chow (1967), Gordon (1989) or Triplett (1989) for examples of this literature.

some models, discount or mail-order transaction prices for others and data from both sources on some models as well. This was a time of tremendous change in the personal computer industry with a great deal of entry and exit of a variety of computer models and manufacturers. The authors seek to construct a methodology that encompasses the simultaneous existence of entering, incumbent and exiting products all of which are competing both in quality and price. Their goal is to disentangle the changing nature of quality and produce a price index that accounts for models that survive over time and the unmeasured aspects of quality embedded in those models. The key to their analysis is the concept of time, age and vintage. Time is the year of the observation. Age is the length of time that has passed since the model was introduced. Vintage is the year in which a particular model was introduced. This results in the identity

$$Time = Vintage + Age$$

Berndt et al. show that these three variables cannot be used in a traditional hedonic model because of the colinearity created by the identity. However if they are used as dichotomous variables, Berndt et al. are able to incorporate all three effects in a hedonic regression. This allows the authors to examine whether surviving models are priced at a premium and how prices of surviving vintages change when new models are introduced with technological innovations.

Using this methodology and incorporating Time/Age, Age/Vintage and Time/Age/Vintage effects, Berdt et al. present a number of quality adjusted hedonic price indices for personal computers. Although the pattern of each index is different, the average annual growth rate (hereafter AAGR[4]) over the 1982-1988 time is relatively consistent. The AAGRs of

[4] Average annual growth rate – computed using simple annual compounding

the indices range from –26.1% for the Vintage/Age pooled regression to –30.1% in a model that breaks the time period up into 3 discrete periods and only constrains the characteristics' coefficients to be equal within periods.[5] These results compare with the BEA index that has an AAGR of –20.33% from 1982-1988. In the results given, all models are weighted equally regardless of their true market share or sales. To account for the changing mix of models and their market shares, Berndt et al. compute a Divisia[6] index weighted by volumes. The results produce approximately the same AAGR over the time period, however the volume weighting produces a much smoother decline over time with declines ranging from –20% to –37% in any given year. In the unweighted indices, the annual declines ranged from –1% to –36%.

The main contribution of BG (1993) is methodological. Accounting for vintage and age allows the examination of survivors and unmeasured elements of quality that are otherwise normally explained as a form of selection bias.

BGR (1995) continues the work of BG (1993) with new data from 1989-1993 on personal computer list prices and characteristics. The dataset differs from their earlier work in that it includes only list prices, but does include a wider variety of characteristics. As before, the

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[5] It should be noted that these rates of price change correspond well to Moore's law and the observed practice of computer pricing. For most manufacturers during this time period, there were multiple price points among their model offerings. The most advanced system would always be priced at $X. When a new, more sophisticated system was introduced, it too would be priced at $X and the old most advanced system would be lowered in price to the next price point. With Moore's law, semiconductor capacity doubles every 18 months. If prices were fixed for the most advanced semiconducters (as it seems to be for the most advanced personal computers), the AAGR would be –37%. (quality adjusted prices fall by 50% over 18 months.)

[6] Volume weighting or market share weighting is important because otherwise the index fails to reflect the changes over time in the mix of products. The notion that the mix of models is fixed or is properly represented by equal weighting by price plans is undoubtedly inappropriate. What would be preferable is an index measure that incorporates market shares of each product/plan and the changes over time. Such an index would require quantity or revenue-sales data for each product/plan.

authors' goal is to construct a quality adjusted price index for personal computers in an unbalanced panel dataset. The market for these products remains remarkably volatile, with rapid technological change accompanied by the continued entry and exit of a variety of models and competitors. Berndt et al. re-use their framework discussed above, incorporating the time, age and vintage dichotomous variables to fully account for the effects of surviving models that are still offered in the market. For comparison purposes, Berndt et al. compute an unweighted mean of prices for each year, not incorporating any measures of changes in quality. This index of prices fell approximately –11% per year during the period 1989-1993. To mimic the normal BEA procedure, the authors use their data to calculate a price index based on a strict "matched models" approach. This index shows annual price declines of –19.35% over the study period. This decline is smaller than the price decline that they measured in the 1982-1998 period. To explore further, Berndt et al. use and extend their previous framework to estimate a hedonic regression model for prices that holds quality, age, and vintage fixed and imposes other constraints. Their augmented framework is termed a 'saturated' parameter model. They use the Box-Cox procedure to determine that log-log is the most parsimonious functional form. They compute a variety of price indices[7], finding that AAGR's over the time period range from –29% to –31%. When the sample is split into desktop and mobile segments, Berndt et al. find that the price decreases are larger in the mobile segment by approximately 6-11%. Their results further buttress the results reported in BG (1993) and support the notion that index construction needs to properly account for changes in quality.

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[7] Their indices include a time/age hedonic model, pooled hedonic model, adjacent years hedonic models, Laspeyres and Paasche indices and a Divisia volume-weighted index.

In another recent work, Berndt, Duhlberger and Rappaport (BDR 2000) continue to examine the relationship between price and quality for personal computers. In this paper, the dataset includes the data from BG (1993) and BGR (1995) and is augmented by other data. The dataset spans the entire period 1976-1999. In this paper, the authors focus on the question of parameter stability within the hedonic regression. This focus comes in two parts. The first is to determine if coefficients on characteristics are stable across the two types of computers under consideration, namely mobile and desktop personal computers. Secondly, the authors wish to investigate the issue of the stability of coefficients on characteristics across time. As the government has moved to make greater use of hedonic methods in the computation of indices, the authors are interested to examine the 'pooled' modeling (fully restricted) being practiced against possible alternatives.

The results from the paper are compared to the 'pooled' estimates from the same sample. In the sample, the 'pooled' regressions give an AAGR over the entire period of –25.94%. When the authors reject the 'pooled' model in favor of a split model based on computer type, the AAGR for desktops is –27.56% and for mobile computers it is –20.59.[8] When the authors consider parameter stability across time, they find that pooled modeling is too restrictive and are forced to estimate a regression for each year (cross-section). Calculating Laspeyres and Paasche indices, the AAGR over the full sample range from –24.29% to –30.44%. As part of the results, the authors document the accelerating rate of change in prices. In both the desktop and mobile segments, the quality adjusted price declines have occurred most rapidly in the most recent years.

[8] Mobile computers only enter the data from 1983 onwards so the results are stated for the period 1983-1999 for the mobile segment.

This pattern persists throughout the data with the smallest changes in price declines coming in the 1970's and accelerating towards the end of the sample period. The authors conclude that it is important to recognize the possibility and consequences of parameter instability within hedonic indices. Because they have shown that this instability is both real and important, the authors suggest that in the specific case of personal computers, changes need incorporated into the hedonic methods that produce the published governmental indices.

There is one recent paper that argues against the prescription of hedonic methods as the solution to the price index and quality relationship, Aizcorbe, Corrado and Doms (2000) argue that "matched models" methods are sufficient given high quality, frequent observations of prices and quantities.

In this paper, ACD (2000) consider data on personal and mobile computers, microprocessors, and a variety of computer memory chips (DRAM). The time period covered by the data extends from 1993-1999 and includes both prices and quantities. The authors seek to compare the "matched model" method against hedonic methods and welfare based methods. The paper explains the justification for "matched models" and shows that the link from index number theory to the other methods is less satisfactory. Using their proprietary data, the authors compute indices using both the "matched model" and hedonic methods. They conclude that for most high technology goods, where turnover and technical change are rapid, it is still appropriate to use "matched model" methods to compute price indices. They add that price indices based on this method succeed in capturing the elements of quality change for these rapidly changing goods. They temper these conclusions by noting that this is only true when high frequency, high quality data is available on both prices and quantities for the goods sold. This is because with high

frequency data, the timeframe between observations is short, and hence there are fewer new models and fewer exiting models that have traditionally made the “matched model” approach unsatisfactory.

There is a long history of investigation into price indices. Most of the work reviewed above is empirical work involving durable goods such as cars, personal computers and memory chips. The focus of the literature is on the long running question of how to “appropriately” account for quality changes when computing price indices. The “matched models” methods are appropriate in some circumstances but suffer from numerous drawbacks. Those drawbacks are mitigated by the use of hedonic regression models. These methods are outlined above and have been practiced and investigated by Griliches, Berdt, and Tripplett among others. Hedonic regression methods allow the calculation of quality-adjusted price indices when the “matched models” methods are either inappropriate or impossible.

Chapter 3 - History of the internet and the emergence of Internet Service Providers (ISPs)

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, an experimental network of four computers using the first versions of the new networking protocols and topology. . Stewardship for the network was handed to the National Science Foundation in the mid 1980s, 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. Over time, the network size and use grew nearly exponentially. Measuring the number of hosts, the continuous growth rate from 1969-96 is 57%. More recently, the annual growth rate from 1985-96 has been 95%. These growth rates exceed any previously recorded for a new technology or product.[9] By 1990 this TCP/IP network had reached a scale that would shortly exceed NSF's needs. For these and related reasons, the NSF implemented a series of steps to privatize the Internet. These steps began in 1992 and were completed by 1995. Diffusion to households also began to accelerate around 1995, partly as a consequence of these steps as well as due to the commercialization and diffusion of an unanticipated innovation, the browser (Greenstein, 2001).

[9] Except possibly the DVD hardware and software market (see Chapter 7)

Table 1: History of the Internet – Some Milestones

Date	**Milestone**
1969	ARPAnet links 4 computers
1972	First email sent
1973/4	TCP/IP specifications invented by Vinton Cerf and Bob Kahn
1975	Network grows to 100 computers
1979/80	Academia connects to network alongside Dept. of Energy & NASA
1983	Network composed of 200 hosts
1984	Network grows to 1000 hosts
1986	NSFNet operates at 56k, military operates its own network, ARPAnet dismantled
1987	4000 BBSs connect hobbyists
1988	Merit/MCI/IBM win contract to upgrade NSFnet to 1.5 mbps and maintain it
1989	WWW debuts at Cern (Tim Berners-Lee)
1989/90	NSFnet is getting obvious commercial use - MCImail, CompuServe, Sprintmail, AttMail
1990	Commercial services connect through CIX - commercial access points
1990	Network size now ~500,000 hosts
1992	Internet commercialized by NSF
1993	Mosaic developed at the University of Illinois
1995	WWW data traffic surpasses FTP data traffic
1995	NSF withdraws from network. Commercial backbones include PSInet, UUnet, ANS/AOL, Sprint, MCI, AGIS
1996	Network size exceeds 6.7 million hosts

Table 2 – Growth of the Internet – Hosts and growth rates

Date	Internet Hosts
1969	4
1975	100
1983	200
1984	1000
1990	500’000
1992	1.14 million
7/93	1.75 million
10/93	2.05 million
1/94	2.22 million
7/94	3.20 million
7/95	6.70 million

1969-1996 continuous annual growth rate = 57% annually

1983-1996 tinuous annual growth rate = 95% annually

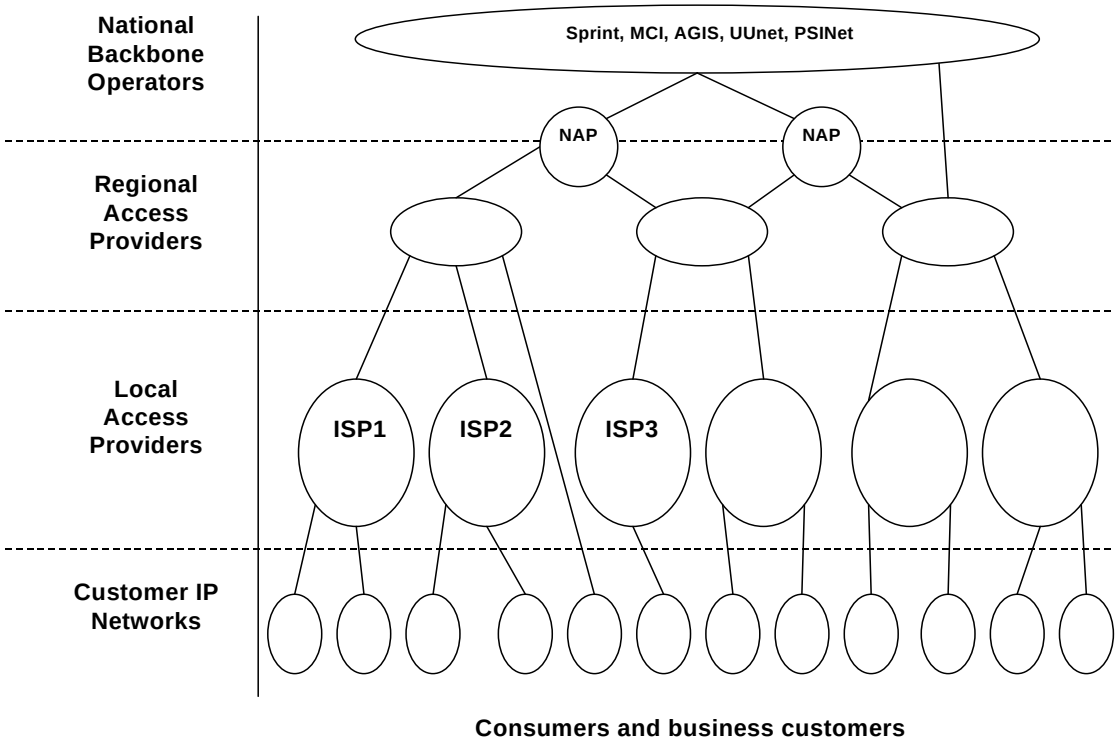
3.1 The Origins of Internet Functionality and Pricing

A household employs commercial Internet providers for many services, most of which had 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 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 interface designed by Tim Berners-Lee, beginning with Lynx, then Mosaic, and more recently, Netscape Navigator, Internet Explorer, Safari, Firefox and the open source browser, Opera. 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. Even before the commercialization of the internet, many private sector firms had adopted the TCP/IP protocol and 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 Points of Presences (POPs) and servers with Internet Protocol (IP) networks. These local access providers derive their connectivity to the wider Internet from other providers upstream, either regional or national ISP's. Regional networks connect directly to the national backbone providers. Private backbone providers connect to public (government) backbones at network access points. Before the commercialization of the internet, private sector firms had adopted the TCP/IP standard and they began to build their own networks. Sprint, MCI, UUnet

were among those who built private Internet backbones. Peering arrangements allowed packet traffic to cross between and among the private and academic networks.



3.2 The Emergence of Pricing and Services at Commercial Firms[10].

What is an Internet Service Provider? An ISP is a service firm that provides its customers with access to the Internet. These are several types of "access providers." At the outset of the industry, there was differentiation between commercial ISP's, "online service providers,"

[10] This section relies heavily on Greenstein (1999), Meeker (1996) and a variety of contemporaneous Internet 'Handbooks.' Specific data are attributed.

("OSP's" - Meeker and Dupuy - 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 in addition to 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 some use among households near the end of the millennium.[11] Dial-up connections are usually made with local toll calls or calls to a toll-free number (to avoid long-distance charges). Corporations often make the physical connection through leased lines or other direct connections. Smaller firms may connect using dial-up technology. These physical connections are made through the networks and infrastructure of Competitive Location Exchange Companies, Incumbent Location Exchange Companies (such as Regional Bell Operating Companies), and other communications firms. Large 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 are responsible for the call handling equipment (modems, routers, access concentrators, etc.) and their own connections to the Internet, but in some locations they may lease services for traveling customers.

Charging for access occurs at the point of access by phone. Internet service providers generally maintain 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

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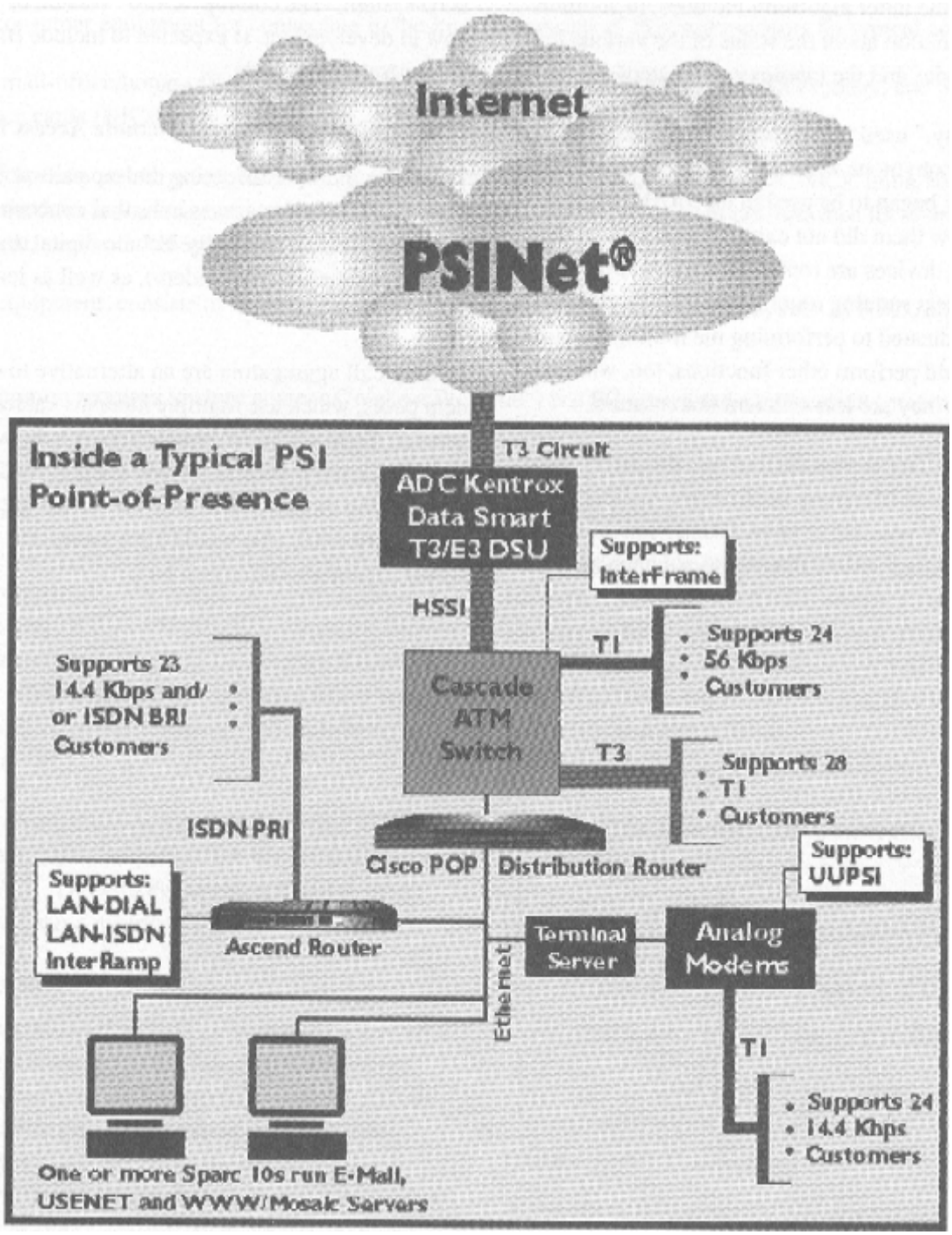
[11] Approximately 15% of US households subscribed to a broadband connection as of 2000, see NTIA, 2001.

many cities so customers do not have to make a long-distance call to reach the ISP offices in another town. Commercial online services, such as America Online, have thousands of POPs across many countries that they either run themselves or lease through a third party.

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



Many ISPs provide services that complement the physical connection. The most important and necessary service is an address for the user's computer. All Internet packet traffic has a 'from' and 'to' address that allows it to be routed to the right destination. An ISP assigns each connecting user with an address from its own pool of available addresses. 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. Software is also provided, either private-labeled or by third parties. Some of it is a standard component of the ISP contract (Greenstein, 2000b, O' Donnell, 2001). Some ISPs also recommend and sell customer equipment they guarantee will be compatible with the ISP's access equipment.

ISPs differ in size. The national private backbone providers (i.e. MCI, Sprint, etc) are the largest "ISPs." The remaining ISPs 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 provide limited geographic coverage.[12] A larger wholesale ISP serves all ISPs further up the connectivity chain. Local ISPs derive 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 POPs, while a local ISP may serve a very limited geographic market.

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[12] In 1999, *Boardwatch Magazine's Directory of Internet Service Providers* listed 4551 providers. Only 436 providers served customers in more than 25 area codes.

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 over time. It is equally difficult to pinpoint exactly the 'start' of ISP's as an industry. The private online services had been in existence alongside special interest BBS's since the 1980's. The earliest ISPs were academic institutions that offered access to students and faculty over campus networks and through dial-in servers from off-campus. 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.[13] In one of the earliest Internet "handbooks," Krol (1992) lists 45 North American providers (eight have a national presence). In the second edition of the same book, Krol (1994) lists 86 North American providers (ten have a national presence). Marine et al. (1993) lists 28 North American ISPs and six foreign ISPs. Schneider (1996) lists 882 U.S ISP's and 149 foreign ISP's. Meeker and Dupuy (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 growth was accompanied by vast heterogeneity in service, access, and pricing.

The physical connections to customers and the related hardware are the only 'capital' good of production for an ISP. Technical, sales and support staffs are the largest human capital elements. Although technological change is rapid, POP equipment is readily saleable and represents minor 'sunk' costs. The upstream connection is the other 'input' to ISP production of

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

access. Descriptions of regional/wholesale connectivity (see of *Boardwatch Magazine's Directory of Internet Service Providers (1996)*) imply that these contracts are short-term and can be terminated by the downstream ISP. Because the protocols and relevant technology had been in use for some time, little expertise was needed to make a commercial ISP physically operational (Greenstein 1999). The low level of sunk capital investment and the ease of exit indicate that this was a market with few substantial barriers to entry.

3.3 Pricing Behavior at Commercial Firms and How It Changed

Prior to the Internet, there were many bulletin boards and other private networks. The bulletin boards were primarily text-based venues where users with similar interests connected, exchanged 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. Knowledgeable and loyal users would answer questions and solve problems for other users and customers of a given company (e.g. Borland, Lotus, Microsoft, Dell, Gateway, etc.). 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[14].

Because much of the usage was for uploading and downloading, it was sensible to charge more for faster access. Pricing by speed is close to pricing by volume (or pricing for traffic). Consequently, many ISPs services varied the hourly charge based on the speed of the connection. In the early 1990's speeds moved from 300 bytes per second ("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, on some lines, 43,000bps) became the norm in the latter part of the 1990s.

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

Only later, after the ISP industry began to develop and mature, and users demonstrated preferences for a 'browsing' behavior, pricing began to shift to plans with an increasingly large number of included hours. Eventually this led to plans that offered an unlimited usage for a fixed monthly price. These plans are commonly referred to as 'flat-rate' or 'unlimited' plans. These unlimited plans caused capacity issues at POPs because the marginal cost to the user was zero and some users remained online much longer. ISPs reacted to this behavior by introducing

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[14] Did pricing drive this behavior or was this endemic to the technology and pricing fit the usage? Capacity and technology made this pricing behavior appropriate. The degree of offline usage reflects a pricing structure that incented users to remain online for minimal amounts of time.

plans with hourly limits and high marginal pricing above the limit. Most such plans were not particularly binding unless the user remained online for hours at a time most days of the month. Some ISPs also instituted automatic session termination when an online user remained inactive, eliminating problems arising from users who forgot to log off. However, this was perceived as poor service by some customers; consequently, many small ISPs hesitated to employ it.

3.4 The Evolution of Market Structure and Pricing[15]

The ISP market began to experience explosive entry around 1994-95, accelerating after the commercialization of the browser around the same time. The two key catalytic events for the commercial Internet access industry were Netscape's IPO in August, 1995, and the Microsoft announcement about their change in strategic direction in December of 1995. After these announcements, there was a recognizable "investment boom" and wave of new entry to take advantage of anticipated growth in demand for applications of the commercial Internet. Prior to that, early movers in this market all had experience with the network used in higher education or in the bulletin board industry. 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.

A signal event in 1995-96 was the entry of AT&T's Worldnet service, which was first explicitly marketed to business in 1995 and then to households starting in early 1996 in anticipation (correctly, as it turned out) of growing demand. It became associated with reliable email and browsing, as well as flat rate pricing at $20 a month. Because this firm entered with a

[15] This is a simplification of a complex set of events. For an extensive analysis of the evolution of market structure for Internet access in the United States, see Greenstein (2007).

near national footprint, it imposed pricing pressure on other ISPs throughout the country. This service also 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, so many of the small providers and large competitors (such as AOL) also grew rapidly.

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 opportunity to alter their service's basic features. When AOL converted fully to Internet access in 1996 it experienced quite a difficult transition. Frequent busy signals generated bad will with users and bad publicity with potential customers. It facilitated further entry by other firms looking to pick up customers. 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. In 1998 AOL bought CompuServe, a merger that, in retrospect, initiated it on the path towards solidifying its leadership of dial-up service.

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

Neither AT&T's entry, nor IBM's or MCI's positioning, had satisfied all new demand. After 1995 thousands of small entrepreneurial ventures also grew throughout the country and gained enough market share to sustain themselves. New entrants, such as Erols, Earthlink, Mindspring, Main One, Verio, and many others, gained large market positions. 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. Even a very narrow part (5%) of the population – found in many different rural locations throughout the US -- had 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 develop.

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 – unevenly and only in urban areas, offering these home users a faster and possibly richer experience (Rosston, 2006). However, less than 4.5 percent of US households used a broadband connection in 2000 (NTIA, 2004). 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.

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

Chapter 4 - Internet Service Provider Dataset Description

The dataset used in this study 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 ISPs at http://www.thelist.com. Before the directory was published, *Boardwatch Magazine* published lists of Internet service providers in its regular magazine. These issues date from November 1993 until July 1995. Another handful of observations in the 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 six-year period. The sample is an unbalanced panel of ISP's prices, tracking a total of 5948 firms with a total of 19217 price plan observations.[16] 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* tallying the percentage of calls completed and the average speed of actual

[16]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 (2000b) confirms that the *Boardwatch* data was incomplete in terms of the number of plans actually offered by an ISP. However, *Boardwatch* does state that the plans represent "the majority of users at an ISP or the most frequently chosen plans." This offers some comfort that the sample represents a majority of the plans offered by ISP's and chosen by consumers.

connections for the national providers in 1998, though we will only partially use this data in this study.

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 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.[17]

Table 4 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 two years were dropped due to the fact that they were extreme outliers. They certainly were unpopular, but because we lack market share, they had an overwhelming and undue impact on the early price index results. No other cleaning of the data has been done, apart from simple verification and correction of data entry. As Table 4 shows, the latter part of the sample period produces the greatest number of observations. This is one indication of how much new entry occurred at this time[18] and how quickly the industry was growing.[19]

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

[18] 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 listings are published in a separate directory that is updated quarterly.

Approximately 21% of the observed plans have an 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.[20] For limited plans, the hours included in the plans continues to increase over time. The number of plans with limitations is decreasing over time as a proportion of the sample. The pattern in the mean of monthly prices is not easy to discern.

Greenstein (2000b) uses 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 three or more. Of the single price quotes, approximately 26% are for limited prices. 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 4, where the average is 1.2 price plan observations per firm.

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.

[19] Consider the publishing pattern of ISP information in *Boardwatch.* In 1993-95, the list of ISPs is relatively short and is included in the magazine, but by 1996 the market is growing rapidly and the listings are published in a separate directory that is updated quarterly. By 1998 changes in the market have slowed enough that the directory is only updated and published semi-annually. By 1999 the directory is updated on an annual basis.

[20] ISDN stands for integrated service digital network. It is a standard for transferring data over phone lines at 128k, and requires both the phone line and the user to upgrade appropriately. Unlike the dial-up connections whose prices we study in this paper, a T-1 line refers to a direct and fast connection, one that brings the network to the user's premise, usually to a business.

The difference between the data here and in Greenstein (2000b) seems to be that in this sample we have more firms who quote only one plan and fewer firms that quote more than two plans. 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 weight the price observations in the calculation of an ideal price index. Hence, we construct our index assuming that most firms were responsive to the same technological trends. We are confident that qualitative change found at one firm spread to others quickly. Another way to say this is this: It is as if we are assuming that the measured improvement at the small firms is informative about the unmeasured improvements at the large. We partly test this assumption later in the study[21] when we examine the sensitivity of price estimates to the age of the ISP, which proxies for the durability of incumbency and stable market presence.

We do not think this assumption makes sense after 2000. After the consolidation of AOL's commercial leadership and its merger with Time Warner, AOL begins to follow its own path. This is also increasingly true for MSN after the browser wars end (in 1998) and after the entry of the free ISPs (in 1999), such as NetZero, whose spectacular growth ceases after 2001.

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[21] See Chapter 6

Moreover, the rate of unmeasured improvement in features of dial-up service begins to decline after the dot-com crash in spring of 2000 (though introduction of new features does not end after that, to be sure). As noted, the lack of market share is more problematic for a stable dial-up market, which, arguably, starts to emerge after 1998, and obviously emerges when adoption of the Internet slows at households, as it does by 2001.[22] Indeed, as the next chapter shows, prices begin to become sensitive to incumbency by 1998-99, the last year of our sample, suggesting that our judgment was correct. Thus, we did not collect data after early 1999.

[22] See NTIA, 2001

Chapter 5 - Pricing at the On-ramp to the Internet: Price Indices for ISPs during the 1990s

5.1 Introduction

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

No simple measurement strategy will suffice for formulating price 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, 2004).

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, 2001). This continues today.

In this paper we investigate 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 providers followed the same technological trajectory. This helps us construct indices without data on market share, which we lack. Third, and somewhat independently, broadband began to diffuse just near the end of our sample. After a few years it connected enough households to influence Internet price indices and would require us to alter the procedures carried out in this paper. Finally, Spring 2000 marks the end of unqualified optimism about the persistence of the Internet boom. This change in mood was affiliated with restructuring of the ISP industry, potentially bringing about a marked departure in price trends.

Using a new 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, especially between early 1995 and the spring of 1996. We also find a 20% decline in price per unit of ISP quality for the 33 month period between late 1996 and early 1999. We assess alternative models that vary in their attention to aspects of qualitative change. We find that this attention matters. Accounting for qualitative change shapes the estimates of price declines and the recorded timing of those declines.

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

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

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

We view this paper as one small step in a much larger research enterprise, measuring the economic changes brought about from the diffusion of and improvement in the Internet. There is much distance between our historical exercise and an ideal cost of living index for the Internet (Greenstein, 2002). During the time period under examination the Internet underwent dramatic

changes. The quality of what users got from the Internet skyrocketed. Said another way, what the user did with the service they got from an ISP also changed dramatically over this time period. We measure only a small piece of that dramatic change in experience.

5.2 Turbulent Times and Price Indices

In a market as turbulent as this one, we are quite skeptical of traditional price index construction using only measured prices weighted by market share, unaltered for qualitative change and competitive conditions. Our working hypotheses are simple: (1) it will be difficult to execute matched-model methods; (2) not accounting for quality will lead to problematic indicators of the true state of the market. Why are these hypotheses our starting point?

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

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

Third, market-wide experimentation imposed competitive pressure on incumbent behavior, even when these were very large firms. Behaving as if they were “paranoid”, the most

nimble largest firms of this era, such as AOL and Earthlink, did not stand still.[23] Incumbent ISPs were compelled to make frequent releases of upgrades to their software, to spend lavishly on marketing, to add new features constantly, and to keep prices low by not charging for extras – to prevent the growing young firms from cutting into the incumbents' leads. Yet, most of these competitive outcomes, except nominal prices, were not measured. In short, while it is often satisfactory to ignore the behavior of small fringe firms, that omission (or de-emphasis) could lead us to throw away useful information. If the large and small acted as if they were close substitutes, the small firms provide information about the unmeasured activities of the large.

In summary, quality changed rapidly, that market share bounced around, and that the large firms acted as if they were afraid of losing market share to the small. These observations will push us to examine the behavior of all firms in this market and not just the top dozen.[24]

5.3 Elementary Price Indices

The most elementary price index is displayed in Table 2. It does not adjust prices for any differences of quality over time. The means of the monthly prices trace a sharp upward path from 11/93-5/96 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

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[23] This paranoia appeared justified since the least nimble firms, such as AT&T WorldNet, did not keep up and, consequently, did not prosper (after a spectacular start in 1995-96).

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

Table 5 is that the observations in each time period reflect very different service goods. For example, the outlying mean of prices in May 1996 is due to the inclusion of high speed contracts. Table 1 shows that more than 581 contracts from May 1996 are ISDN contracts, which Boardwatch reports that issue (and then never again).

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.

5.4 Alternative Unweighted Matched Models

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

Table 3 – Matched model formulae

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

Using the matched observations, it is possible to compute the values of Dutot, Carli and Jevons indices. Given a number of prices for matching services, represented as $P_{i,t}$ [25], these formulas are used for the indices. More precisely, to construct the "matched model" indices, we matched price plans where $firm_i$, $speed_j$ at $time_t$ are matched with $firm_i$, $speed_j$ at $time_{t+1}$

Table 4 reports results for an analysis for this 'strict' matching, where both firms and speeds must match for a plan to be included in the calculation.[26] The hypergrowth and turnover

[25] The i subscript designates the price plan and t subscript designates the time period.
[26] Even the strict matching ignores any change in hours. We have ignored situations in which a plan switched between limited and unlimited.

of the industry in the first few years results in relatively few matches in the 1993-1996 period. In 1996, 510 plans[27] 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

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

(Diewart, 1987). 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.

The results suggest that prices are declining throughout the sample period, with especially dramatic changes arising in between January 1995 and May 1996, though the sample is quite small for that time period. The notable exception is the Carli index, which shows price increases in nearly every period except May 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. These results are intriguing and suggest that more precise quality controls will yield interesting insights.

5.5 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 complementary service offerings. Contract length and setup costs may also be

important, but they are not recorded in this data. Firm quality, experience and the competitive environment are also potential determinants of price.

One of the key developments in ISP service offerings over the 1993-1999 time period is the move from limited and metered plans to largely flat-rate unlimited usage plans. As noted earlier, in 1993, when ISPs began to offer services to consumers, there was little need for unlimited plans. In **Error! Reference source not found.**, we show the mean fixed monthly cost of Internet access in this sample of ISPs. In each year, the mean price for limited contracts is below the mean price for unlimited contracts. These differences are all statistically significant with p-values less than 1%. The table also illustrates the shift away from limited plans over the 1993-1999 timeframe. At the outset, the limited plans make up roughly 50% of the sample plans. By 1999, limited plans make up just 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 **Error! Reference source not found.**, we continue to examine the effect of plan limitations on ISP pricing. The data in the table indicate that for nearly every year, there is a persistent pattern to the mean prices and the hourly limits. The lowest prices are from the contracts that include 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 appear to have no obvious relation to price that is consistent across the observational periods in the sample.

Survey data from March 2000 report that 93.4% of users have monthly usage of 82 hours or less and 90% of users have monthly usage of 65 hours or less (Goldfarb, 2004). Thus it is not surprising that limitations higher than 100 hours have little effect on ISP price. Comparing the

higher limitation mean prices with the unlimited plans in **Error! Reference source not found.**, we observe that it is clear that these high limitation plans are not priced very differently than the unlimited plans.

Other relevant variables are in Table 7. 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.[28]

There are a number of other measures in the data set that could signal ISP quality. More specialized types of access services being offered by an ISP could signal the technical expertise of their staff and their reputation for quality and adoption of leading technology. While there are many different ways to proxy for quality, we for the most part do not employ them in our hedonic analysis.[29] Partly this is due to data limitations. Moreover, as we show below, however, we employ a random effects estimator which correlates errors at an ISP over time. This will capture a portion of any unobserved quality that is correlated at the same firm.[30]

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[28] 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.

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

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

5.6 Hedonic Price Indices[31]

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

$$\ln P_{ijt} = \alpha_0 + \alpha_t Year_{ijt} + \beta_1 Limited_{ijt} + \beta_{2-9} dHrly_{ijt} * Limited_{ijt} + \gamma_{1-5} dSpeed_{ijt} + \varepsilon_{ijt} \qquad (0.1)$$

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.. Those divisions and frequencies are shown in **Error! Reference source not found.** 8. Note that use of indicator variables provides flexibility for the coefficient estimates.

The specification in Eqn. (0.1) was estimated for the whole pooled sample and for each pair of adjacent time periods. Regression results are reported in

Table 12. In all cases, the standard errors are robust standard errors with corrections for clustering. Because of the abundance of data between 1995 and 1999, and because of the similarity of pricing strategies across ISPs in a given year, we expect most of the coefficients to be tightly estimated. In general, we also expect the specifications for adjacent time periods to be superior to the pooled specification.

We observe in the data that over time ISPs offer increasingly fast connection speeds. Unlimited plans have become more prevalent over time, while the hours allowed under limited

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[31] We construct our indices assuming that most firms were responsive to the same technological trends. We are confident that qualitative change found at one firm spread to others quickly. Another way to say this is as follows: It is as if we are assuming that the measured improvement at the small firms is informative about the unmeasured improvements at the large. In the next chapter we partly test this assumption by examining the sensitivity of price estimates to the age of the ISP, which proxies for the durability of incumbency and stable market presence. We find it makes sense to do so.

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 each successive coefficient estimate represents an accumulated price decline.

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

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

The regression results based on Eqn. (0.1) appear in

Table 12. The largest hourly limitation buckets have been discarded from the full model, so we focus on the coefficients of the restricted model and the accompanying adjacent period regressions. In the restricted regression (second column), all estimated coefficients are significant predominantly at the 1% 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. Specifically, plans with a limited number of hours are priced at a discount to unlimited plans, but this discount diminishes as the number of included hours increases.[32]

The coefficients on the **time** indicator variables agree largely with the hypotheses given above. Apart from the period from 11/93-1/95, the estimated coefficients indicate that quality-adjusted prices were falling, and the coefficients become successively more negative as time passes, consistent with the hypothesis described earlier.

There are two anomalies regarding the **time** indicator variable. The difference between the coefficients on **year95** and **year96a** is very large (indicating that 5/96 prices are 40% of the level of 1/95 prices). This dramatic large price decline needs to be investigated further, which we do below.

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[32] After testing the coefficients for each of the hourly buckets, all but the lowest four were dropped from the model. Results from hypothesis tests (For example testing H0: **Hrs80*L** – **limited** = 0) indicated that these coefficients were not significantly different from the coefficient on **limited**, because they added no more information than the **limited** variable. In the unrestricted models (both pooled and adjacent year models), the omitted **hourly*limited** indicator variable is for all hourly limits above 250 hours. The omitted **speed** indicator variable is for plans offering 14.4k access. The omitted time period indicator variable (**year**) is for 11/93.

One interesting result from the regression is that prices appear to increase on a quality-adjusted basis from 11/93 up to 1/95. This is a recurring pattern through many of the models. It can be explained by the fact that the nature of Internet access changed during the intervening time period. In 11/93 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. SLIP is a more highly interactive connection that has all the capabilities of UUCP plus additional features (including multimedia capabilities).[33] When the quality increase is the same across all of the sample products, then it cannot be identified separately in an hedonic regression from the time period indicator variable. Thus in 1/95 prices are higher than in 11/93, but it is because Internet access technology has fundamentally improved. Because all the ISPs have adopted the new type of access and "quality" has increased, there is no heterogeneity in the sample and no way to control for the "quality" change.

The final six columns in

Table 12 display results from the adjacent period regressions. The pooled model is a significant restriction. In the pooled model, intercepts may vary across time, but the slopes with regard to the characteristics are restricted to be equal across periods. The adjacent period models relax this restriction so that the slopes are restricted to be equal only across two periods in any model. In the latter years of the data this restriction does not affect the estimated coefficients

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

much. The restriction does matter in the early years of the data. The estimate on **limited** and some of the specific hour limitations varies paired-year to paired-year. As we have an abundance of data for later years and not in early years, so we lose degrees of freedom with the adjacent year regressions during the earliest part of the sample, when we most need it.

Although some of the coefficients among the adjacent period models are statistically insignificant, the majority of coefficients confirm the stated hypotheses. The hourly limitations and speeds affect price in the same way as the pooled model. The price increase in 1/95 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 Eqn. (0.1) lead to a calculation of the estimated price indices. These estimates are a consequence of the form of the model, plus a correction for the bias from exponentiating estimates of Eqn. (0.1).[34] The models estimated in

Table 12 lead to estimated price indices in **Error! Reference source not found.**, where 11/93 is our base time period. These are easily reconverted to period-to-period indices. The models in

Table 12 that consider adjacent time periods also lead directly to estimates of the period-to-period indices.

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

The results are shown in **Error! Reference source not found.**0. 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 thereafter.[35] 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 deserves an explanation. Two factors produce this drop. First, there is a large difference in the number of firms. The observations from January 1995 describe a couple dozen ISPs selling connections to the Internet for purposes of using a *Mosaic* browser or a beta version of the *Netscape* browser, and basic email client. By May of 1996 most of the new entrants are small ISPs selling connections for the Netscape browser and email. Second, by the spring of 1996 AT&T WorldNet has entered home service and the market is heading towards a twenty dollar price point for basic service at 28K speeds. Even without controlling for quality, Table 5 shows that prices declined during this period for both unlimited and limited plans. However, Table 5 does not control for precise levels of limits. With such raw data it is not a surprise that estimated price declines by more than half once hedonic estimates control for the same level of limits.

This finding is consistent with popular perceptions about the growth in the Internet, usually timed to Netscape's IPO in August, 1995. To our surprise, the price declines do not stop

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[35] 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.

after the spring of 1996. We also find a 20% decline in price per unit of ISP quality for the 33 month period between spring 1996 and early 1999.

5.7 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 the model specified in Eqn. (0.1). One concern is that unmeasured quality at an ISP is roughly the same across contracts and across years. In other words, if an ISP guaranteed high quality service (e.g., large modem banks that rarely have busy signals), or offers the same enticements to all its customers (e.g., large email accounts), then this quality will be unmeasured for contracts coming from the same firm. Because of the (unbalanced) panel nature of the dataset, the firm-specific unmeasured quality can be at least partially corrected using a random-effects model, where the unmeasured error is assumed to be the same for all contracts offered by one firm.

In this case the regression model given above in Eqn. (0.1) will be changed by adding a firm specific error term (υ_i).

$$\ln P_{ijt} = \alpha_0 + \alpha_t Year_{ijt} + \beta_1 Limited_{ijt} + \beta_{2-9} dHrly_{ijt} * Limited_{ijt} + \gamma_{1-5} dSpeed_{ijt} + \upsilon_i + \varepsilon_{ijt} \quad (0.2)$$

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

We have estimated both the fixed and random effects specifications of model (0.2) – using the standard sub-routines in Stata. The regression results are shown in Table 14. 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 indicates that the random effects specification is preferred.[36] We therefore examine the random effects results in further detail.

The random effects regression results does not differ from the earlier results much except in one key place. The main difference is that the drop in prices ascribed to 1/95 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 estimated coefficients on the speed indicator variables also follow the pattern outlined in the hypotheses above and reconfirm the results from the earlier regression. Table 14 also reports the adjacent period regression results. They follow the same pattern of the earlier results with, again, the main difference being a dampened drop in the index from 1/95 to 5/96.

Using the regression results from the random effects "restricted" model and the random effects adjacent period model, we have recalculated the cumulative and period-to-period indices in Table 15, which are biased predictors under the stochastic specification. Even then, the results are qualitatively similar. The cumulative index drops from 1.00 in 11/93 to 0.51 in 1/99, imply that the "quality" adjusted prices fell by 49% over this period. As before, the period to period indices swing wildly in the initial periods, but then settle to steady declines of almost 7% per year on average. The notable difference between the random effects model results and the earlier

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

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 15, 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 difference is the 11/93 to 1/95 index, but this is an insignificant coefficient in the adjacent period regression.

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

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

5.8 Analysis of Subsample with Speeds Below 28.8k

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

We have repeated the random effects modeling (from Eqn. (0.2)) with a subsample of plans that offer connection speeds at or below 28.8k. **Error! Reference source not found.** presents the regression results from this subsample. The results shown for the subsample correspond well to the full sample regression. The coefficients display the same pattern as the earlier full sample regressions, supporting the hypotheses given above. Quality adjusted prices decline over the sample period, with the coefficient for each time period being more negative than the previous one. The apparent quality adjusted price rise from 11/93 to 1/95 persists, suggesting that this pattern is not an artifact of the higher speed plans. The plans with hourly limitations reconfirm the pattern of the full sample.

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

in **Error! Reference source not found.**, this estimated coefficient is positive and statistically significant.

Coefficient estimates from the adjacent period regressions are also shown in **Error! Reference source not found.**. 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 for speed of plan because only 28.8k speed plans are considered in the remaining part of the subsample.

Using the regression results from the random effects restricted model and the random effects adjacent period model, we have recalculated the cumulative and period-to-period quality-adjusted price indices; they appear in

Table 17. The results are consistent with the results from the full sample. The cumulative index reveals that prices in this subsample drop from 1.00 in 11/93 to 0.48 in 1/99. This implies that the estimated “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 adjacent period calculations are consistent with the full sample results. The price index increases between the first two periods, which is followed by a sharp decline, and then steady annual declines of 1-7% thereafter.

In summary, repeating the analysis of the random effects estimation of Eqn. (0.2) on a subsample of plans with speeds at or below 28.8k yields results consistent with the full sample.

This suggests that the treatment of the hourly limitations in the higher speed plans is not significantly skewing the results for the full sample. It also suggests that although many new entrants appeared over time offering higher speed plans, the pattern of "quality adjusted" prices was not different between the "old" and "new" providers. The most important conclusion is that the unobserved limits for the high speed plans are not affecting the overall results.

5.9 Weighted Hedonic Price Indices

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

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

Second, the interpretation of the area code variable changes when many facilities-based firms initiated programs to rent their backbones and modem banks to others, who could in turn offer access elsewhere in the country. This is especially common in the later years of our sample (1997-99), rendering the area code variable almost meaningless as a measure of market share. That is, the footprint of area code coverage for many firms became disconnected from ownership of facilities. Hundreds of firms advertised a national footprint in 1998 and 1999, even small ISPs with only a few customers who had just entered service.

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

Another (and simpler) alternative is to weight the plans based on the connection speed offered. Such data is available from the GVU lab www surveys (Georgia Tech, 1997). The Graphics, Visualization and Usability laboratory at the Georgia Institute of Technology has conducted a WWW users survey semiannually since January 1994. The surveys cover a broad range of topics but one portion of the survey inquires about online services, Internet usage and speed of connection to the Internet. GVU has collected information on Internet connection speeds since 1995. Their data are shown in Table 18.

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 **Error! Reference source not found.**. The only substantial difference between our 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 clear that the proportions in 1998 and 1999 are roughly the same. Since 1997 was not a year of dramatic change in measured contracting behavior, such as hourly limitations, the impact on a re-calculated index is minimal.[37]

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

5.10 Conclusion

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

Using a new dataset, we have computed a variety of price indices, ranging in sophistication from very crude averages to quality adjusted ones based on hedonic models. The results show decisively that ISP prices have been falling rapidly over time. The bulk of the price decline is in the early years of the sample, especially the period between early 1995 and spring of 1996, but a significant and steady decline continues throughout. We conclude that ignoring aspects of quality underestimates the price declines. It also alters the timing of the measured declines.

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[37] Available from the author upon request.

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

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

Chapter 6 - Pricing in the Shadow of Firm Turnover: ISPs during the 1990s

6.1 Introduction

Despite widespread interest in the Internet there is surprisingly little statistical evidence about the pricing behavior of suppliers of the infrastructure that operate the network. This paper focuses on understanding pricing behavior of the commercial market for Internet access. It started from almost nothing at the outset of the 1990s and grew into 15.6 Billion dollar industry by 2001 (US Department of Commerce, 2003, pp 733). In particular, it focuses on the earliest providers of Internet access, dial-up Internet Service Providers (ISPs).

This paper investigates the relationship between pricing and the introduction of new services and/or entry of new firms. Using a new dataset about the earliest period of this industry, we compute a variety of hedonic price indices under many different methods. We then consider how this index changes when we compare continuing firms with entrants, or firms providing existing services with those providing new services, such as faster modem speeds. We begin with the earliest point when we could find data, 1993, when the commercial ISP market was still nascent. We stop in 1999, after a long period of demand growth, firm entry and instability.

One of our primary goals is to understand how introduction of new services, entry, and exit shapes prices. This is part of a broad agenda to understand the relationship between evolution in market structure and firm pricing in young markets. Specifically, the ISP market is a spatially segregated industry with growing demand, comparatively small fixed costs, and fast paced technology change. Many, but not all, ISPs offer more than one type of contract for service. Physical

attributes are not key features of the service, but features of the contract for service are. These features can improve 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.

This setting provides some challenges for measurement, as well as some opportunities. Because firms do not offer precisely the same service one year to the next it is not possible to use "matched-model" methods for constructing changes in average price levels. We test different ways to control for quality at the level of the ISP and at the level of the contract offered to users. We investigate and apply hedonic methods to establish price indices for a service good. We then investigate various determinants for changes in prices.

The results show that ISP pricing has been falling rapidly over time. The bulk of the price decline is in the early years of the sample, especially between early 1995 and the spring of 1996, just as a boom of entry begins to take advantage of the commercial Internet. We also find a 20% decline in price per unit of ISP quality for the 33 month period between late 1996 and early 1999, as the mass market grew.[38] We test models that vary in their attention to aspects of qualitative change, firm entry and exit. We find that this attention matters. Accounting for such change shapes the estimates of price declines and the recorded timing of those declines.

We find several causes behind the change in price/quality. We show that new firms enter the market at a small but significant price discount to established incumbents. At the same time, introduction of new products/technologies also are priced at a significant price premium to the

[38] For documentation of the diffusion of the Internet, see e.g., NTIA, 2004. Between the October, 1997, and August, 2000, the fraction of households adopting the Internet rose from 18.6 to 41.5 percent.

existing offerings, but the premium declines rapidly. We also find a survivor bias in pricing: ISPs who survive tend to have higher prices than younger firms. This bias interacts with the evolution of the market. Early in our sample, when new entrants gain market share, prices are driven down by entry. Later in our sample, as incumbent firms solidify their market shares in a growing market, the pricing of incumbent firms does not decline as much when new entrants appear. Lastly, we find that exit plays a small role in shaping pricing in comparison to entry.

The findings conform to a vision of a rapidly changing industry, but suggest a nuanced role for firm turnover and product improvement. The entry of new technologies led to higher prices, but only temporarily. This suggests that the early adopting firms had at least some limited local monopoly power in the sales of these goods. The increasing premium for age also suggests that surviving firms have built a stock of reputation or a set of comparatively captive customers who are reluctant to switch.

This adds to the growing line of studies about differences in the pricing behavior of incumbents and entrants in young or evolving markets. This also adds evidence to the set of studies characterizing firm behavior in markets with significant turnover and technical advance. It is a theme found in personal computers, as documented in Berndt and Griliches (1993), Bendt, Griliches and Rappaport (1995), and Berndt, Dulberger and Rappaport (2000), as well as in semi-conductors, as documented by Aizcorbe, Corrado and Doms (2000), and in other communication equipment markets, as studied in Doms (2003) and Doms and Forman (2005). Our contribution also follows in the spirit of Raff and Trajtenberg (1997), who use hedonic price indices to shed light on changes occurring in the early US automobile industry. As there, we highlight the interaction of the evolution

of the market for ISPs and the pricing patterns observed. As there, our study employs a mix of extensive qualitative evidence complemented by statistical evidence of that qualitative change.

This study also follows on the companion study in the previous chapter[39] and Prud'homme, Marc and Kam Yu (1999), both of which focused on estimating price indices for Internet access. In this study we take for granted what the prior work established: that there was, in fact, a change in prices, and it is robust to a variety of measurement approaches. This study leans towards understanding the links between those changes in price levels and the evolution of market structure during this time.

6.2 Turbulent times and price indices.

In a market as turbulent as this one, we are quite skeptical of traditional price index construction using only measured prices weighted by market share. Our working hypothesis is that prices *must* account for qualitative change and competitive conditions. This presents challenges for constructing a price index of all firms, whether incumbent or entrant.

In a traditional price index the pricing behavior of a few large firms receives the bulk of attention. This is the appropriate procedure when quality does not change rapidly, when market shares are stable over time, and when the measured behavior of large firms shapes the experience of most users. In our case, however, we are certain that quality changed rapidly, that market share bounced around quite a bit, and that the large firms acted as if they were afraid of losing market share to the small. These observations will push us to examine the behavior of all firms in this market, both recent entrants and incumbent firms, and not just the top dozen providers.

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[39] Published as Stranger and Greenstein (forthcoming),

6.3 Dataset Description

The dataset used in this chapter was described in Chapter 4 and was used in the previous chapter.

6.4 Elementary price indices

The most elementary price index has already been displayed in the previous chapter. 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 5 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. These issues are discussed in more detail in our earlier paper (Stranger and Greenstein, 2007). 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.

6.5 Determinants of Price

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 4, 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 timeframe. At the outset, the limited plans make up roughly 50% of the sample plans. By 1999, limited plans make up just 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 5 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 (Goldfarb, 2004). Thus, it is not surprising that limitations higher than 100 hours have little effect on ISP price. Comparing the

higher limitation mean prices with the unlimited plans in **Error! Reference source not found.**, it is clear that these high limitation plans are not priced very differently than the unlimited plans.

Other relevant variables are in Table 6. 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.[40]

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 do not show all the results in this paper.[41] As we show below, however, we can use a random effects estimator which correlates errors at an ISP. In part this will capture any unobserved quality that is correlated at the same firm.

6.6 Hedonic Price Indices with random effects

To uncover the role of new entry and new products, we first estimate a baseline pricing model. Then we show how the different factors shape the results in this model. Extensive analysis of, and support for, the baseline model can be found in the previous chapter. Here we

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[40] 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.

[41] 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 (or as well as the factors we left in the hedonic analysis). In this paper we show only the robust findings, using features we can measure over the entire period. For more on measuring quality at ISPs, see Augereau and Greenstein (2001), Augereau, Rysman, and Greenstein (2007), and Greenstein (2000a).

only provide a summary of the baseline model and, unlike the prior work, instead concentrate on analyzing the factors that alter the pricing declines over time.

The dataset covers very few characteristics of each plan/product, and there are undoubtedly unmeasured elements of quality that are missing. The firm-specific unmeasured quality can be corrected using a random-effects model. In this case our baseline model will have a firm specific error term (υ_i). Specifically, we estimate:

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

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 **Error! Reference source not found.** 7.

The specification in equation (1) was estimated for the whole pooled sample and for each pair of adjacent time periods. Regression results are in Table 8. After testing the coefficients for each of the hourly buckets, all but the lowest four were dropped from the model. The tests[42] 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. Depending on which

[42] For example testing H0: **Hrs80*L** – **limited** = 0. For the full range of specification tests, see Stranger and Greenstein (2007).

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

We have estimated both the fixed and random effects specifications of model(1). The regression results are shown in Table 9. 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 pattern among the time period indicator variables is as expected, dropping over time with some volatility in the early years.[43] The significance and pattern among the plan limitations fits with the earlier discussion. The coefficients on the speed indicator variables also follow the anticipated pattern. Table 14 8 also shows the adjacent period regression results. They also follow the same patterns.

Using the regression results from the random effects "restricted" model and the random effects adjacent period model, we have calculated the cumulative and period-to-period indices in Table 9.[44] 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. The period to period indices swing wildly in the initial periods, but then settle to steady declines of 0-7% per period. In Table 15, the index drops to 0.44. The index values calculated from the adjacent period models are all nearly the

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[43] The random effects regression results differ only slightly from the results not using a random effects estimator (reported in Stranger and Greenstein, 2007). The main difference is that the drop in prices for 1/95 to 5/96 dampens.
[44] See the discussion in Berndt (1991). The correction involves adding half of the squared standard error of the regression to the simulated price, correcting for the non-zero expectation of an exponentiated normal error. Sometimes this correction can make a big difference to the estimate for the price index. See Pakes (2002) for such an example. In our case it did not make much difference to the estimated price index.

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.

One interesting result from the regression is that prices appear to increase on a quality-adjusted basis from 11/93 up to 1/95. It can be explained by the fact that the nature of Internet access changed during the 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. SLIP is a more highly interactive connection that has all the capabilities of UUCP plus additional features (including multimedia capabilities).[45] When the quality change is the same across all of the sample products, then it cannot be identified separately in an hedonic regression from the time period indicator variable. Thus in 1/95 prices are higher than in 11/93, but it is because Internet access technology has fundamentally improved. Because all the ISPs have adopted the new type of access and "quality" has increased, there is no heterogeneity in the sample and no way to control for the "quality" change.

The extreme drop in the index from 1/95 to 5/96 also deserves an explanation. Two factors produce this drop. First, there is a large difference in the number of firms. The observations from January 1995 describe a couple dozen ISPs selling connections to the Internet for purposes of using a *Mosaic* browser or a beta version of the *Netscape* browser, and a basic email client. By May of 1996 most of the new entrants are small ISPs selling connections for the

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[45] Looking carefully at the data and the advertisements, we observed that it is clear that firms were promoting "slip" accounts as a premium service (as opposed to UUCP). The data seem to indicate that they were charging a premium for it as well.

Netscape browser and email. Second, by the spring of 1996 AT&T WorldNet has entered home service and the market is heading towards a twenty dollar price point for basic service at 28K speeds

These results suggest two conclusions. First, there was a significant change in the decline in prices around the time of the Netscape IPO and Microsoft announcement about its change in strategic direction. This is consistent with popular perceptions. Second, we should divide our analysis of the determinants of price declines between the period prior to late 1995 and after. The latter period experienced an enormous amount of entry and turnover in the identities of firms, which made it qualitatively different from the earlier period.

6.7 The Sources of Price change

In this section of the paper, we investigate the sources of prices change. In particular, we examine the price choices of entrants and incumbents in the sample, showing that entrants priced at a discount to incumbents. We also examine the pricing decision of ISPs when new products are introduced (higher speed access). New products command a price premium initially, and this is competed away over time, sometimes quite rapidly. This section also examines firm age and tenure. As noted, age is a proxy for quality and incumbent stability. 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.

6.8 Entrants

Numerous firms enter the dataset during each period. What were entrants' pricing strategies as they came into this market? Did entrants differentiate their price in some meaningful way 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.

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

The new regressors are ***entrant***, ***newfirm*****$_{(year)}$**, and ***vintage*****$_{(year)}$**. In Table 20 10, 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 11, 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.

Error! Reference source not found.2 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 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 **Error! Reference source not found.**2, 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 12 is another less restricted version of model (2), 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 12 is another version of model (2). 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 12 is the unrestricted version of model (2). This model incorporates all of the entrant variables as well as all of the vintage variables.[46] 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 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 12, 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 12, because the time coefficient is also partly accounted for in the

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

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.[47]

Altogether, the results support the view that entrants used price as a competitive weapon to gain entry to this market. 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 under-sampling successful new entrants would lead to an upward bias in a price index.

6.9 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

[47] 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.

determines the rate of adoption. The introduction of higher speed 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 had been gradual.[48] This pattern could leave 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, which we cannot assess. However, we can assess whether, in the short run, firms acted as if there was room to price the new, higher speed service at a premium. If so, then we can assess how much this behavior shaped general pricing trends.

To understand the effect of new product introductions, we estimate the following model

$$\ln P_{ijt} = \alpha_0 + \alpha_t Year_{ijt} + \beta_1 Limited_{ijt} + \beta_{2-9} dHrly_{ijt} * Limited_{ijt} + \gamma_{1-5} dSpeed_{ijt} + \delta Entrant + \lambda New56 + \phi NewBoth + \upsilon_i + \varepsilon_{ijt} \quad (3)$$

Model (3) 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 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.

[48] See Augereau, Greenstein and Rysman (2007) for an account of the battle over the 56k modem standard and the effects on adoption.

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 13 displays the regression results for full and restricted versions of model (3)**.** 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 model (3) 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** (3). 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 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 13, 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 13 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 opportunity 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. In other words, in a market where $20 prevailed, ISPs with faster speeds charged $25 until the faster speed became more common, at which point, competition brought prices back to $20.

6.10 Firm age/tenure

Following the example of Berndt et al (1995), we next calculated hedonic estimates with a full array of age and vintage effects.

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. There 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. It is clear from looking at the simple averages that there is no obvious prediction or easy interpretation for these effects. 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’ ISPs may be able to charge a price premium compared with 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 is such a learning curve, such as making investments to achieve optimal customer/port/bandwidth ratios, then older firms may have knowledge and cost advantage over younger firms. This effect would argue for possibly lower prices from older firms due to potential cost advantages. Since this effect operates on costs our ability to observe it could be attenuated by higher margins.

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.[49] To determine the effects of firm age, the hedonic regression framework is again employed to estimate the following model.

$$\ln P_{ijt} = \alpha_0 + \alpha_t Year_{ijt} + \beta_1 Limited_{ijt} + \beta_{2-9} dHrly_{ijt} * Limited_{ijt} + \gamma_{1-5} dSpeed_{ijt} + \delta FirmAge + \phi NewBoth + \upsilon_i + \varepsilon_{ijt} \quad (4)$$

Table 14 shows the regression results. The two models shown are the hedonic random-effects model (1) and the estimation of model (4) 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 14 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 14 and 15 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 (4) show that older firms have maintained a significant price premium. While this does not refute the hypothesis that accumulated learning could lower costs and prices, it does show that the quality and loyalty effects overwhelm any other factor leading to lower prices.

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[49] 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)

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, and many 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.[50] 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, most industry reports indicated that established incumbents did not *lose* market share to these entrants. The magnitude of these premiums in Table 15 and 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 by 1999.

6.11 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, especially after 1995. 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

[50] Recall, however, that AOL only began to provide unlimited 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.

sample. The variety of possible reasons for exit means that it is impossible to give a clear interpretation to exit, even though it has the potential to affect pricing.

We explored a number of ways to capture the effect of exit on pricing. The simplest turned out to be the most informative. We looked at the correlation between the regression residual and the likelihood of exit in the next period. We found that a mildly high residual does predict exit, but the effect is rather small. Specifically, firms which are about to exit (in the next period) have prices that are roughly $0.25 higher than their contemporaries. Price indices decline over time because of the exit of contracts coming from the high priced firms, but it amounts to less than a dollar over the second half of the dataset. The contribution from entrants and qualitative change is much larger, as an economic matter, so we did not pursue the point further.

6.12 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 the sensitivity of a variety of price indices to the entry and exit of firms. New firms enter the market at a small but significant price discount to established incumbents. The introduction of new products/technologies also are priced at a significant price premium to the existing offerings, but the premium decline quite rapidly. ISPs who survive tend to have higher prices than younger firms. This bias interacts with the evolution of the market. When new entrants gain market share, prices are driven down by entry. As incumbent firms

solidify their market shares in a growing market, the pricing of incumbent firms does not decline as much when new entrants appear. Lastly, we find that exit plays a small role in shaping pricing in comparison to entry.

The results show decisively that there are links between changes in market structure and ISP pricing. Entry lowered prices, and later entrants entered with differentially lower prices than earlier entrants. Both of these facts are consistent with positive sorting through entry. We also conclude that ignoring aspects of quality underestimate the price declines. It also alters the timing of the measured declines.

Chapter 7 - Determinants of Price, Hedonic price indices and the impact of qualitative features: A study of the hyper-growth DVD hardware market

7.1 Introduction

This paper examines a newly created dataset with an eight year history of DVD hardware prices. No research on the DVD market has examined the rate of changes of prices during the growth of this market. Given the size and unprecedented growth of the market, understanding the degree to which prices are changing is an important input into reported government data on the economy and the GDP. No other good has grown this fast or diffused this quickly into American households. This paper is the first to establish a hedonic price index in the most rapidly changing market ever seen and adds to the durable goods hedonics literature. This paper is also one of very few studies that have attempted to incorporate qualitative descriptors of quality into the hedonic framework and the first for a durable good.

The goal of this paper is to extend the existing literature on hedonic models for DVD hardware and construct a quality adjusted price index covering the time period from the introduction of the DVD through September 2005. This paper addresses the determinants of DVD hardware prices in the hedonic model context. It examines the impact of high level capabilities, characteristics and features, brand impact and combinations of these factors on DVD hardware prices. In parallel, the paper examines the impact of those various specifications on the estimates of the hedonic model and the price indices. Using review data from *Consumer*

Reports, this paper also examines the impact of qualitative measures of quality on the prices of DVD hardware and how those qualitative factors impact the price index.

The hedonic price indices constructed in this paper show that DVD hardware prices have been falling at a ~24% compounded annual rate since the product's introduction in the marketplace in 1997 and through the eight years of the sample data. This is significantly faster than we find using elementary price indices or matched models methods. The paper shows that the hedonic framework is suitable for such rapidly growing and changing product market and is an improvement over BLS methods. The results below show that easily discernable high level features of DVD hardware drive most of the variability in price. Despite having many obvious ancillary features, these lesser known, more esoteric or features largely common to most DVD hardware do not appear to have a significant impact on price. Brand is another easily observable characteristic that does impact price but the impact has less explanatory power than the high level features of the DVD hardware itself. The hedonic pricing results and the pricing indices created are extremely robust to various specifications. The results on qualitative measures of quality suggest that they are not significant determinants of the price in the hedonic model used here, however if quality is discernable among DVD players then various features of this dataset suggest that the answer found here may not be conclusive.

7.2 The growth of the DVD marketplace

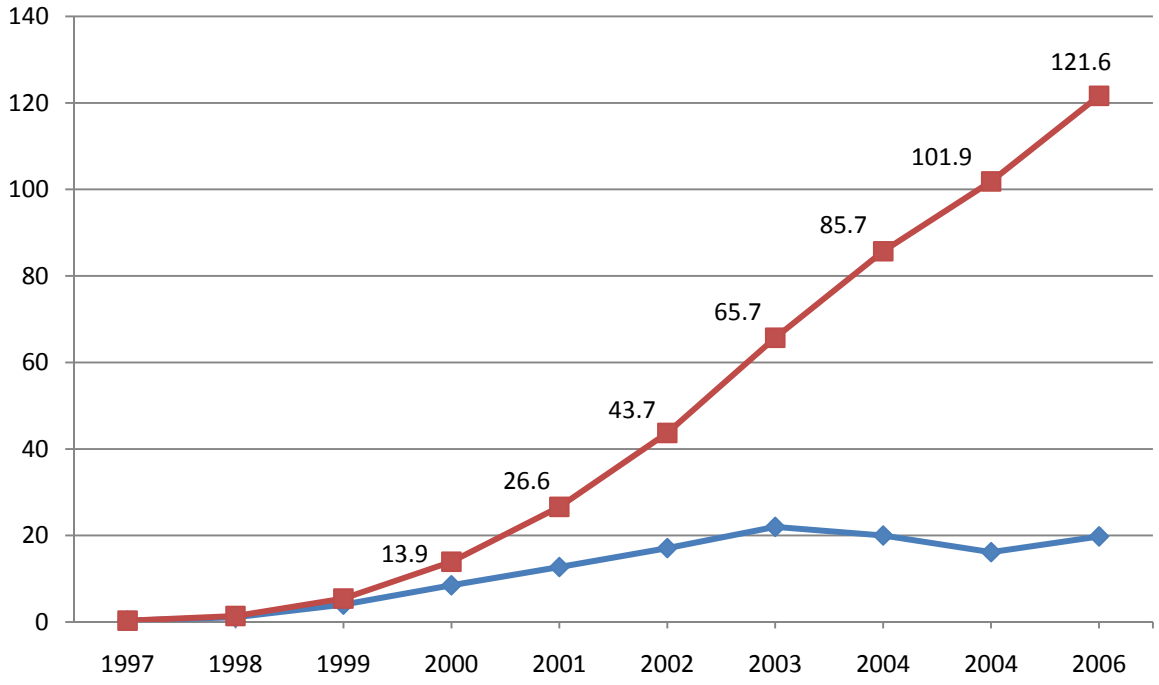
The DVD market encompasses the fastest growing consumer good in history.[51] To put this in context, after 10 years in the market place the VCR had penetrated just 10% of US households. After 10 years, the Compact Disc player had penetrated into nearly 20% of US households. In 2007, the DVD player celebrated its 10 anniversary and over 125 million DVD hardware units have shipped to US consumers (see

[51] See Dranove and Gandal (2003) for a good history of the early DVD market

). In these first ten years, DVD players have penetrated nearly 85% of US households and are not far behind VCRs in overall household penetration despite being introduced 23 years later.[52]

[52] Source: US Census data, MPAA.org, thedigitalbits.com. Sites last visited in August 2007

Figure 2: DVD annual shipments and cumulative sales (in millions of units)



This incredible growth story is based on technology that is not too dissimilar from Compact Discs but that has enabled a quantum leap forward in the quality of the home movie viewing experience. A DVD player combined with surround sound audio equipment and a digital television rivals the experience in theaters. The experience is far ahead of the quality that can be produced with the product it has generally replaced, the VCR. A DVD is a 3.5" diameter plastic disc, digitally encoded with compressed video and audio. When the DVD format was introduced in the Spring of 1997, the industry boasted that one DVD could hold four feature length movies and the accompanying high quality digital soundtrack. The audio quality is only rivaled by Compact Discs and a DVD player can be coupled with a specialty stereo receiver to output true Dolby Digital surround sound on 6 channels. DVD software offers more than just movies. There are often additional scenes cut from the final film, games, outtakes and director's

commentary. Many DVD titles allow the viewer to select language for subtitles and some DVDs offer a variety of camera angles that are viewer selectable and other special features.

As is shown in

Figure 3 below, the availability of DVD software (titles to watch) has grown nearly as explosively as the hardware market.[53] This penetration of DVD players combined with the growth in the software market have combined to trigger growth in all aspects of home theater and hi-fi equipment as well as specialized installers to put it in your home. Television and cable shows are now serialized onto DVD and it is easy to go home from your local video rental store with a season's worth of your favorite show on DVD. The technology has thrown the video rental business into upheaval as new entrants such as Netflix are able to exploit the small form factor of the DVD and the availability so many titles and variety to build an entirely new business model.[54]

Remarkably, all of this growth has come from mostly new consumer spending. One might think that this high quality in home entertainment platform would encourage people to consume more entertainment in their home and less elsewhere. The movie industry disagrees. The Motion Picture Association claims that per capita admissions to movies are on a par with 10 years ago so that there is no evidence of switching[55]. There is evidence that television viewing behavior is changing, but that is not solely due to the DVD marketplace. The increase in available content (cable and satellite channels) and the advent of the PVR has changed television forever. However there is no denying the convenience of sitting down at your own convenience

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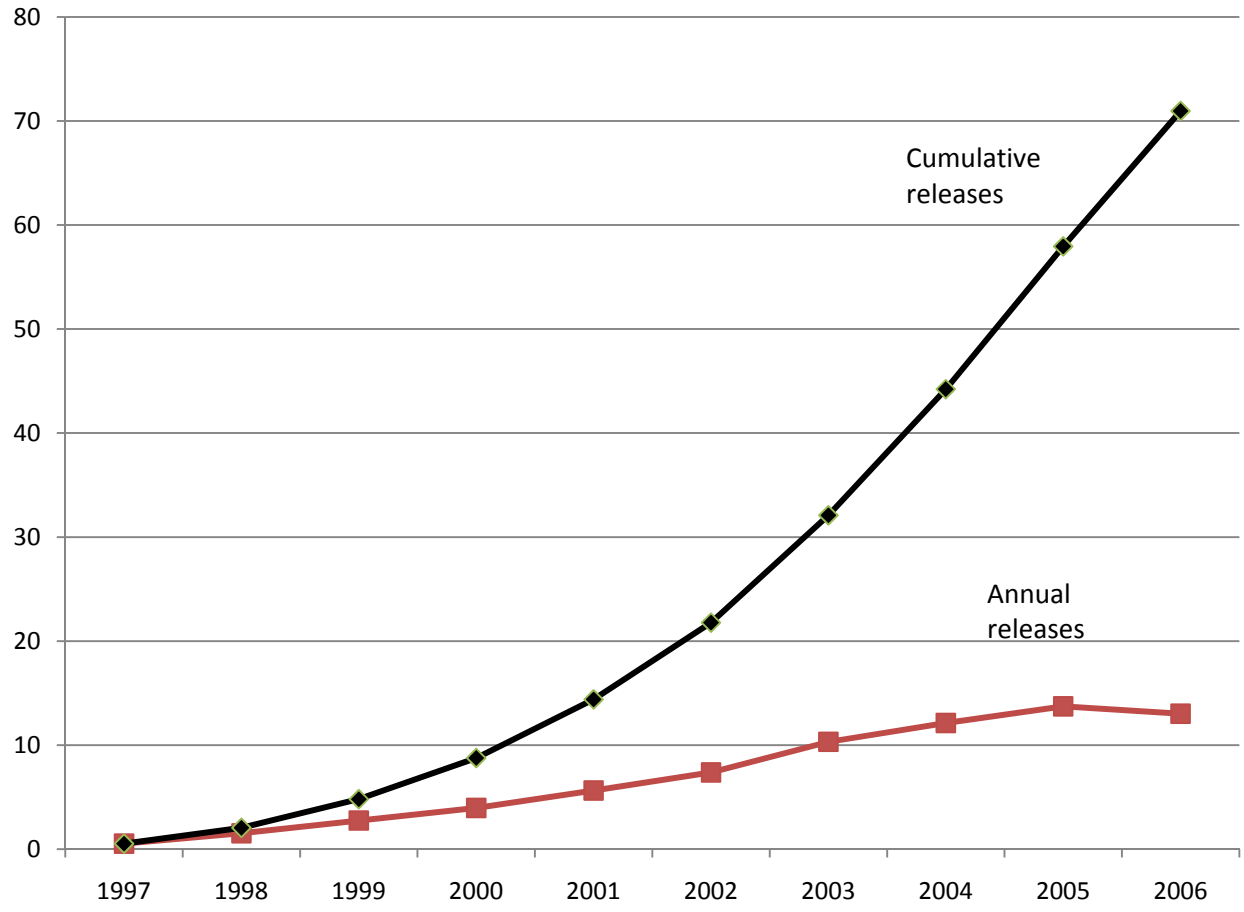
[53] I make no attempt to determine the causality, but the Dranove and Gandal (2003) do show that software availability did influence the rate of growth DVD hardware sales. Gandal, Kende and Rob (2000) demonstrate this causality for Compact Disc players and discs.

[54] Netflix claims to have 6.7 million subscribers and offers over 85,000 DVD titles for rental by mail. (source: Netflix.com press kit at Netflix.com, last visited August 2007)

[55] MPA 2006 US Market statistics, p.8 shows that from per capita theater admissions have only declined from 5.05 to 4.81 between 1996 and 2006. This may be misleading as peak admissions occurred in 2002 (5.70) and have generally declined since that time (~5%). However, other portions the report show that total admissions and total box office gross are substantially higher in 2006 than 1996. Source: mpaa.org, last visited August 2007

to watch a DVD of your favorite shows, all commercial free. All of this improvement is really a change in the quality of the good of home entertainment. DVD hardware is just one part of the infrastructure that has facilitated this enormous quality shift and consequent market growth.

Figure 3: DVD titles – annual and cumulative releases (in thousands)



7.3 Background and other research

7.3.1 Hedonic models

There is an enormous body of literature concerning price indices and hedonic prices for various durable goods. See Michaels (1979), Bernt and Griliches (1993), Bernt, Griliches and Rappaport (1995), Bernt and Rappaport (2001) and Pakes (2002) for applications of hedonic methods to the PC industry and Gandal (1995) for applications to spreadsheets. Griliches (1961) and Raff and Trajtenberg (1997) apply hedonic methods to price indices for the automobile industry. There are also many examples of hedonic studies of non-durable goods. McConnell and Strand (2000) use hedonic models to study the determinants of prices of Tuna at auction in Hawaii. Stanley and Tschirhart (1991) estimate a hedonic model to study the determinants of price for breakfast cereals. Schwartz and Scafidi (2004) use hedonic models to construct a price index for four year colleges.

There is only one paper[56] that attempts to incorporate qualitative information on quality into the hedonic framework. Unlike physical features or other objective measures or information, qualitative information in this context is information on experienced quality. The wine juries involved rated the wines after blind tastings and as such the qualitative measure is their perception of the quality of the wines. The key is that this information cannot be discerned by inspection of the wine, but instead can only be ascertained through experience[57]. Combris, Lecocq, and Visser (1997) use the hedonic framework to examine the determinants of price for

[56] This is the only paper that I am aware of in the literature that attempts to disentangle the influence of qualitative measures in the hedonic framework

[57] Additionally, qualitative measures will vary depending on the tastes and perceptions of the reviewer. As will be discussed later, the degree to which the qualitative measures are discernable may also be important.

Bordeaux wine. They incorporate the objective characteristics of the wine from the label (sub-region, chateau, vintage, etc.) but also incorporate qualitative grades of sensory quality of the wine from blind tasting juries. They find that in their hedonic model, market price is largely determined by the objective characteristics and that the qualitative measures have little or no influence on prices.

7.3.2 DVD focused research

Despite the amazing growth of the DVD marketplace, it has attracted very little attention from researchers. Almost no research has been focused on the DVD market, despite work on its predecessors, VCRs and Compact Discs.

Dranove and Gandel (2003) examine the early history of the DVD market and focus on finding network and pre-announcement effects from the preannouncement of a potential competing DVD standard called DIVX. They do find evidence of both affects, concluding that the DIVX preannouncement did very temporarily affect the early trajectory of DVD player sales. In the Compact Disc market, Gandal, Kende and Rob (2000) examine the interaction between the diffusion of the hardware good (CD player) and the availability of the software (CD titles). They find significant interactions whereby availability of Compact Disc titles has a significant impact on the diffusion of Compact Disc players. This lends support to the parallel in the DVD market, underlining the necessity of DVD title availability as a driver of DVD hardware sales. In the VCR market, Liegey and Shepler (1999) estimate a hedonic model for VCR prices to help account for quality differences in the CPI when model ‘substitution’ occurs.

One other study examines DVD hardware pricing in a hedonic framework, but is limited to a snapshot of data and does not pursue any aspect of determining the rate of changes of prices and DVD price indices. Liegey (1999) explores the ability of the BLS to use hedonic estimates for DVD player prices to help inform their consumer price index calculations when a "substitution" occurs in the relevant time-series. The BLS uses a 'matched-models' methodology to construct price indices and when a model in the sample is replaced by another model, the BLS may use hedonic estimates to adjust those two unmatched model's prices and make the two models comparable. Essentially they convert apples to oranges and then make comparisons between the price of the converted apple (now an orange) and the price of a real orange.

In his study, Liegey examines a sample of ~250 prices covering 45 DVD models collected from multiple retail locations in the late spring of 1999. He estimates a hedonic model for this snapshot data and finds that few observable features of the DVD players have impact on price. His first observation of the data on the players themselves is that there is very little functional or feature variability among players. Nearly all players share a common set of physical features such as digital audio outputs, composite video output, s-video output and remote controls. Many players also share functional features such as multi-speed preview and review, chapter features and choice of aspect ratios.

Liegey estimates a hedonic equation using the DVD data. He finds that DVD prices are largely determined by brand, by availability of a built-in Dolby decoder and by the length of the manufacturer's warranty. The brands results suggest that brands are a proxy for unmeasured quality. Liegey finds that the brand coefficients are estimated significantly and the coefficients

fit with popular industry beliefs concerning brand hierarchy. He also finds significantly that touted features such as component video connections do not affect price. He concludes by claiming that the hedonic method would not be so dominated by brand if there were better details on the technical differences among players (and essentially more variability in the data).[58] His policy recommendation is that BLS analysts use these hedonic results to adjust unmatched models. At this early point in the DVD history there is little measurable turnover[59] ("substitution" in BLS parlance) in DVD models and because DVDs are such a small part of the *Other Video Equipment* category, he also concludes that the use of these hedonic results will not affect the index in any significant manner.

7.4 Data

The main body of data used in this paper was collected from various DVD review articles in issues of *Consumer Reports. Consumer Reports* is a monthly magazine is published along with its companion annual buying guides and website. The organization has been reviewing consumer goods and reporting on the results since the 1930's. The magazine consists of product previews, various individual product reviews, articles comparing and reviewing a number of products from a given category and news and information on product recalls. The magazine and

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[58] As I will detail later in this paper, I disagree and would argue that it is consumer perception of features and differences that are important and that what essentially he is observing is that the majority of price variation is being driven by unmeasured beliefs about quality that consumers associate with the brands. From a practical standpoint, this answer is not very helpful to the BLS. If brand is the major price determining factor, then the prices for new models "substituting" for old models from the same manufacturer would not need to be adjusted for any quality change because the brand would remain the same.

[59] Some "substitutions" do not lend themselves to quality adjustment. New models from the same brand may appear, substituting for older models with the same physical characteristics or features. While these are a new good, there is no measurable dimension of quality difference (apart from theoretically vintage or model age) that could be used to adjust the price for a change in quality.

accompanying website are published by Consumers Union, "an expert, independent nonprofit organization whose mission is to work for a fair, just, and safe marketplace for all consumers and to empower consumers to protect themselves."[60]

The sample covers the time period from June 1997 until September 2005, slightly more than eight years. The sample is an unbalanced panel of DVD model prices, tracking a total of 218 models with a total of 291 price observations (see Table 1**Error! Reference source not found.**). The data was collected from past issues of *Consumer Reports* where the magazine reviewed and reported on DVD players for consumers. The annual December issue is focused on consumer electronics and there is occasionally one updated report before the next December issue. The first observations in the sample are from a short article in June 1997 as DVD players began to appear in the market and the most recent are from a website review update in September 2005. Approximately two-thirds of the sample datapoints are unique models where there is just one datapoint in the whole panel. The remaining one third of the observations are of models with two observations, often from adjacent time periods. There are a handful of models which are represented by 3 observations in the sample (see Table 26). In all, the sample covers 11 time periods within that range and represents 218 unique models of DVD players from 32 different manufacturers (see Table 27).[61]

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[60] This is how the Consumers Union describes themselves. Quote from www.consumerreports.org in August 2007

[61] The sample is not a comprehensive dataset of all DVD models from these time periods. *Consumer Reports* does not purport to catalog and review every existing model and nor does the data contain any information about market share or sales quantities (we will address this again later). The data admittedly is missing models aimed at the narrow audio/videophile submarket, but also appears to omit the truly budget type players that began to appear at the end of the sample period. By the nature of the source and despite this limitation it does appear that the data covers a wide breadth of the DVD models consumers would find in retail locations.

The data itself falls into three main categories. The pricing data reported is the estimated retail price[62]. The articles in the various issues also catalog an ever changing set of characteristics for each DVD model. These include physical characteristics such as number of discs or types of video and audio connections. The data also includes information on various features such as surround sound, warranties, screen savers, Dolby or DTS decoders. There is also information about the capabilities of the DVD model to play various audio formats, show slideshows of still images, etc. The data also differentiates among standard single disc players, multi-disc players, progressive scan players, DVD recorders, DVD/VCR combo players, portable DVD players, DVD/HD recorders and various combinations of these categories. (See Table 28 for the complete list of data).

The reviews are not uniform across time and do not always have the equivalent information concerning the features or characteristics of each model. For example information is not offered on warranties in June 1997, but is available for December 1999 and December 2000. It is missing again in December 2001 but is available from March 2002 to March 2003. After March 2003 warranty information is not reported again in the reviews. The reviews fairly consistently report on the audio and video connections, but for example in December 2000, the review only denotes if the DVD player has optical **or** coaxial digital audio connections whereas other time periods report if a DVD player has one, both or no such connections.

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[62] *Consumer Reports* prides themselves on not accepting free samples from manufacturers, bolstering their independence and their credibility. To source products for reviews, *Consumer Reports* actually purchases the products at retail. Because of the lag between their purchase and the publication of the magazine and associated review articles, they report estimated retail prices at the time of publication.

Because Consumer Reports is billed as a guide for consumers considering purchasing these products, they also test the products. The third category of data in the sample is the experience from these tests. Several of the reviews mention that the audio quality of these players (like CD players) is so high that they cannot differentiate among the DVD models based on audio quality, so no audio quality is reported. For each DVD model, there is a qualitative score for 'picture quality' and another score representing 'ease of use.'

7.5 Estimation and empirical results

In this section, I describe the analysis of the data including empirical results on both elementary and matched model price indices, determinants of price in a hedonic model, hedonic price indices and the effects of brands and direct qualitative measures of quality.

7.5.1 Elementary price indices

The most elementary price indices are displayed in Table 6

Table 30. These price indices do not adjust prices for any differences in quality over time. The first column shows the date of the issue of *Consumer Reports.* The second column shows the average prices observed for DVD models in the sample. The fifth column shows the median prices for each issue. The last column on the right shows the number of observations in the sample at each date. Two indices are calculated based on the average and median prices.

Index97 is computed with a base value of 100 in June 1997. **Index99** is computed with a base value of 100 in June of 1999.[63]

For the average prices, both indices show prices falling substantially from the base year to the end of the sample. Index97 drops from 100 to 20.5, implying that prices dropped at a 17.5% compounded annual rate for just over eight years. Index99 based on average prices shows a similar result, dropping from 100 to 36.2, implying that prices dropped at a 16.2% compounded annual rate over the last nearly 6 years of the sample.[64]

Table 6 also shows the same indices calculated for median prices. In each time period during the sample, the average prices exceed the median prices, showing the influence of high price outliers on the average prices. The median indices also show a substantial drop from the base year to the end of the sample. **Index97** drops from 100 to 18.3, implying that prices dropped at a 20.5% compounded annual rate for just over eight years. **Index99** shows a similar result, dropping from 100 to 31.9, implying that prices dropped at a 19.9% compounded annual rate over the last nearly 6 years of the sample. The other interesting finding about both the median and average price indices is the path of the price declines. In both cases, the indices drop sharply in the early years of the sample but rise in March 2002 for the average prices and stay steady for the median. The indices for the average prices indicate that prices were particularly low in December 2002 and then increased and decreased until a sharp drop in September 2005.

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[63] These two indices will be used throughout the paper. I compute **Index99** for comparison purposes to results later in the paper where the June 1997 observations are excluded due to missing DVD hardware characteristics.

[64] For reference, in Liegey (1999), the author reports that the official price index for the *Other Video Equipment* category drops from 100 in December 1997 to 73.5 in December 1999. This implies an annualized compounded price drop of 14.3% for the overall category. This result is far less than the elementary DVD indices show over the same time period, but the overall BLS category has other products (including VCRs and Camcorders) which are a different stage in their product life cycle where presumably prices are falling less rapidly.

The average price indices are nearly at the same level in March 2003 that they were at in December 2000. The median indices follow nearly the same pattern, with a low value in December 2002 that is followed by increased prices in March 2003 with another drop in December 2003. The median price index level increases again until it drops significantly from December 2004 to September 2005.

The fundamental problem with the data presented in Table 6 is that the data sample in each time period reflects very different DVD hardware. For example, in March 2002 combination DVD and VCR players first enter the sample and influence the average and median prices to higher levels. In March 2003, the same phenomenon occurs with the introduction of DVD recorders, which again influences the prices and elementary price indices towards higher levels. Both of these products are dissimilar to the products reviewed through December 2001. They both contain features and functionality not available in the DVD players in the early part of the sample. The influence of these rapid changes in hardware capability accompanied by the rapidly changing prices and market growth are the crux of the problem with traditional elementary indices.

Table 31 shows that homogenizing the sample does reduce some of the variability discussed above. The data in Table 31 is a subset of 183 observations from the main data sample. The rightmost column in the data shows the number of observations from each time period. This subset of the sample excludes **multi-disc DVD players, DVD/VCR combo players, DVD recorders, DVD/Hard Drive recorders and portable DVD players. Essentially this is an elementary price index for single disc DVD players. The average prices shown in the second column are the same or lower than the average prices for the same time periods in Table 6**

Table 30. The path traced by the indices shows a much more monotonic drop in prices with the exception of March 2002. Despite the homogeneity of the sample, the index levels in

September 2005 are only slightly lower than in Table 30[65] and imply similar, though slightly larger rates of price declines from the beginning of the sample until the end.[66]

The indices shown in Table 31 look more familiar in pattern to *a priori* expectations and result in similar overall price declines in the sample period. However even this homogenized subsample fails to capture continuing innovation and change in the hardware and must necessarily understate the price declines. For example, progressive scan technology is introduced in 2000 and is a portion of the single DVD player sample through the middle of the time sample and eventually eclipses the non-progressive scan technology which disappears from the sample after December 2004.[67] Overall, these elementary indices fail to capture quality changes that are prevalent throughout the sample and both misrepresent and understate the degree of price change that occurred. The BLS and others overcome some of this problem by calculating the indices using matched models.

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[65] This may be partially due to the fact that the September 2005 sample is already partially homogenized. The data only includes single DVD players, multi-disc DVD players and DVD/VCR combination players. The September 2005 does not include DVD recorders, DVD/HD recorders or portable DVD players.

[66] **Index97** drops from 100 to 19.1, implying that prices dropped at a 18.1% compounded annual rate for just over eight years. **Index99** shows a similar result, dropping from 100 to 33.8, implying that prices dropped at a 17.2% compounded annual rate over the last nearly 6 years of the sample

[67] Table 32 shows the average prices and price indices for a subsample of 92 observations of single disc DVD players without progressive scan technology. This subsample ends in December 2004. The calculated price indices are shown in the table and monotonically decline at a faster rate than the indices of average prices calculated in Table 30 or Table 31. At the end of this subsample, there are very few data points as these types of players disappear from the sample. Contemporary comments in *Consumer Reports* suggest that by 2005 the default technology choice is becoming progressive scan.

7.5.2 Matched model indices for DVD hardware

Matched model indices are calculated using prices from the same model of hardware in two adjacent time periods. In effect this allows the calculation of a price index where comparisons of prices are "apples to apples." However this method does not account for the introduction of new goods until they have been in the sample for two periods and does not make use of the price information about a model in the period after it is retired.

This dataset and the DVD hardware market in general do not make for a good combination to examine matched model indices. During the rapid growth of the market, there has been an enormous amount of model turnover. As is shown in Table 26, there are 218 distinct models in our sample, but only 63 models appear with two observations and only five appear with three observations. These matched observations account for approximately half of the sample observations and one-third of the models. Table 33 shows that the matches are not distributed evenly throughout the sample. Of the 64 matched model pairs, 58 of them occur in four time periods. In March 2002 and March 2003, *Consumer Reports* issued updates to their previous December DVD reviews. In each of the updates a few new models were added, a few discontinued models were dropped and the remaining models were reported again. These two updates account for 37 of the matched models. The March 2005 update and the September 2005 online update provide another 21 total matches. The remaining time periods throughout the sample have between zero and three matches. As Table 33 also shows, there were 35 price

changes among the 64 matched models. Of those 35 price changes, 32 were price decreases and 3 were price increases.[68]

This is enough information to compute Dutot, Carli and Jevons unweighted matched model price indices.[69] The results are shown in Table 34. Because there are no matched models among the first two time periods, I have set the base index in December 2000 equal to 47.1 across all the indices to make the remainder of the indices comparable to the elementary indices in Table 6. The results in Table 10 show prices declining throughout most of the sample and unlike the results in Table 6, the price changes are monotonic declines except for December 2003 when no models matched and December 2002 where there was a price increase.[70] The differences across the various matched model calculations are relatively minor. The final index values in September 2005 range from 19.4 to 22 and are very similar to the index value of 20.5 in Table 6.

The main benefit of matched model price indices is to correct for changes in quality by excluding new and discontinued models and ensuring that the price index is comparing like goods. In the case of this DVD hardware price dataset, the calculated matched model indices measure a very similar price change to the elementary indices from December 2000 to September 2005. The more noticeable improvement is in the path of the price indices. With the exception of one suspect datapoint, the indices decline monotonically throughout the sample time period more closely conforming to our *a priori* expectations.

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[68] Given the general trend in prices for most electronic goods and the overall DVD dataset, my sense is that these price increases are misprints and data errors. Of course, without the source data it is hard to be sure, so I have not suppressed, changed or otherwise edited the data.

[69] See chapter 1 of this dissertation for further details on the calculations of these price indices.

[70] The index value for December 2002 is based on one matched model observation. This one model has a price increase which, as stated above, is suspect.

7.5.3 Determinants of price and the hedonic model

DVD hardware is part of a system of complementary goods that make up the whole "home theater experience." DVD hardware itself has no standalone value. It requires at least two complements, a television and “software.” Optionally a compatible audio system is the third complement that enables the highest quality experience. In the timeframe of the sample data, the reviews related that DVD hardware is becoming less expensive and adding features or quality. The same is undoubtedly true for complementary audio systems and televisions. The availability of DVD software (movies and other titles) is growing as well which increases the utility (to a point) of any of these home theater system hardware components and enhances the consumer experience. If we do not capture that quality change of the consumer experience into account, then the hedonic model in the paper **understates** the quality adjusted price declines. A similar issue was addressed in the earlier chapters concerning ISPs/internet access. Speed of access and price were changing, but in parallel, what you can get/access on the internet in the late 90's is changing rapidly as well so the quality adjusted ISP price declines are also understated.

Within the hedonic framework, there is fundamentally no way to fully adjust for the ongoing quality change of the DVD experience. Hedonic models do allow us to adjust prices for changes in features and characteristics of the DVD hardware, but the limits of the data do not allow us to

quantify the improvement that is brought by improvements in other complementary goods such as the release of the next season of the *Sopranos* or a classic movie.[71]

Based on the discussions in the *Consumer Reports* reviews, there are a number of features that we expect will be determinants of price in the hedonic model. Much of the discussion in the accompanying articles emphasizes picking a player that has compatible connections with your audio and television equipment. Optical and coaxial audio connections are not standard on every player and nor are the inputs standard on every receiver. Matching is important. Connections to television equipment are equally emphasized. All players have composite video connections, many have S-Video connections and some have component video connections. Each of these has quality implications. The choices among major features are emphasized by talking about the use of the hardware (e.g. if you want to play continuous music, then consider a multidisc player,

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[71] Capturing the impact of "DVD availability" is not possible due to an estimation issue. The estimation issue is not simply endogeneity (which could be attacked with instrumental variables). The issue is deep within the hedonic model and the indicator variables that allow us to construct a price index. The problem is that any measure of software availability at time t would be collinear with the associated time period indicator variable. There are no compatibility issues or distinctions among the match between any differential types of DVD software and DVD hardware (that I am aware of) that would break this compromise. All of the models can play DVDs, so there would be no variation in a "DVD availability" measure among the models at time t, so the software measure and time period indicator could not both be identified.

The only possibility that I see would have been DVD & DIVX. From a practical standpoint, DIVX arrives and disappears between the first two datapoints in this sample and there is no data on the ability of any of the players to play DIVX software. Hypothetically, had DIVX survived longer and become more of a competing standard, there would be players in the sample which supported DVD, DIVX or both. If that were the case, then I could use software availability measures of the various incompatible formats (and possibly the superset for players of both) to adjust the price indices for the impact on the consumer of the improving selection and availability of DVD & DIVX titles.

There are non-core features of DVD hardware where this adjustment could theoretically work in this hedonic model with this sample. For example, and again hypothetically, if SACD and DVD-Audio were important uses of DVD players and if there were good data in the sample (and variation) on those hardware features and if there was variation in the SACD and DVD-audio software availability, then the collinearity with the time period indicator would be broken and the estimation and quality adjustment could potentially work. This quality adjustment would only cover the availability of that specific software, but it would be a more comprehensive adjustment than the current model. In a few years it might be possible to incorporate the effect of DVD software availability with a dataset adding the intervening time periods and the period with Blu-Ray and HD-DVD.

etc.). DVD recorders, progressive scan players (that only achieve increased quality with a complement – a high quality television), DVD/VCR combo players, etc. are all also factors that should effect pricing. There are numerous other characteristics listed in the data list in Table 28 that may influence price in the hedonic context. Many of these features are common to most if not all of the DVD models reviewed. For example, features like S-Video connections (which is a feature on 97% of models with this data) or parental controls (which is a feature on 98% of models with this data) are unlikely to be significant drivers of price. Features which are rarer and differentiate the models are likely to be drivers of price if consumers find them valuable. For example Dolby Digital decoders are built into 20% of the models where we have the data. If a consumer has an audio system that is compatible, but without a decoder, then an onboard decoder on the DVD player would be valuable. If a consumer has an audio system with optical or coaxial digital inputs and a Dolby Digital decoder, then a 2nd decoder on the DVD hardware is not valuable. Overall we expect that differentiated features will be among the determinants of price in the hedonic framework. These will include obvious differentiators such as brand, type of DVD hardware (player, recorder, etc.), progressive scan, Dolby Digital decoders and warranty terms. Other less differentiated features such as connections or very common ancillary features should have little or no impact on price.

Hedonic models can be used disaggregate prices for any product (i.e. bundle of characteristics) at any given time into marginal prices for its characteristics, features or qualities. With panel data, the use of indicator variables for each time period allows for time period specific constant terms which can be converted into a price index. Based on the discussion above concerning determinants of price, the first model that I estimate is:

$$LPRICE_{i,t}$$

$$= \alpha_0 + \alpha_t ISSUE_{i,t} + \beta DVDTYPE_{i,t} + \gamma AUDIO_{i,t} + \delta VIDEO_{i,t} + \theta FEATURES_{i,t} + \varepsilon_{i,t} \quad (1)$$

where the subscripts designate DVD model i, at time t. ***LPRICE*** is the natural logarithm of the DVD model price.[72] ***ISSUE*** is a vector of indicator variables representing the date of the particular issue of *Consumer Reports* where the price of DVD model i appears. ***DVDTYPE*** is a vector of indicator variables[73] denoting multi-disc DVD players, progressive scan DVD players, DVD/VCR combination players, DVD recorders, DVD/Hard-drive recorders and portable DVD players. ***AUDIO*** is a vector of indicator variables denoting the available audio connections including coaxial digital audio and optical digital audio. ***VIDEO*** is a vector of indicator variables denoting the availability of various video connections including composite video, S-video and component video. ***FEATURES*** is a vector of various other features and capabilities of DVD hardware that are not captured in the earlier variables. These include built in Dolby or DTS encoders, universal remote controls, screensaver, dialogue audio enhancement, surround sound enhancement, dynamic audio control, plays MP3 audio, plays SACD, plays DVD audio, plays WMA audio, displays JPG files, plays CD-R/CD-RW, plays DVD+/-R, plays DVD+/-RW, parental controls, and the length of the labor warranty.

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[72] Equation (1) was also considered without the natural log transformation of the DVD hardware price. The Box-Cox maximum likelihood test strongly and significantly rejected the linear model in favor of the model shown above.

73 The variable DISCS is not an indicator variable, but rather is the number of discs in a multi-disc DVD player. The variable COMBOHDS also is not an indicator variable, but represents the size of the combined PVR/HardDrive in gigabytes. Essentially these could be thought of as combination variables where the indicator variable for the type of hardware is interacted with the more descriptive variable quantifying differences among DVD hardware of these specific types. The model was robust to either specification. Using pure indicator variable versions of these variables (MULTIDISC and COMBOHDI) did not affect coefficients on other variables and these results are also shown in Table 11.

The coefficients on the time indicator variables ***ISSUE*** are expected to be negative, reflecting dropping prices with each successive time period in the panel. All estimates of the α_t are relative to the omitted variable representing the June 1997 time period.

The estimates for the coefficients on the ***DVDTYPE*** variables are all expected to be positive. The ***DVDTYPE*** indicators are constructed so that the omitted type is a single disc non-progressive scan DVD player. All other types have important high level features and functionality which are expected to more valuable to consumers than the most basic DVD player.

The estimates for the coefficients on the ***AUDIO***, ***VIDEO*** and ***FEATURES*** variables are all expected to be neutral to positive. It may be the case that certain features are included with various DVD models that are valueless to consumers in which case the coefficient should be zero. It is unlikely that any of these characteristics would lower the value for consumers and cause the coefficient to be negative.

Equation (1) was estimated with the pooled data from the whole sample. The model was estimated with the ***ISSUE*** and ***DVDTYPE*** variables along with various combinations of the ***AUDIO***, ***VIDEO*** and ***FEATURES*** variables. Because of the sparseness of the data on some features, the lack of variability on others and the multicollinearity among many of the variables, the coefficients on ***AUDIO, VIDEO*** and ***FEATURES*** were not well estimated or could not be estimated at all. The results were directionally correct in that the coefficients were generally positive, but in most cases the subset of the data used resulted in estimates that were not

statistically significant.[74] Liegey (1999) had found significant positive coefficients for the inclusion of a Dolby digital decoder and for a longer than standard warranty. For these two features in particular, the coefficients in the estimate of equation (1) were positive and significant at the 1% and 5% levels respectively. The estimates were also similar in value to the results in Liegey (1999) suggesting a 23% price premium for built in Dolby digital decoders. My results suggested a higher price premium of 21% for a 12 month labor warranty whereas the results in Liegey (1999) suggest a 13% premium.

Equation (1) was also estimated without the ***AUDIO***, ***VIDEO*** and ***FEATURES*** variables on the full sample. The results are shown in Table 11. The estimates for the coefficients on each of the ***ISSUE*** variables is of the correct sign and is statistically significant. The expectation was that the coefficients would be increasingly negative, indicating monotonically decreasing prices over the sample time period. This is the case except for the coefficient on the indicator variable for March 2005. The coefficients show a sharp price drop (relative to June 1997) in December 2004 and then a price **increase** in March 2005 after which the coefficients become more negative indicating further price declines.[75]

Each of the coefficients on the ***DVDTYPE*** variables is positive as expected and is statistically significant. Because of the log-linear specification, the coefficients can be

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[74] For reasons of space, these detailed results are not reported here, but can be obtained from the author upon request.

[75] This appears to be mainly an artifact of the data sample. In December 2004, there were 16 models of progressive scan single DVD players reviewed with an average price of $107. In March 2005, there are 7 models reviewed with an average price of $124. The same is true in the subset of multidisc players. In December 2004, 5 multidisc models were reviewed with an average price of $132 and a maximum price of $180. In March 2005, there are only 3 multidisc players reviewed with two players at $115 and an Onkyo player at $500, raising the average price of the multidisc subsample to $243. Because the coefficients on the DVDTYPE variables are restricted in this model across time periods, the ISSUE indicator variable is absorbing some part of these supposed price 'increases.'

exponentiated[76] to reveal the price impact relative to the base standard DVD player in a given time period. For instance the coefficient on DISCS (.083) multiplied by five[77] and then exponentiated, reveals that a multidisc player should price at ~150% of the price of the base DVD player (*ceteris paribus*). The coefficient on PROGSCAN also implies that a progressive scan player would price at just more than 150% of the base DVD player. Additionally, these effects are additive (in exponents, or multiplicative in price premia). This means that a 5 disc progressive scan player should price at >225% of the base DVD player. The coefficient on RECORDER implies that recorders should price at 400%+ (or just more than four times) the price of the base DVD player. The coefficient on PORTABLE is slightly larger and again implies a price at five times the price of the base DVD player. The COMBOVCR coefficient is positive, but relatively small, implying only a 25% premium over the base DVD player.[78] The COMBOHDS coefficient implies that these DVD recorder/PVR combinations have an additional 27% price premium over a standard DVD recorder.[79]

These results show that the hedonic model can be used to estimate the decline in prices across the sample but also is useful in understanding and quantifying the determinants of price from the consumer perspective. Unlike Liegey (1999), these results are robust across a multiple period data sample. The results are similar in that the vast majority of connection types and

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[76] The exponential function is the inverse of the natural logarithm function and is raising the constant e (2.718…) to the power of x, where x in this case is the estimated coefficient on the variable.
[77] 5 discs is the most common capacity of a multidisc DVD player
[78] This result makes intuitive sense as the combination player was simply a DVD and VCR combined. The coefficient implies that consumers do value the combination player higher than a standalone DVD player, but only by $40-$100 (depending on where you are in the sample), which is not far from the price of a basic VCR.
[79] Combination DVD and hard drive recorders are coded in the sample as a recorder and as a combination with a hard drive. Most hard drive combinations in the sample had 80gb drives so the price premium shown above is for that configuration.

other features are not sufficiently distinct and valuable to the consumer to be estimated with any precision. The high level features encompassed in the ***DVDTYPE*** variables explain the vast majority of the price dispersion across the DVD hardware models in the sample.

7.5.4 Hedonic price indices

The estimates of the coefficients on the ***ISSUE*** variables in equation (1) are easily converted to a price index for DVD hardware.[80] The results are shown in Table 12. The hedonic price version of **Index97** drops from 100 to 11.1, implying that prices dropped at a 23.4% compounded annual rate for just over eight years. The hedonic version of **Index99** shows a similar result, dropping from 100 to 19.5, implying that prices dropped at a 24.7% compounded annual rate over the last nearly 6 years of the sample. The hedonic price index results show a significantly greater price decrease[81] over the period of the sample than either the elementary or matched model indices.[82] Also the hedonic price index implies that DVD prices dropped at approximately **twice** the rate that Liegey (1999) reports for the BLS *Other Video Equipment* category and over a much longer time period.[83] The path of the hedonic DVD price index is largely monotonic with significant price declines through December 2001 while the market was growing rapidly and then another large price decline in December 2003 as the DVD hardware sales were reaching their peak velocity. The December 2004/ March 2005 data artifact discussed

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[80] This is another benefit of the log-linear functional form in Equation (1)

[81] Using the standard errors for the September 2005 coefficient estimate (0.134) and the adjustment suggested in Bernt (1991), the 95% confidence interval for the September 2005 Index97 value ranges from 9 to 15, well below the elementary index values of 20.5 and 18.3 shown in Table 30.

[82] The results are not directly comparable to the matched models because of differing base years. When recalculated on an equivalent basis the hedonic model shows a 24.1% annual decline from December 2000 as compared with 15%-17% annualized declines from the matched models.

[83] The quoted BLS results covered 1997-1999. Given the growth of the DVD hardware market from1997-2005, understating the price declines by as much as 50% would be a significant measurement error in this BLS category.

above persists in the price index as does a weaker version of the same phenomenon between December 2001 and March 2002. This hedonic DVD hardware price index accounts for the quality differences among the various models and is able to incorporate the full sample data (unlike the matched models). As expected, the index shows a larger quality adjusted decline in DVD hardware price than was measured with either the elementary or matched models indices.

7.5.5 Brand effects

As discussed above, Liegey (1999) found that brand identity variables were important to explain the DVD hardware prices in his hedonic model. To explore the value of brands in this hedonic model, the following equation was estimated with various versions of ***BRAND*** variables

$$LPRICE_{i,t} = \alpha_0 + \alpha_t ISSUE_{i,t} + \beta DVDTYPE_{i,t} + \gamma BRAND_{i,t} + \varepsilon_{i,t} \quad (2)$$[84]

Table 37 shows the regression results for three different versions of the ***BRAND*** variables.[85] The "fixed effects" model uses brand indicator variables for each brand that has more than one observation in the sample.[86] The "largest brands" model uses a subset of those indicator variables for all brands with more than ten observations in the sample. The "condensed brands" models uses categories described by Liegey (1999) to separate

[84] For brevity, I have omitted the ***AUDIO***, ***VIDEO*** and ***FEATURES*** variables in equation (2). The model was estimated with these variables, but similar to the first set of results, these characteristics were not well estimated and are omitted from the reported results.

[85] There are proponents and detractors of these various specifications. Ioannidis and Silver (1997) use individual indicator variables, while Moulton, Moses and LaFleur (1999) use categorical brand groupings.

[86] The brands with single observations in the sample that are excluded from this specification are Audiovox, Harman Kardon, Initial, LG, Magnavox, Marantz and Sampo.

audio/videophile targeted brands and mass consumer brands into two indicator variables, SOPHISITCATED and STANDARD.[87]

The results for the "fixed effects" model are not surprising. The coefficients on the brand variables are relative to the missing brands (which are of a mixed quality). The coefficients are thus nearly relative comparisons to each other. Obvious higher end brands such as Denon, Onkyo and Yamaha have positive coefficients as would be expected, but their statistical significance is borderline. The remaining brands generally have negative coefficients but very few are significant. This specification has so many variables that it is stretching the dataset significantly, so it is not surprising that most of the individual brand variable coefficients are not significantly estimated. The ***ISSUE*** and ***DVDTYPE*** variables continue to be estimated significantly and the coefficient estimates themselves are very similar to the results in Table 11.

The "largest brands" specification with only nine brand indicator variables has similar results. These are the brands with the largest number of observations in the sample and are likely to be mass market aimed brands. Not surprisingly, the coefficients on these brand indicator variables are negative indicating a price discount relative to the other brands in the sample. Sony is the exception, but the statistical significance is so low that it can be ignored. The remaining brands are mixed in terms of the significance of the coefficients. RCA, Samsung and Zenith are the only brands with borderline statistical significance. Similar to the "fixed effects"

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[87] The SOPHISTICATED indicator variable encompasses Harmon Kardon, Marantz, Onkyo, Denon, Yamaha, V Inc and Mitsubishi. Liegey (1999) originally included Sony in that grouping, but over the longer time period of this sample that appears inappropriate as Sony has models aimed at the mass market as well. The STANDARD brand indicator variables include RCA, Samsung, Panasonic, Philips, Pioneer, JVC, Mintek, Toshiba, Zenith and Apex. Sony is omitted as it arguably spans both groupings.

specification estimate, the ***ISSUE*** and ***DVDTYPE*** variables continue to be estimated significantly and the coefficient estimates themselves are very similar to the results in Table 11.[88]

The "condensed brands" specification uses just two indicator variables to differentiate between higher end brands (SOPHISTICATED) and the mass market brands (STANDARD). The coefficient estimates on these two variables conform to expectations. The sign on STANDARD is negative and significant, while the sign of the coefficient on SOPHISTICATED is positive and significant. Similar to the two previous brand specification estimates, the ***ISSUE*** and ***DVDTYPE*** variables continue to be estimated significantly and the coefficient estimates themselves are very similar to the results in

[88] Because Sony appears to straddle both ends of the quality spectrum, the "fixed effects" and "largest brands" specifications were re-estimated with the Sony indicator variable in the model. The estimates of the other brand coefficients improve in significance with this change and the estimates of the ***ISSUE*** and ***DVDTYPE*** coefficients are nearly unchanged.

Table 35 Table 11.

Table 38 shows the hedonic price indices based on the original regression of equation (1) in Table 11 and the brand regressions from Table 37. The results across each of these models are nearly identical for the price indices shown. From June 1997 to September 2005 the annualized price declines range from 23.4% to 24.4% while the price declines from December 1999 to September 2005 range from 24.7% to 25.8%. The only minor difference between the brand indices and the original hedonic DVD price index is in the path of the price decline. For example, the "condensed brands" hedonic DVD price index is monotonic through the December 2001 and March 2002 periods and the transition from December 2003 to March 2005 is less abrupt.[89] The other brand specifications show a similar path of price decline.

The "condensed brands" model was estimated on an adjacent year basis to allow more flexibility than the specification in Equation (2). The lack of variability between the December/March pairs of time periods made it difficult to estimate all the adjacent year pairs. When the March data was discarded (three time periods), the restricted model was re-estimated with similar results to Table 37. Adjacent year regressions for this subsample yielded hedonic index results that were again consistent with the results in

[89] The price index in all brand specifications continues to show a drop in price in December 2004 and a rise in prices in March 2005. The brand specifications cannot overcome this powerful artifact of the data in the sample.

Table 38. The regression results for the restricted and comparable adjacent year models on the data subsample are shown in Table 39. The resulting hedonic price indices for the subsample are shown in Table 40 and are much the same as the other hedonic price indices in the paper.

Including brand identity in the hedonic model strengthens the overall fit of the model and explains more of the variation in the data. This is consistent with the results from Liegey (1999). For this particular sample, the use of the brand identities in the model pushes the price indices closer to our expected monotonic price decline. The difference between the original hedonic price indices and those resulting from this specification is small. A less restricted set of models from adjacent years was also estimated and again yielded consistent hedonic price indices. This underlines the robustness of the hedonic model and the price index results discussed in this section and the previous section.

7.5.6 Effects of qualitative measures of quality on the hedonic model

As discussed above, there is very little research on the impact of qualitative measures of quality in hedonic models and more specifically with regard to the calculation of price indices. Quality is a feature of every product and fits equally well in the hedonic framework as any other characteristic of a product. Some measures of quality can be known before purchase from reviews or other sources. Brands are often thought to embody these often unmeasured dimensions of the product. For example, for many products *Consumer Reports* publishes

reliability and repair statistics. These measures are historical but can point consumer to brands that have a history of reliability and away from brands with a history of problems.[90]

In nearly all the DVD hardware reviews published in *Consumer Reports*, the publication tests and reports consistently on two measures of quality. "Picture quality" is ranked on a scale from one to five. Likewise, "ease of use" is measured on a scale of one to five. The summary for these variables is shown at the bottom of Table 29. In the reviews, "picture quality" is nearly always ranked excellent (=5).[91] As the data summary shows there are only rare occasions where picture quality was deemed to be lower (mean across sample is 4.94). "Ease of use" is meant to describe the ease or difficulty of accessing the features of the DVD hardware. This includes the menus and command structure, the ergonomics and functionality of the remote control, the console mounted display and controls, etc. The summary in Table 29 shows that there is more variability in the "ease of use" scores (mean=4.14 with a standard deviation of 0.6) across the DVD hardware sample.

To investigate the impact of these qualitative measures we expand equation (2) to include the PICTUREQ and EASEOFUSE variables.

$$LPRICE_{i,t} =$$

$$\alpha_0 + \alpha_t ISSUE_{i,t} + \beta DVDTYPE_{i,t} + \gamma BRAND_{i,t} + \delta PICTUREQ_{i,t} + \theta EASEOFUSE_{i,t} + \varepsilon_{i,t} \quad (3)$$

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[90] For DVD hardware, *Consumer Reports* did publish DVD reliability data in the December 2004 issue, but this paper does not make use of that data. Apart from the endogeneity issue, the data only appeared once and could not have influenced purchasers or prices until the very last part of our sample.

[91] The most notable exceptions to this are the portable DVD players, all of which are deemed to have "picture quality" of three or four. There are another handful of observations near the beginning of the sample with "picture quality" of four, but after March 2002 all non-portable players are deemed to have "excellent" "picture quality".

The expected sign on both quality variables is positive as consumers will typically pay more for a higher quality good (to a point). Based on the results in the previous section, equation (3) is estimated using the "condensed brand" specification with the SOPHISTICATED and STANDARD indicator variables. The regression results are shown in Table 41. The model was estimated with both quality measures, "ease of use" only and "picture quality" only.[92]

The results in Table 41 show that the estimated coefficients on the quality variables in all variations of the model have the expected positive sign. However, none of the estimates is statistically significant. With very little variation in these measures of quality, this is not unexpected.[93] An alternative explanation may be that there really is very little variation in consumer discernable quality among DVD hardware. The leap in quality from a VCR to DVD is clear, but perhaps the inter-DVD quality differences are too hard for consumers (and in this case reviewers) to detect. If that is the case then we should not be surprised by this result. If there are no discernable differences in quality, then it follows that we should not expect quality to influence DVD hardware pricing.

The coefficients on the ***ISSUE*** variables are different than in each of the previous regressions. In this specification, the omitted issue is December 1999 instead of June 1997.[94] The coefficients show are all relative to December 1999 and it is relatively easy to show that they are essentially equivalent to the coefficients from the previous regressions. As in each of

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[92] The model was also estimated without the brand effects and with and without various ***AUDIO***, ***VIDEO*** and ***FEATURES*** variables. None of these results were materially different from the results in Table 41.

[93] Essentially, there is so little variation in the quality variables that the remaining price variation in the error term is only being estimated with a handful of observations. More variation would not necessarily prove the hypothesis, but it would allow for the possibility.

[94] The data in the June 1997 issue had no quality rating information.

the previous two sections above, the ***ISSUE*** and ***DVDTYPE*** variables continue to be estimated significantly and the coefficient estimates themselves are very similar to or consistent with the results shown in Table 11.

Updated versions of the hedonic DVD price indices based on these regressions are shown in Table 42. The resulting indices are very close to the original model results in Table 12 with the only discernable difference being the path of the price declines. As was demonstrated in the previous section above, this is a result of the inclusion of the ***BRAND*** and is not caused by adding these measures of quality.

Unfortunately, these results do not appear to suggest a conclusive result regarding integrating qualitative measures of quality into the hedonic model. The sample data has only two potential measures that have very little variation concentration among only a few observations. The regression results for this sample suggest that qualitative measures of quality are not important determinants of price in the hedonic model and do not impact the hedonic DVD price indices in any material way. The positive result from this is that the hedonic model once again was shown to be robust to this change in specification despite the lack of a conclusive answer regarding the quality measures.

7.6 Conclusion

This paper examines a new data set covering the eight year history of DVD hardware prices. During this time, the DVD has grown to be the most successful consumer product in history, penetrating into 85% of US households in ten short years. Existing research on the DVD market has failed to examine the rate of changes of prices during the growth of this market. This paper

is the first to establish a hedonic price index for a good in the most rapidly changing market ever seen. This paper is also one of very few studies that have attempted to incorporate qualitative descriptors of quality into the hedonic framework and the first for a durable good.

The hedonic price indices constructed in this paper show that DVD hardware prices have been falling at a ~24% compounded annual rate since the product's introduction in the marketplace and through the eight years of the sample data. This is significantly faster than the results garnered from elementary price indices or matched models methods with the same data sample. The paper shows that the hedonic framework is suitable for such rapidly growing and changing product markets and is an improvement over typical BLS methods. This paper demonstrates that it is the easily discernable high level features of DVD hardware (i.e. multiple discs, recorder, portable, combo DVD/VCR, progressive scan) that drive most of the variability in price. Lesser known, more esoteric or features largely common to most DVD hardware do not appear to have a significant impact on price. Brand is another easily observerable characteristic of DVD hardware. This paper finds that brand impacts price but the impact has less explanatory power than the high level features of the DVD hardware itself. The hedonic pricing results and the pricing indices created are extremely robust to various specifications. The results on qualitative measures of quality suggest that they are not significant determinants of the price in the hedonic model used here. There is no way to reach a conclusion as to whether this is a feature of this dataset or if quality differences among DVD hardware are truly too difficult to discern.

Chapter 8 - Tables

Table 4: ISP Price Dataset – Counts of Firms and Observations[95]

Years	11/93	1/95	5/96	8/96	3/97	1/98	1/99	
Directory Firms[96]	24	35		2934	3535	4167	4511	
Sample Firms[97]			710					
Total obs	25	47	1283	2822	3813	5659	5568	
Speeds	Number of observations at each speed by year							Total
14.4k	25	42						67
28.8k		5	702	2822	3367	3972	2562	13430
56k					446	1564	3006	5016
ISDN 64k			299			54		353
ISDN 128k			282					282
T1 1.544mb						69		69
Limited Hours	13	22	303	996	1024	1130	581	
Unlimited	12	25	980	1826	2789	4529	4987	
% Limited	52%	47%	24%	35%	27%	20%	10%	
28.8k speed								
Limited Hours		2	303	996	1024	1130	581	
Unlimited		3	399	1826	2343	2842	1981	
% Limited		40%	43%	35%	30%	28%	23%	

[95] 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.
[96] Some firms disappear from the published data and others continue to be listed without price plan information. We are not sure of the fate of these firms, though it is likely that the ones that disappear have either been consolidated or failed. Firms that continue to appear without price data provide evidence that *Boardwatch* did in fact continue to monitor and update the pricing in their listings. This eliminates some bias in the results that would have occurred if the prices were not up to date.
[97] 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.

Table 5: Nominal Price Index – Mean and Median of Monthly Price – Full 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 6: Nominal Price Index –Mean and 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 7: Matched Model - Strictly Matched Observations

Date	No. of Matches	Indices 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 8: Descriptive Statistics for Prices of Limited and Unlimited Plans[98]

Prices		Limited	Unlimited
Nov-93	Mean	15.15	47.83
	Sdev[99]	12.65	25.06
	N	13	12
Jan-95	Mean	27.71	48.67
	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

[98] All of the differences between means are significant at p-values of 1% or smaller.
[99] Sdev is the standard deviation.

Table 9: Descriptive Statistics of Nominal Prices by Hourly Limitation[100]

		Hourly Limitations								
Prices		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

[100] Survey data from March 2000 in Goldfarb (2004) 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.

Table 10: Descriptive Statistics for Hedonic Regression Exlanatory Variables – full sample

Variable	Obs	Mean	Std. Dev.	Min	Max
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
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

Table 11: Frequency Counts for Limited Hours Bins

Variable	Hourly limitation[101]	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

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

Table 12: Regression Results from Estimation of Eqn. (0.1)[102]

	Model		Adjacent period regressions					
Variable	Full	Restricted	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 [103]	0.534	0.533	0.402	0.496	0.548	0.233	0.576	0.593

[102] a: significant at p-values <1%; b: significant at pvalues < 5%' c: significant at p-values <10%

[103] 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 13: Direct Price Indices Calculated from Hedonic Specification Eqn. (0.1)

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 14: Regression Results from Estimation of Eqn. (0.2)

	Models			Adjacent period regressions – random effects specification					
Variable	Full, FE	Full, RE	Restricted, RE	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 15: Direct Price Indices Calculated from Estimation of Hedonic Eqn. (0.2)

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 16: Regression Results from Estimation of Eqn. (0.2) - 28.8k Speed Plans Only[104]

	Model (0.2)	28.8 (1.2)	Adjacent period regressions					
Variable	Full Sample	Sub sample	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	0.566[a]	0.414	0.479[a]	–	–	–	–
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	0.532	0.533	0.394	0.291[105]	0.257	0.242	0.2251	0.209

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

[104] See format of notes to Table 9 above. For estimates in 1996 and later 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.

[105] 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 17: Direct Price Indices Calculated from Estimated Coefficients in Hedonic Eqn. (0.2) 28.8k Speed plans

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 18: GVU WWW Survey data - Internet Connection Speeds[106]

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

Source: Georgia Tech (1997)

Table 19: 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

Source: Georgia Tech (1997)

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

Table 20: Counts of price plans by entrants and incumbents over time

	Observation date						
Price plans (N)	Nov-93	Jan-95	May-96	Aug-96	Mar-97	Jan-98	Jan-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 21: Counts of price plans by vintages and time

	Observation date						
Price plans (N)	Nov-93	Jan-95	May-96	Aug-96	Mar-97	Jan-98	Jan-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 22: Regression results from estimation of model that includes entrants and vintages

	Models			
Variable	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 23: Regression results from model (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 14: Regression results from model (includes firm age and new products)

	Models	
Variable	Standard RE Model	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 24: 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%

Table 25: Data sample – Distribution of observations across time periods

Issue date	Observations
Jun-97	3
Dec-99	6
Dec-00	28
Dec-01	25
Mar-02	33
Dec-02	26
Mar-03	36
Dec-03	39
Dec-04	42
Mar-05	18
Sep-05*	35
Total	291

* September 2005 data was collected from a DVD review update posted on the ConsumerReports.org website

Table 26: Count of DVD models and observations

Models	observations
150	1
63	2
5	3

Table 27: DVD manufacturers represented in sample

Manufacturer	Observations
Apex	9
Aspire	3
Audiovox	1
Denon	3
Fisher	2
Go-Video	2
Harman Kardon	1
Hitachi	9
Initial	1
JVC	25
Kenwood	3
Konka	2
LG	1
Magnavox	1
Marantz	1
Mintek	2
Mitsubishi	8
Onkyo	6
Oritron	2
Panasonic	39
Philips	17
Pioneer	18
RCA	12
Sampo	1
Samsung	24
Sanyo	2
Sharp	7
Sony	32
Toshiba	37
V Inc	2
Yamaha	5
Zenith	13
Total	291

Table 28: Sample data categories

Price
DVD brand
DVD model
Multi-disc / number of discs
Progressive Scan
Combo VCR
DVD Recorder
Combo DVD/HD/PVR
Portable DVD
Portable battery life
Portable sound quality
Coax audio out
Optical digital audio
Dolby / DTS Decoder
Component video out
S video out
Composite video out
MP3
DVD audio
SACD
WMA audio files
JPG files
Video CDs
DVI output
Universal remote
Virtual surround sound
Screen saver
Chap preview
Plays CD-R audio
Plays CD-RW audio
DVD+R
DVD-R
DVD+RW
DVD-RW
Dialogue enhancement
Goto by time
Dynamic audio
Bookmark
Parental controls
Warranty length (labor)
Picture quality
Ease of use

Table 29: Summary of the sample

Variable	Obs	Mean	Std. Dev	Min	Max
PRICE	291	230.5498	163.3925	50	1300
MULTIDISC	291	0.182131	0.386617	0	1
DISCS	291	1.694158	1.501471	1	6
PROGSCAN	291	0.560138	0.497225	0	1
COMBOVCR	291	0.079038	0.270263	0	1
RECORDER	291	0.109966	0.313386	0	1
COMBOHDP	291	1.924399	13.55987	0	120
PORTABLE	291	0.020619	0.142348	0	1
PORTBATT	6	3.25	0.758288	2.5	4.5
PORTSOUN	6	3.833333	0.408248	3	4
COAXAUDI	260	0.842308	0.365155	0	1
OPTICALD	284	0.714789	0.452312	0	1
COMPONENT	227	0.933921	0.24897	0	1
DOLBYDECODE	152	0.197368	0.399329	0	1
UNIVREMOTE	113	0.477876	0.501735	0	1
SVIDEO	271	0.97417	0.158922	0	1
MP3	256	0.6875	0.46442	0	1
DVDAUDIO	212	0.221698	0.416372	0	1
SACD	160	0.075	0.264218	0	1
WMAAUDIO	253	0.256917	0.437799	0	1
JPG	239	0.380753	0.486591	0	1
VIDEOCD	253	0.284585	0.452111	0	1
DVIOUTPUT	187	0.010695	0.103139	0	1
SURROUNDSOUND	146	0.828767	0.378009	0	1
SCREENSAVER	149	0.765101	0.425366	0	1
CHAPPREVIEW	101	0.693069	0.463521	0	1
PLAYSCDR	164	0.871951	0.335168	0	1
PLAYSCDRW	202	0.871287	0.335714	0	1
DVD-R	167	0.982036	0.13322	0	1
DVD+R	167	0.994012	0.077382	0	1
DVD-RW	96	0.802083	0.400521	0	1
DVD+RW	93	0.892473	0.311461	0	1
DIALOGUENHANCE	89	0.685393	0.46699	0	1
GOTOBYTIME	52	0.961539	0.194184	0	1
DYNAMICAUDIO	127	0.913386	0.282383	0	1
PARENTALCONTROL	131	0.984733	0.123084	0	1
WARRANTY	151	5.344371	3.902215	3	12
PICTUREQUAL	278	4.935252	0.299425	3	5

EASEOFUSE	274	4.138686	0.607432	3	5

Table 30: Elementary price indices

	Average prices			Median prices			
Date	Price ($)	Index97	Index99	Price ($)	Index97	Index99	Obs
6/1/1997	617	100.0		600	100.0		3
12/1/1999	349	56.6	100.0	345	57.5	100.0	6
12/1/2000	291	47.1	83.3	268	44.6	77.5	28
12/1/2001	202	32.7	57.7	200	33.3	58.0	25
3/1/2002	219	35.5	62.7	200	33.3	58.0	33
12/1/2002	196	31.7	56.0	150	25.0	43.5	26
3/1/2003	276	44.8	79.0	175	29.2	50.7	36
12/1/2003	214	34.7	61.4	145	24.2	42.0	39
12/1/2004	251	40.7	71.9	230	38.3	66.7	42
3/1/2005	244	39.5	69.8	155	25.8	44.9	18
9/1/2005	126	20.5	36.2	110	18.3	31.9	35
						Total n=	291
Annualized rate of price decline							

Table 31: Elementary index of single disc DVD players

	Avg price	Index97	Index99	obs
6/1/1997	617	100.0	176.6	3
12/1/1999	349	56.6	100.0	6
12/1/2000	269	43.6	77.0	20
12/1/2001	195	31.6	55.8	21
3/1/2002	200	32.4	57.2	23
12/1/2002	175	28.3	50.0	20
3/1/2003	169	27.4	48.4	22
12/1/2003	118	19.2	33.9	23
12/1/2004	108	17.5	30.9	15
3/1/2005	124	20.2	35.6	7
9/1/2005	118	19.1	33.8	23
			Total n=	183

Table 32: Elementary index of single disc DVD players without progressive scan

	Avg price	Index97	Index99	Obs	to single disc (Index)
6/1/1997	617	100.0	176.6	3	0.0
12/1/1999	349	56.6	100.0	6	0.0
12/1/2000	246	39.9	70.5	19	-3.7
12/1/2001	181	29.4	51.9	17	-2.2
3/1/2002	189	30.7	54.1	16	-1.7
12/1/2002	153	24.8	43.8	15	-3.5
3/1/2003	118	19.1	33.8	12	-8.3
12/1/2003	80	13.0	22.9	3	-6.2
12/1/2004	50	8.1	14.3	1	-9.4
			Total n=	92	

Table 33: Matched models in sample data and price changes

Matching periods		Matched models	Price changes
Jun-97	Dec-99	0	0
Dec-99	Dec-00	0	0
Dec-00	Dec-01	3	3
Dec-01	Mar-02	18	6*
Mar-02	Dec-02	1	1*
Dec-02	Mar-03	19	12
Mar-03	Dec-03	0	0
Dec-03	Dec-04	2	2
Dec-04	Mar-05	9	6
Mar-05	Sep-05	12	5*
		Total matches= 64	

* - One price change among each of these matched models is a price increase

Table 34: Matched model indices

	Dutot	Carli	Jevons
Jun-97			
Dec-99			
Base - Dec-00	47.1	47.1	47.1
Dec-01	33.2	33.8	33.5
Mar-02	32.0	32.8	32.4
Dec-02	33.1	33.9	33.5
Mar-03	30.2	31.4	30.9
Dec-03	30.2	31.4	30.9
Dec-04	23.8	25.2	24.8
Mar-05	21.6	23.4	23.0
Sep-05	19.4	22.0	21.4

Table 35: Regression results – Equation (1)

	Full model		Pure indicator variable model	
variable	coef	t-stat	coef	t-stat
Jun-97	omitted		omitted	
Dec-99	-0.564	-5.95	-0.564	-5.95
Dec-00	-0.884	-6.56	-0.900	-6.75
Dec-01	-1.254	-10.42	-1.259	-10.48
Mar-02	-1.245	-12.08	-1.247	-11.97
Dec-02	-1.458	-12.78	-1.455	-12.62
Mar-03	-1.551	-14.81	-1.548	-14.67
Dec-03	-2.003	-15.62	-2.001	-15.59
Dec-04	-2.314	-17.36	-2.314	-17.36
Mar-05	-2.177	-9.76	-2.175	-9.71
Sep-05	-2.196	-16.36	-2.198	-16.42
RECORDER	1.379	21.87	1.371	21.91
DISCS	0.083	4.07		
MULTIDISC			0.316	4.13
PROGSCAN	0.434	7.00	0.438	7.16
COMBOVCR	0.223	4.26	0.222	4.18
PORTABLE	1.612	11.32	1.612	11.34
COMBOHDS	0.003	2.75		
COMBOHDI			0.315	3.70
CONSTANT	6.327	64.63	6.411	66.40
r-squared	0.74		0.73	
n	291		291	

Table 36: Hedonic price indices based on estimates of Equation (1)

	Full model	
	Index97	Index99
Jun-97	100	
Dec-99	56.9	100.0
Dec-00	41.3	72.6
Dec-01	28.5	50.2
Mar-02	28.8	50.6
Dec-02	23.3	40.9
Mar-03	21.2	37.3
Dec-03	13.5	23.7
Dec-04	9.9	17.4
Mar-05	11.3	19.9
Sep-05	11.1	19.5
Annualized rate of price decline		
	23.4%	17.9%

Table 37: Brand regression results for Equation (2)

	"Fixed effects"		Largest brands		Condensed brands	
variable	coef	t-stat	coef	t-stat	coef	t-stat
Jun-97	omitted		omitted		omitted	
Dec-99	-0.591	-6.32	-0.604	-6.74	-0.589	-6.28
Dec-00	-0.864	-6.33	-0.937	-6.42	-0.948	-6.67
Dec-01	-1.215	-11.28	-1.318	-9.97	-1.316	-11.04
Mar-02	-1.253	-12.35	-1.319	-12.99	-1.353	-13.91
Dec-02	-1.523	-15.92	-1.550	-14.47	-1.588	-16.30
Mar-03	-1.527	-15.93	-1.609	-14.04	-1.654	-15.44
Dec-03	-2.012	-17.79	-2.099	-15.92	-2.119	-18.46
Dec-04	-2.291	-20.29	-2.406	-17.37	-2.423	-20.06
Mar-05	-2.170	-11.03	-2.241	-10.52	-2.285	-12.09
Sep-05	-2.221	-19.02	-2.267	-18.34	-2.307	-18.56
RECORDER	1.389	22.05	1.391	22.83	1.454	26.17
DISCS	0.069	5.03	0.088	3.91	0.089	6.23
PROGSCAN	0.388	11.15	0.469	7.56	0.420	10.55
COMBOVCR	0.282	7.84	0.252	6.44	0.280	7.27
PORTABLE	1.535	7.44	1.583	10.37	1.647	12.25
COMBOHDP	0.003	2.84	0.003	2.74	0.003	3.26
STANDARD					-0.149	-2.85
SOPHIST					0.468	3.06
APEX	-0.603	-3.07				
ASPIRE	-0.408	-2.03				
DENON	0.473	2.34				
FISHER	-0.174	-0.91				
GOVIDEO	-0.261	-1.33				
HITACHI	-0.318	-1.62				
JVC	-0.325	-1.65	-0.176	-1.83		
KENWOOD	-0.141	-0.66				
KONKA	-0.255	-1.31				
MINTEK	-0.760	-3.67				
MITSUBIS	-0.171	-0.85				
ONKYO	0.341	1.71				
ORITRON	-0.669	-3.44				
PANASONC	-0.299	-1.52	-0.176	-1.67		
PHILIPS	-0.330	-1.71	-0.185	-1.99		

PIONEER	-0.295	-1.51	-0.151	-1.60		
RCA	-0.444	-2.26	-0.288	-3.11		
SAMSUNG	-0.370	-1.89	-0.235	-2.40		
SANYO	-0.397	-2.09				
SHARP	-0.279	-1.47				
SONY	-0.113	-0.58	0.023	0.23		
TOSHIBA	-0.300	-1.51	-0.175	-1.68		
VINC	0.443	2.13				
YAMAHA	0.486	2.46				
ZENITH	-0.518	-2.59	-0.386	-3.85		
Constant	6.641	31.34	6.498	49.15	6.470	60.94
r-squared	0.85		0.77		0.82	
n	291		291		291	

Table 38: Hedonic price indices based on Brand regressions

	Full model		"Fixed effects"		Largest brands		Condensed brands	
	Index97	Index99	Index97	Index99	Index97	Index99	Index97	Index99
Jun-97	100.0		100		100		100	
Dec-99	56.9	100.0	55.4	100.0	54.7	100.0	55.5	100.0
Dec-00	41.3	72.6	42.1	76.1	39.2	71.7	38.7	69.8
Dec-01	28.5	50.2	29.7	53.6	26.8	49.0	26.8	48.3
Mar-02	28.8	50.6	28.6	51.6	26.7	48.9	25.9	46.6
Dec-02	23.3	40.9	21.8	39.4	21.2	38.8	20.4	36.8
Mar-03	21.2	37.3	21.7	39.2	20.0	36.6	19.1	34.5
Dec-03	13.5	23.7	13.4	24.2	12.3	22.4	12.0	21.7
Dec-04	9.9	17.4	10.1	18.3	9.0	16.5	8.9	16.0
Mar-05	11.3	19.9	11.4	20.6	10.6	19.4	10.2	18.3
Sep-05	11.1	19.5	10.9	19.6	10.4	19.0	10.0	17.9
Annualized rate of price decline								
	23.4%	24.7%	23.6%	24.7%	24.0%	25.1%	24.4%	25.8%

Table 39: Adjacent year "unrestricted" model results with "condensed brands"

	Full Model restricted		97/99		99/00		00/01		01/02		02/03		03/04		04/05	
	coef	t-stat	coef	t-stat	coef	t-stat	coef	t-stat	coef	t-stat	coef	t-stat	coef	t-stat	coef	t-stat
Jun-97																
Dec-99	-0.585	-6.24	-0.588	-4.89												
Dec-00	-0.946	-6.69			-0.403	-4.80										
Dec-01	-1.311	-11.17					-0.378	-5.80								
Dec-02	-1.583	-17.33							-0.263	-5.48						
Dec-03	-2.107	-21.21									-0.528	-7.68				
Dec-04	-2.417	-23.77											-0.309	-5.16		
Sep-05	-2.292	-20.77													0.074	0.96
RECORDER	1.478	23.51									1.634	20.95	1.463	22.52	1.378	12.63
DISCS	0.092	6.95			0.126	11.85	0.104	7.64	0.072	5.28	0.089	3.39	0.103	4.24	0.088	6.03
PROGSCAN	0.404	6.91			1.135	18.93	0.545	4.23	0.330	6.15	0.340	4.47	0.376	3.89	0.528	8.50
COMBOVCR	0.255	5.78									0.441	8.97	0.276	4.85	0.242	3.34
PORTABLE	1.652	12.18											1.615	9.52	1.762	13.67
COMBOHDP	0.004	3.59											0.004	3.56	0.004	3.41
SOPHISITCATED	0.546	3.87			-0.024	-0.25	0.267	1.25	0.742	6.92	0.460	3.16	0.390	1.74	0.753	4.20
STANDARD	-0.127	-2.11	-0.144	-1.7	-0.169	-1.65	-0.083	-0.90	-0.102	-1.11	-0.183	-2.82	-0.130	-1.77	-0.07	-0.88
Constant	6.446	57.48	6.554	54.49	5.861	58.75	5.450	61.80	5.151	50.75	4.851	50.94	4.365	38.73	3.892	52.19
r-squared	0.83		0.79		0.66		0.60		0.71		0.82		0.86		0.85	
n	204		9		34		53		51		65		81		77	

Table 40: Hedonic price index results based on adjacent year estimations

	Full model		Adjacent periods	
	restricted		unrestricted	
	Index97	Index99	Index97	Index99
Jun-97	100		100	
Dec-99	55.7	100.0	55.5	100.0
Dec-00	38.8	69.7	37.1	66.9
Dec-01	26.9	48.4	25.5	45.8
Dec-02	20.5	36.9	19.6	35.2
Dec-03	12.2	21.8	11.5	20.8
Dec-04	8.9	16.0	8.5	15.2
Sep-05	10.1	18.1	9.1	16.4
Annualized rate of price decline				
	24.2%	25.7%	25.2%	26.9%
	-27.8%	-29.7%	-29.0%	-31.4%

Table 41: Regression results with Qualitative measures of quality

	Both ratings		Ease of Use		Picture Quality	
variable	coef	t-stat	coef	t-stat	coef	t-stat
Dec-99	omitted		omitted		omitted	
Dec-00	-0.378	-4.83	-0.408	-5.00	-0.365	-4.48
Dec-01	-0.720	-9.00	-0.739	-8.66	-0.704	-8.63
Mar-02	-0.767	-11.19	-0.776	-11.04	-0.752	-10.32
Dec-02	-1.003	-13.95	-1.008	-14.06	-0.990	-13.49
Mar-03	-1.084	-13.20	-1.088	-13.24	-1.049	-12.81
Dec-03	-1.488	-15.09	-1.492	-15.04	-1.506	-14.34
Dec-04	-1.764	-17.70	-1.766	-17.53	-1.808	-18.15
Mar-05	-1.650	-11.64	-1.656	-11.55	-1.667	-11.88
Sep-05	-1.670	-19.01	-1.673	-18.78	-1.690	-19.38
RECORDER	1.385	23.64	1.383	23.56	1.456	26.41
DISCS	0.086	5.66	0.087	5.68	0.087	5.82
PROGSCAN	0.363	7.11	0.364	7.05	0.393	8.62
COMBOVCR	0.293	8.22	0.295	8.08	0.276	7.39
PORTABLE	1.759	5.98	1.543	9.73	1.859	6.67
COMBOHDP	0.004	4.24	0.004	4.29	0.003	3.26
STANDARD	-0.154	-2.96	-0.153	-2.91	-0.152	-2.78
SOPHIST	0.475	3.09	0.472	2.99	0.473	3.16
PICTUREQ	0.127	1.18			0.144	1.32
EASEOFUSE	0.034	1.10	0.041	1.26		
Constant	5.127	10.05	5.738	47.65	5.167	9.48
r-squared	0.80		0.80		0.82	
n	274		274		278	

Table 42: Hedonic price indices with Qualitative measures of quality

	Full model	Both ratings	Ease of use	Picture quality
			only	only
	Index99	Index99	Index99	Index99
Dec-99	100.0	100.0	100.0	100.0
Dec-00	72.6	68.5	66.5	69.4
Dec-01	50.2	48.7	47.8	49.4
Mar-02	50.6	46.4	46.0	47.1
Dec-02	40.9	36.7	36.5	37.1
Mar-03	37.3	33.8	33.7	35.0
Dec-03	23.7	22.6	22.5	22.2
Dec-04	17.4	17.1	17.1	16.4
Mar-05	19.9	19.2	19.1	18.9
Sep-05	19.5	18.8	18.8	18.4
Annualized rate of price decline				
	24.7%	25.2%	25.2%	25.4%

Chapter 9 - References

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