

Role of Complementarities in Technology Adoption:

The Case of DVD Players

This paper estimates complementarities between DVD player adoption and availability of content on DVD. Model is estimated using household level panel data on adoption decisions, and panel data on the availability of movies for rental on DVD at different local regions as well as time series data on the number of movies released on DVD nationally. Estimated complementarities are statistically and economically significant, and suggest that DVD player manufacturers could achieve profit gains from subsidizing DVD content providers to release more movies on DVD. (JEL D12, D62, L11, L82, O33)

Keywords: indirect network effects, complementarity, new technology, diffusion

I. Introduction

What factors influence a consumer's decision on when to adopt a new technology? She faces a trade-off. On the one hand, by adopting today, she could use the product for additional periods. On the other hand, by waiting, she might get a potentially higher quality product at a lower price in the future. This trade-off is the key factor in any adoption process. The availability of complementary products that consumers use concurrently with the new technology can affect the dynamics of this trade-off. For example, hardware products do not have much value if there is not enough software that is compatible with them. Similarly, consumers will not use their hardware product much if there is not a sufficient number of compatible software.

In the context of the Digital Video Disc (DVD)¹ technology, impact of DVD content availability on DVD player adoption and the impact of DVD player installed base on the supply of content on DVD, known in the literature as "indirect network effects" or "complementarities", create a strategic inter-dependence between the firms involved in the supply of DVD players (hardware firms) and the firms involved in the supply of content on DVD (software firms). In particular, any demand generation activity of the hardware firms impacts the consumer demand for the combined hardware/software product, and thus indirectly affects the software firms and vice-versa. Such interaction might significantly influence the valuation, and hence the diffusion of the technology.

This paper examines which factors determine a consumer's decision on when to adopt a DVD player (the hardware-side), and assesses the role of complementarities in the valuation and the adoption of the technology. The parameters of the hardware

¹ Also stands for Digital Versatile Disc

adoption model are estimated using household-level panel data. As a measure of DVD content, the paper uses data on both the number of movies released on DVD which is available to any consumer nationally, and the number of DVD movies available locally for rental at the video rental stores. The local area considered in the analysis is a “Designated Market Area” (DMA), a definition coined by Nielsen Media Research, and commonly used in media related research (Mortimer , 2007a, 2007b). A DMA represents a group of counties covered by a specific group of television, and roughly corresponds to Metropolitan Statistical Areas designated by the Census Bureau. There are 210 DMAs in the U.S. Since the data on DVD content is available starting 2000, the analysis focuses on monthly adoption decisions in 2000 and 2001.

The cross-sectional and time variations in DVD player adoption and in DVD content availability provide a significant data advantage, and distinguishes it from existing literature on complementarities in hardware/software systems. For new technology products such as the DVD players, hardware prices decline over time due to decreasing costs while hardware adoption increases over time. Therefore, time-series based data alone would have a difficulty identifying whether the increasing hardware adoption is due to increasing software availability, or to decreasing hardware prices. On the other hand, cross-sectional data alone would have difficulty identifying whether the cross-sectional differences in hardware adoption are due to cross-sectional differences in software availability, or due to systematic cross-sectional unobservables. Using both the regional variation and time variation in hardware adoption and in software availability, one can relate the changes in hardware adoption to changes in software availability over time in different regions while controlling for declining hardware prices and other trends

that affect consumers similarly in all regions. Moreover, observing a group of regions over time allows for controlling systematic differences across regions that arise either in terms of the general preferences (i.e. taste for movies) of the population, and/or basic contextual factors such as the presence of video stores, or large electronic chain stores.

Given the simultaneous nature of the DVD player adoption decision and the release of content on DVD at a given time, one needs to account for potential endogeneity of the DVD content availability. Using an instrumental variables approach, DVD content availability is instrumented using the number of nationally available VHS releases, and the regional video store inventory of VHS releases available for rental. The availability of VHS movies (nationally and locally) is certainly correlated with the availability of DVD movies through the release of movies by movie studios. The identifying assumption is that the number of VHS releases, and the availability of VHS movies by video rental stores does not respond to the demand for watching movies on DVD after controlling for changes (observable and unobservable) over time, and systematic differences between regions. This is a reasonable assumption for the time period spanned in this paper, February 2000-May 2001, as this was a period in which all theatrically released movies were released first on VHS, and the movie studios decided which movies to also make available on DVD.² Similarly, movie rental stores likely ordered a set of movies on VHS, and a subset of that on DVD.

Another concern is the potential endogeneity of DVD player prices. However, anecdotal evidence suggests that DVD player prices are continuously going down as a response to declining production costs instead of being set strategically by responding to

² A Universal public relations representative interviewed on October 15, 2003 stated that studios started releasing movies simultaneously with DVD only after the retailers made a commitment to display/market the product, which was later in 2000.

changes in consumers' preferences or perceptions. For example, industry insights from Taylor (2001) indicate that mass production of DVD-ROM drives and plummeting costs of audio/video decoder chips are the main driving force behind decreasing prices of DVD players. As data on audio/video decoder chips were not available for the study period, semiconductor price index published by the Bureau of Labor Statistics is used to instrument for DVD play prices.

Estimated parameters imply that a 1% increase in DVD player prices decreases monthly sales of DVD players on average by 0.24%. In terms of the DVD content availability, a 1% increase in the inventory of regional DVD movie rental per household increases monthly sales on average by 0.16%, and it increases the DVD player installed base by 0.01%. The national inventory of DVD movies released also significantly influences the sales and thus the installed base. A 1% increase in the inventory of DVD movies nationally increases the sales of DVD players by 1.4% on average. Policy experiments using these estimates suggest that the availability of the rental channel increases sales significantly. For example, 12 million households would have owned DVD players by May 2001 in the absence of regional rental availability instead of the 14 million under status quo. Similarly, if there were no growth in the number of movies released on DVD, and an average of 40 movies were released on DVD every month throughout 2000 and 2001 as in early 2000, DVD player installed base in May 2001 would have been lower by 1.8 million.

Furthermore, calculations based on these estimates suggest that DVD player manufacturers could achieve profit gains from subsidizing DVD content providers to release more movies on DVD. For example, an additional movie released on DVD would

generate the same number of DVD player sales even if the DVD player price was \$0.15 more. In May 2001, this would imply that the hardware firms jointly could have gained profits of about \$390,000 from an additional release. Similarly, during the holiday season of November 2000-December 2000, hardware firms' gains could have been \$428,000 higher if an additional DVD movie were available in each of these months.

From a policy perspective, the results of this study reveal how a technology take-off and technology value can be accelerated by the availability of complementary products. Although this study focuses on the network effects between DVD players and the availability of movies on DVD, its results can be generalized to other hardware/software-like systems, for which, without sufficient availability of a given complementary component, consumer gains from the technology can be severely limited. Not only will fewer people adopt the technology, but those who adopt will also make less use of their technology. Therefore, the results of this study could provide a useful guide for the launch of similar future technologies.

In fact, the current debate of the next-generation DVD format is an interesting case-in-point. The DVD format as a single standard was announced in September 1995 and launched in the U.S. in April 1997 after much debate between two competing formats, one backed by Sony and Philips and the other by Toshiba, Matsushita and Time Warner. However, immediately after the DVD standard was established, each camp started working on the next generation system, with Sony/Philip's efforts leading to the current Blu-ray disc, and Toshiba's to the current HD DVD. These two rival and incompatible formats have been launched in spring 2007, and are setting the stage for a similar fight between the VHS and Betamax formats. Although there is a stronger studio

support behind Blu-ray including Disney, Twentieth Century Fox, Lionsgate, as well as the two Sony-owned studios: Columbia Tristar and MGM, major studios such as Warner Home Video, Paramount Pictures Home Entertainment, Universal Pictures, HBO Video and New Line Home Entertainment have released around 50 HD titles with the launch of HD-DVD during Spring 2007. In addition, HD-DVD's lower production costs make it more promising on the price-side. It is too early to say which camp will become the successor of the current DVD technology, but as this paper empirically demonstrates, each camp will need the strong support of the studios and movie rental stores in their favor.

The remainder of this paper is organized as follows. Section II. discusses the related literature. Section III. presents the data. Section IV. provides a framework for modeling and estimating the parameters of the adoption decision. Section V. discusses the econometric model with emphasis on estimation method, identification and instrumental variables. Section VI. reports estimation results and discusses policy experiments. Section VII. concludes and discusses directions for future research.

II. Related Literature

Understanding of the determinants of new technology adoption and new technology valuation has received considerable attention in the economics literature. Mahajan, Muller and Bass (1990), Guptam, Jain and Sawhney (1999), Hall and Khan (2003) provide excellent reviews of both the theoretical and the empirical literature on new product adoption and diffusion models. These models, in general, describe the diffusion process of a technology and suggest implications for new product targeting, for building forecasting tools, and for developing marketing strategies aimed at potential

adopters under different market structures. Among the newer studies, Melnikov (2002) analyzes the adoption of differentiated durable products in a dynamic setting with forward looking consumers. He estimates the model for the U.S. computer printer market. Gowrisankaran and Rysman(2007) and Song and Chintagunta (2003) build on Melnikov (2002) model by allowing consumer heterogeneity and changing mix of consumers.

Most empirical studies on network effects have mostly relied either only on time-series data, or only on cross-sectional data. Studies using time-series data typically utilize aggregate data on hardware sales units and prices, along with the availability of complementary product. Gandal, Kende and Rob (2000) identify the positive feedback between hardware/software systems with an application to CD technology. Dranove and Gandal (2003) acknowledge the complementarity between DVD disc availability and the DVD installed base with the main focus of presenting evidence on standard wars between DVD and DIVX systems. Ohashi (2003) and Park (2004) present evidence of network effects for the VHS and Beta formats; Nair, Chintagunta and Dube (2003) for the Personal Digital Assistant (PDA) technology; Shankar and Bayus (2003) as well as Clements and Ohashi (2004) for the video game industry. These studies all use a time-series identification strategy using aggregate data on hardware sales units and prices of differentiated products as well as the availability of complementary product.

Another set of studies use cross-sectional data to identify the network effects. Rysman (2004) uses a cross section of Yellow Page directories and shows that advertising on a Yellow Page directory increases in consumer usage of that directory, and that consumer usage of a directory increases in the level of advertising on it. Using the estimated parameters, he analyzes the relative benefits of a monopoly (which internalizes

network effects) and of an oligopoly (which reduces market power). Ryan and Tucker (2006) study the adoption of videoconferencing technology within a firm across different occupational groups and firm locations using a dynamic estimation method, while Augereau, Greenstein and Rysman (in press) study the adoption of incompatible 56 K modem formats by Internet Service Providers in different markets. Goolsbee and Klenow (2002) provide evidence on learning and network externalities in the diffusion of home computers by using household-level data. In general, cross-sectional studies are limited by the difficulty to entangle whether the correlations in adoption decisions are due to network effects, or other regional variations in preferences that are unobservable to the researcher.

Some recent studies use both time-series and cross-sectional data. Gowrisankaran and Stavins (2004), Akerberg and Gowrisankaran (2006), and Tucker (2005) use a panel data set on bank adoption and consumer usage of automated clearinghouse electronic payment system (ACH), and provide evidence of moderate level of network externalities in this industry. Knittel and Stango (2007) study the automated teller machines (ATMs), and show that incompatibility is harmful to consumers. These studies primarily focus on adoption decisions at the firm level (i.e. banks), and in later stages of the technology diffusion rather than focusing on a short period after the initial introduction.

III. Data

The primary data source used in this paper is a survey provided by Communications, Entertainment, and Technology Research and Information Service (CENTRIS) which

surveys households each month using random-digit-dialing.³ When we restrict attention to the surveys conducted between January 2000 and May 2001, and to households with non-missing information on key demographics (discussed below), the data includes 47,893 unique households. Each household is surveyed only once. For each household, the survey reports a detailed set of demographic information as well as the zipcode and the designated market area (DMA) in which the household resides. In addition, the survey includes information on whether the household owns a DVD player, a VCR, a DVD-ROM, a camcorder, a pc, a digital camera and a digital cable. Households that own a DVD player report when they purchased their DVD player. As such, the survey allows for constructing a panel for each household from January 2000 up-to and including the time of household's survey with information on whether the household has purchased a DVD player or not at any given month.

Information on monthly DVD Player prices is obtained from NPD Intellect⁴ as CENTRIS survey does not provide information on the transaction prices of DVD players for each household. Measures of DVD content availability come from two sources. To proxy national availability of DVD movies, information on monthly VHS and DVD

³ CENTRIS tracks over 75 communications, entertainment and technology areas on a daily basis at the household level. CENTRIS's omnibus product, Access, is an on-going national omnibus service that profiles each sample household's electronics inventory, entertainment subscriptions, telephone services and software usage, in addition to demographic variables such as household composition, income, race, employment status and education of the household head, type of dwelling unit, zipcode. The methodology Access uses for sampling is random-digit-dialing (RDD), which means that respondents are contacted using computer generated sample telephone numbers. The survey is fielded every day with approximately 1,000 weekly interviews, amounting to an average of 52,000 records annually. The sample is weighted to ensure that the sample matches known population characteristics. Various household characteristics such as gender, age, education, race, region and metropolitan status of households are used in the weighting procedure.

⁴ NPD is a market research firm collecting point-of-sale data from a comprehensive sample of each industry's key retail and distribution channels for the consumer electronics, home appliance, information technology and imaging industries.

movie releases by studio, rating, and box office revenue is extracted from the Video Retailer Magazine supported by the trade organization Video Software Dealers' Association (VSDA). This information is available starting February 2000.⁵ As a potential DVD player adopter most likely cares about the full set of movies that s/he can watch on her/his player instead of just the new releases, monthly new release information is cumulated over time with February 2000 as the base year. Thus, the measure reflects all available movies on DVD for any given month.

The second measure of DVD content availability is based on the tabulations from RENTRAK Corporation and captures local DVD movie rental availability at the household's DMA. Many independent video rental stores and larger chain stores subscribe to RENTRAK for ordering DVD and VHS movies and for monitoring their revenue-sharing contracts with major movie studios. RENTRAK data on average represent around 30%-50% of the video retail stores in the industry. Two major chains, Blockbuster Video and Hollywood Video are not represented.⁶ Therefore, RENTRAK data is supplemented with information on Yellow Pages listing of all video retail stores in each DMA for 2000 and 2001. Specifically, the average number of DVD titles ordered per store (ratio of title orders of all RENTRAK stores and the number of RENTRAK stores in any month-DMA pair) is multiplied by the total number of local video retail stores (from the Yellow Pages). This measure is then cumulated over time and divided by the number of households with a television (obtained from Nielsen Media) in each DMA-

⁵ <http://www.videoretailer.com/worksheetarch.htm> (accessed during November'01 and January'02)

⁶ I thank Julie Mortimer for providing me these tabulations. More details on the RENTRAK data can be found in Mortimer (2006a,b).

month pair. The final measure varies by DMA and time, and represents the DVD movie rental inventory of video stores per household.

Table 1 presents descriptive statistics of the 47,893 unique households surveyed January 2000-May 2001. An average household composes of three individuals, 77% of households consists of a married couple or partners living together. 84% of households are white, 10% black. In 60% of the household, the head of the household works full time, in 11% part time, and in 15%, s/he is retired. 56% of the household heads are at least college educated and 40% of the households have at least \$50,000 of household income. In terms of technology ownership, 95% of the households own a VHS, 36% own a camcorder, 63% own a personal computer. Ownership of digital technologies is less common with on average 5% owning a DVD player, 9% digital camera, and 10% subscribing to digital cable.

Table 2 reports descriptive statistics in the beginning and end of the study period (February 2000 and May 2001) for the 140 DMAs included in the study.⁷ On average there are 78-79 video rental stores per DMA. While monthly VHS movie order per store is similar throughout the study period with 154 movies in February 2000 and 179 in May 2001, there is a significant increase in average DVD movie orders per store with 7 movies in February 2000 and 45 in May 2001. As discussed earlier, inventory measures are cumulative and they take February 2000 as the base year since data on DVD movie releases and store purchases is not available prior to that. The key measure of local DVD content availability is the DVD movie rental inventory per household. In February 2000, an average DMA had 9 DVD movies per 10,000 households, while in May 2001, the

⁷ 179 DMAs were represented in the full survey, but only 140 were included in the study as others had limited sample size.

corresponding value was 236 DVD movies per 10,000 households. In terms of nationwide availability of DVD content, 42 new titles were released on DVD in February 2000, while 60 were released in May 2001. Release of new movies on VHS is about the same in two snap shots with 64 in February 2000 and 66 in May 2001.

Figure 1 presents the time trend in DVD player prices and installed base. From February 2000 to May 2001, average DVD player prices fell by 50% from \$300 to \$200. These figures come from NPD Intellect. The DVD player installed base as tabulated from the CENTRIS survey increases steadily from approximately 4 million of the 100 million households owning a DVD player in February 2000 to about 14 million in May 2001.

Figure 2 presents trends in content availability. As Panel (A) shows, the monthly availability of movies on DVD and VHS are converging over time with more and more of the movies released on VHS also starting to be released on DVD. Similarly, average monthly order of DVD movies by video retail stores per household is increasing over time (Panel B) while the monthly order of VHS movies per household remains the same over time (Panel C).

Figures 3 and 4 demonstrate the variation across time and DMAs of DVD player ownership and the DVD movie rental inventory respectively. Based on Figure 3, in 25% of the DMAs, 6% or less of the households had a DVD player during May 2001, representing the bottom quartile cutoff for DVD player ownership percentage across DMAs. On the other hand 25% of the DMAs had 18% or more of the households with a DVD player, with 10% of the DMAs within this group having 27% of households with a DVD player. Another interesting point from Figure 3 is that the variation across DMAs is smaller in earlier periods and consistently increasing over time. In particular, the gap

between bottom quartile and top quartile cutoffs for the DVD player ownership percentage increases from 5.8 percentage points in February 2000 to 11.3 percentage points in May 2001. A similar pattern is evident also for the distribution of DVD movie rental inventory per household demonstrated in Figure 4. By May 2001, bottom quartile of the DMAs have an inventory of about 84 movies per 10,000 households while the top quartile of the DMAs have an inventory of about 241 movies per 10,000 households and top 10th percentile have an inventory of 650 movies per 10,000 households.

IV. Household Decision

The basic dilemma a household faces between buying a DVD player today versus tomorrow is due to the trade-off between the utility from use today and lower quality adjusted price in the future. An ideal model of consumer decision would incorporate consumer expectations about future quality, introduction of new DVD player models, and future pricing of different models and so on. This would entail a fully dynamic model of a durable good as in Gowrisankaran and Rysman (2006), Gordon (2006), Esteban and Shum (2005), Carranza (2004), Song and Chintagunta (2003) or Melnikov (2001).

As discussed above, the data used in this paper does not provide information on the price and brand/model of the DVD player households purchase. Moreover, data on DVD player prices is limited to a time-series of average monthly prices nationwide. These data constraints hamper the feasibility of estimating a fully dynamic consumer decision model that structurally incorporates quality and price expectations as well as the introduction of new DVD player models.

Therefore, the modeling approach in this paper is not able fully exploit dynamic expectations, and rather it considers DVD players as a homogenous good, assumes no

replacement of the DVD players⁸ and focuses on the dynamics of the tradeoff consumer faces by adopting today and using the DVD player an additional period versus waiting until tomorrow and paying a lower price. The availability of movies on DVD directly influences the additional value consumer receives by owning the DVD player earlier, and thus plays a key role in this tradeoff. The model is very similar to that of Gandal, Kende and Rob (2000) who analyze the adoption of another durable technology, compact disc (CD) players. However, while Gandal, Kendel and Rob (2000) rely on aggregate data on sales and prices of CD players, this paper uses unique individual level data which identify exact adoption time for each household.

The net present discounted utility household i gets from purchasing a DVD player at time t can be written as the value household obtains from the product in the current time period ($Value_{i,t}$) and in all future time periods ($\sum_{k=1}^{\infty} \beta^k E_t(Value_{i,t+k})$) net of the DVD player price paid at the time of purchase:

$$U_{i,t} = Value_{i,t} - \alpha price_t + \sum_{k=1}^{\infty} \beta^k E_t(Value_{i,t+k}) + \varepsilon_{i,t}$$

The term $\varepsilon_{i,t}$ represents random shocks such as sales/advertising efforts, observed to the household at the time of purchase, but unobserved to the researcher. The household observes only the current shock, not the future shocks, but can derive an expectation of the future shocks based on a known distribution function. The household has to decide whether to purchase at period t , or to wait for a future period. By waiting until $t + 1$, the household forgoes the value of using the product in period t , but s/he might pay a lower

⁸ Replacement of DVD players is not a concern given the early time period post technology introduction considered in this paper.

quality adjusted price in $t + 1$. From period t 's point of view, the expected net present discounted utility from purchasing in any period $t + \tau$ in the future with $\tau \geq 1$ can be written as

$$E_t(U_{i,t+\tau}) = \beta^\tau E_t(\text{Value}_{i,t+\tau}) - \beta^\tau \alpha E_t(\text{price}_{t+\tau}) + \sum_{k=\tau+1}^{\infty} \beta^k E_t(\text{Value}_{i,t+k}) + E_t(\varepsilon_{i,t+\tau}).$$

Now, we make simplifying assumptions which adjust the fully dynamic decision making process to fit the data limitations and to allow for comparing the net present discounted utility of purchasing in period t to that in $t + 1$ only, instead of comparing it to the net present discounted utility of purchasing in a full spectrum of future periods.

$$\text{A1 (a): } E_t(\text{Value}_{i,t+1} + \varepsilon_{i,t+1}) \geq \text{Value}_{i,t} + \varepsilon_{i,t},$$

$$\text{A1 (b): } E_t(\text{Value}_{i,t+\tau+1} + \varepsilon_{i,t+\tau+1}) \geq E_t(\text{Value}_{i,t+\tau} + \varepsilon_{i,t+\tau}) \text{ for every } \tau \geq 1 \text{ and}$$

$$\text{A2 (a): } \text{price}_t - \beta E_t(\text{price}_{t+1}) \geq E_t(\text{price}_{t+1}) - \beta E_t(\text{price}_{t+2})$$

$$\text{A2 (b): } E_t(\text{price}_{t+\tau}) - \beta E_t(\text{price}_{t+\tau+1}) \geq E_t(\text{price}_{t+\tau+1}) - \beta E_t(\text{price}_{t+\tau+2}) \text{ for every}$$

$\tau \geq 1$.

The first two assumptions mean that the household expects to get at least as much value from the DVD player in the next period as s/he does in the current period. This is reasonable, since at least the same number of movies would be available on DVD if not more in the future. The last two assumptions state that, although the DVD player prices are declining over time, the rate of decline is slower. This conjecture also fits in well with new technology products where early adopters pay high prices, but prices decline over time, and as the technology becomes main stream, further price reductions is expected to level off. Figure 5 presents a scatter plot of $\text{price}_t - \beta \text{price}_{t+1}$ during February 2000-May 2001 with a fitted polynomial, and confirms this conjecture.

Proposition:

Under A1 (a), A2 (a), A1 (b) and A2 (b), if $U_{i,t} \geq E_t(U_{i,t+1})$, then

$U_{i,t} \geq E_t(U_{i,t+1+\tau})$ for any $\tau \geq 1$.

Proof:

We want to show that if $U_{i,t} \geq E_t(U_{i,t+\tau})$, then $E_t(U_{i,t+1}) \geq E_t(U_{i,t+1+\tau})$ for all $\tau \geq 1$, which would imply that $U_{i,t} \geq E_t(U_{i,t+1+\tau})$ for any $\tau \geq 1$.

We need to accomplish two steps;

Step 1. Show that $E_t(U_{i,t+\tau}) \geq E_t(U_{i,t+1+\tau})$ for $\tau = 1$

If $U_{i,t} > E_t(U_{i,t+1})$, then $Value_{i,t} + \varepsilon_{i,t} \geq \alpha price_t - \beta \alpha E_t(price_{t+1}) + E_t(\varepsilon_{i,t+1})$.

A1 (a) and A2 (a) imply that

$$E_t(Value_{i,t+1} + \varepsilon_{i,t+1}) \geq \alpha E_t(price_{t+1}) - \beta \alpha E_t(price_{t+2}), \text{ or } E_t(U_{i,t+1}) > E_t(U_{i,t+2})$$

Step 2: Assume that $E_t(U_{i,t+\tau}) \geq E_t(U_{i,t+\tau+1})$ holds for some $\tau = \kappa$

Show that it also holds for $\tau = \kappa + 1$

Assume $E_t(Value_{i,t+\kappa} + \varepsilon_{i,t+\kappa}) \geq \alpha E_t(price_{t+\kappa}) - \beta \alpha E_t(price_{t+\kappa+1})$

A1 (b) and A2 (b) imply

$$E_t(Value_{i,t+\kappa+1} + \varepsilon_{i,t+\kappa+1}) \geq \alpha E_t(price_{t+\kappa+1}) - \beta \alpha E_t(price_{t+\kappa+2}), \text{ or}$$

$$E_t(U_{i,t+\kappa+1}) \geq E_t(U_{i,t+\kappa+2})$$

Q.E.D

In summary, the proposition above suggests that under the assumptions listed, it is sufficient to compare net present discounted utility in period t to that in $t + 1$, and the household will adopt the technology in the earliest period (smallest t) that satisfies

$$Value_{i,t} + \varepsilon_{i,t} \geq \alpha price_t - \beta \alpha E_t(price_{t+1})$$

V. Estimation

V.I. Econometric Specification

As discussed above, a household adopts a DVD player if the current usage value from the DVD player exceeds the DVD player price differential the household has to pay by deciding not to wait an additional period. If the current usage value from the product is modeled as a function of local DVD movie rental inventory, national inventory of movie titles released on DVD format and household level demographics, the key estimation equation can be written as a latent utility model

$$y^*_{irt} = \alpha_o - \alpha_1(price_t - \beta E_t[price_{t+1}]) + \alpha_2 rental_inventory_{rt} + \alpha_4 release_inventory_t + \alpha_5 Demog_i + \gamma_{rt} + \mu_{irt} \quad (1)$$

where i indexes households, t indexes each month in the study period, and r indexes DMAs. The variable $rental_inventory_{rt}$ is the DVD movie rental inventory per household, and $release_inventory_t$ is the inventory of all movie titles available in DVD format for the corresponding time period. The γ_{rt} captures time and region specific unobservables such as unobserved quality perception of the DVD technology, or marketing/advertising and sales efforts. The μ_{irt} represent unobserved consumer heterogeneity, and is identically, independently distributed across households.

The researcher does not observe y^*_{irt} , but instead observes the adoption decision of each household i in region r at time t . If the household adopts the technology at time t , $y_{irt} = 1$ is observed which corresponds to $y^*_{irt} > 0$. Otherwise, $y_{irt} = 0$ is observed.

Assuming there are no repeat purchases, once a household adopts, there are no more choice situations for that household. In this sense, the econometric framework has a discrete-time hazard model interpretation.

If the potential correlations of DVD player prices, local DVD movie rental inventory and national inventory of movie titles available on DVD with region-time specific unobservables γ_{rt} were not of concern, equation (1) could be directly estimated using a maximum likelihood estimation with certain distributional assumptions on the error terms γ_{rt} and μ_{irt} .

This paper uses a two-step estimation strategy that takes this correlation into account via the use of instrumental variables. The estimation method is an application of Berry, Levinsohn and Pakes (1995) and Berry (1994) to disaggregate data. This approach was suggested by Berry (1994) and implemented by Goolsbee and Petrin (2004). The basic idea of the estimation procedure is to first decompose the utility into a component that is constant for all households in a given region and time, and to another component that varies by households. In the second step, estimated component that varies by region and time is regressed on region/time specific observables using standard instrumental variables approach while accounting for the covariance among fixed effects.

The specific estimation procedure is as follows. First, the parameters of equation

$$y^*_{irt} = \alpha_5 Demog_i + d_{rt} + \mu_{irt} \quad (2)$$

are estimated for each region r separately using a binary probit specification where

$$d_{rt} = \alpha_0 - \alpha_1(price_t - \beta E_t[price_{t+1}]) + \alpha_2 rental_inventory_{rt} + \alpha_4 release_inventory_t + \gamma_{rt} \quad (3)$$

The d_r 's are captured using monthly time fixed effects for the estimation using households in region r . In practice, one could estimate (2) jointly for all regions while capturing d_r 's with the interaction of region and time fixed effects. Given that the estimation uses about 140 DMAs and 17 time periods, separate estimation for each region proved computationally more tractable, and flexible.

As a second step, estimated \hat{d}_r 's for each region r are stacked and used as the dependent variable in the estimation of (3) with generalized least squares, while taking into account the standard errors of the dependent variable estimated in the previous step. To account for endogeneity of various covariates, it is straightforward to use instrumental variables at this step. In actual estimation, γ_r 's which vary by DMA and month are decomposed into factors specific to each DMA via the use of DMA fixed effects, and factors specific to each quarter via the use of quarterly time dummies. The remaining error term is then interpreted as the deviations of unobserved factors from DMA specific means and quarter specific means. The estimation also takes into account potential serial correlation, and Newey-West standard errors are reported.

V.II. Instrumental Variables

Finding instrumental variables in the context of identifying network effects is generally a challenging task. In this application, there are three potential endogeneous variables: $price_t - \beta E_t[price_{t+1}]$, $rental_inventory_r$ and $release_inventory_t$. Regarding the endogeneity of prices, industry reports argue that the decline in DVD player prices is due to the mass production of DVD-ROM drives and plummeting costs of audio/video

decoder chips (Taylor, 2001). Data on the price of audio/video decoder chips would be ideal to illustrate that the decline in DVD prices is due to a decline in costs rather than strategic pricing. Due to unavailability of systematic data on the price of audio/video decoder chips, semiconductor chip price index published by the Bureau of Labor Statistics is used as an instrument to support the same argument.

Regarding DVD content availability, two instruments are used, one for the local DVD movie rental inventory per household ($rental_inventory_{it}$), and the other for the national inventory of titles available on DVD ($release_inventory_t$). For the former, local VHS movie rental inventory per household is used as instrument. For the latter, inventory of titles available on VHS is used as an instrument. The availability of VHS movies (nationally and locally) is certainly correlated with the availability of DVD movies through the release of movies by movie studios. The identifying assumption is that the number of VHS releases, and the order of VHS movies by video rental stores do not respond to the demand for watching movies on DVD after controlling for changes (observable and unobservable) over time, and systematic differences between regions. This is a reasonable assumption for the time period spanned in this paper, February 2000-May 2001, as this was a very early period in which all theatrically released movies were released first on VHS, and the movie studios decided which movies to also make available on DVD. Similarly, movie rental stores would typically order a set of movies on VHS, and a subset of that on DVD. Nevertheless, to investigate whether the introduction of the DVDs increased overall demand for movies, we examined the number of new VHS releases before January 2000 (the date on which video retailer stores could start ordering their DVD movies with order sheets as they did for the VHS format) and after January

2000. There was no statistically significant difference in the number of VHS movie releases before and after January 2000.

VI. Results

VI.I. Parameter Estimates

Table 3 reports the parameter estimates from the estimation of equation (2) using a probit specification. The estimation is performed separately for each DMA, and it uses 370,854 person-month observations from 140 DMAs. The dependent variable is a binary variable indicating whether the household has purchased a DVD player at a given period while the regressors are household level demographics, and monthly time fixed effects. Coefficient estimates differ across DMAs, but for the ease of reporting, Table 3 presents means of the coefficients, and correspondingly the standard error of the means, as well as marginal effects on adoption probability across DMAs. Adoption of the DVD technology is more likely in asian and white households, in households where the head of the household is working full time or part time, and in households with at least \$50,000 annual income. Households in which the head of the household is retired or a student are also more likely to adopt. Moreover, households that own other technology products such as a camcorder, pc, digital camera, or those that subscribe to digital cable are more likely to adopt. On the other hand, younger households with teenagers or kids, and households that consist of married couples or partners living together are less likely to adopt.

Table 4 reports eight different specifications of equation (3), corresponding to the second step of the estimation. The first six specifications are estimated via OLS, while the last two are estimated using instrumental variables. The dependent variable is a stack

of the vectors of monthly time fixed effects obtained from the estimation of (2) for each DMA, thus it varies by month and DMA. The regressors include the DVD rental inventory per household or its lagged value, ($rental_inventory_t$), which varies by month and region, number of DVD movie releases available nationally, ($release_inventory_t$), the price difference of the DVD players from one period to the next, ($price_t - \beta E_t[price_{t+1}]$), DMA fixed effects, and controls for the time trend either through quarterly fixed effects, linear time trend and/or quadratic time trend. To construct $E_t[price_{t+1}]$ in ($price_t - \beta E_t[price_{t+1}]$), actual next period DVD player prices are used with the value of β set to 0.99. The results were robust to instead constructing $E_t[price_{t+1}]$ in a way that reflects expectations based on past price trends by specifically setting

$$E_t[price_{t+1}] = price_t - price_slope_{t_0-t}$$

where $price_slope_{t_0-t}$ is the magnitude of the estimated coefficient on the time trend in the regression of price on time a trend spanning the earliest period for which price data is available t_0 (January 1998) and t .

In all specifications (1) – (8), the coefficients on regional DVD rental inventory and national DVD release inventory are positive and statistically significant at 1%. As expected, the price coefficient is negative and statistically significant at 1%. All specifications report Newey-West standard errors that adjust for serial correlation up to two lags. Specifications (7) and (8) use instrumental variables. Specification (7) considers national DVD movie release inventory and the price difference of the DVD players from one period to the next as endogenous variables, and uses VHS movie release

inventory and semi-conductor price index as instrumental variables. Specification (8) considers regional DVD rental inventory per household as an endogenous variable in addition to the two endogenous variables in specification (7), and uses regional VHS rental inventory per household as an additional instrumental variable. However as the Hausman test statistic with p-value of 0.66 indicates, the null hypothesis that the regional DVD rental inventory per household is endogenous cannot be rejected, suggesting that after controlling for DMA fixed effects and quarterly fixed effects, remaining unobserved shocks do not vary significantly across DMAs and within quarters. Table 5 reports the first stage estimation for specifications (7) and (8) and verifies the correlation of endogenous variables with the instruments.

The estimates reported in specification (8) of Table (4) imply that a 1% increase in DVD player prices decrease monthly sales of DVD players on average by 0.24%. In terms of the DVD content availability, a 1% increase in the inventory of regional DVD movie rental per household increases monthly sales by 0.16%, and it increases the DVD player installed base by 0.01% on average. The national inventory of DVD movies released also significantly influences the sales and thus the installed base. A 1% increase in the inventory of DVD movies nationally increases the sales of DVD players by 1.4% on average. Corresponding increase in the installed base of DVD players is on average 0.10%.

VI.II. Size of Complementarities

Figure 6 presents DVD player installed base estimates under different scenarios of regional DVD rental inventory. One of the projections assumes that all DMAs have the same movie rental inventory which is set at the status quo 25th percentile level across all

DMAs (presented in Figure 4). This corresponds to an inventory of approximately 36 movies per 10,000 households in January 2001, and 84 movies per 10,000 households in May 2001. The other projection assumes that the movie rental inventory is set at the 90th percentile level presented in Figure 4, corresponding to an inventory of 370 rental movies per household in January 2000, and 650 in May 2001. The predictions in Figure 6 reveal that under low DVD movie rental availability, the DVD player installed base would be similar to that of the status quo with approximately 14 million households in the U.S owning DVD players in May 2001. However, the high level of DVD movie rental availability could have led to 23 million households with DVD players in May 2001.

Figures 7 and 8 provide additional counterfactual analyses that aim to quantify the size of complementarities between DVD player adoption and DVD content availability. Figure 7 presents the predicted number of new DVD player adopters, and Figure 8 presents the predicted DVD player installed base under the status quo as well as under three different scenarios of DVD content availability. The first scenario assumes no regional DVD movie rental availability. The second scenario also assumes no regional DVD movie rental availability, and in addition no growth in the nationally available releases. In other words, this scenario assumes that every month, forty movies are made available on DVD as was the case in the beginning of the study period, February 2000. The third scenario also assumes no rental availability, but in addition a reduction of 50% in the number of movies released nationally every month. This corresponds, for example to release of 20 movies instead of 40 in February 2000, and 30 instead of 60 in May 2001.

Comparing the status quo, and scenario 1, Figure 7 suggests that the availability of the rental channel increases sales significantly, especially in later periods. Approximately 1.8 million households adopt the technology in May 2001 under no rental availability as opposed to 2.6 million in status quo, representing a reduction of 760,000 in DVD player sales. As Figure 8 suggests, 12 million households would have owned DVD players by May 2001 instead of 14 million in the absence of regional rental availability.

Scenario 2 suggests that the availability of releases nationally has also been an important driving force behind the sales of DVD players and the diffusion of technology. Comparing Scenario 1 and Scenario 2, if there were no growth in the number of movies released on DVD, there would be 543,000 less DVD player sales in May 2001, and the DVD player installed base would have been lower by 1.8 million. Comparing Scenario 1 with Scenario 3, the 50% reduction in the release of movies each month would have a major impact with the number of sales declining by 1 million, and the DVD player installed base declining by 4.6 million in May 2001.

VI.III. Cross-Subsidies

The results discussed above present evidence that the complementarities play a significant role in the consumer decision to adopt DVD players. The strategic interdependence between the DVD player manufacturers (hardware firms) and the movie studios that supply content on DVD (software firms) imply that any demand generation activity of the software firms impacts the hardware firms indirectly. Although it is not within the scope of this paper, any demand generation activity of the hardware firms presumably also positively influences the software firms indirectly. Therefore, in

general, both the hardware firms and the software firms could benefit from strategies designed to align their incentives.

For example, if a given amount of increase in hardware firms' revenues can be generated through an action by the software firms at a lower cost, hardware firms might want to subsidize software firms. In particular, how much subsidy should the DVD player manufacturers be willing to give to movie studios for them to release more titles on DVD, or how much should the local video rental stores be compensated for bringing in more movies for rental on DVD?

If the DVD content availability increases (decreases), DVD players can sell the same number of DVD players at a higher (lower) price. Here we analyze two scenarios. The first scenario asks by how much the DVD player prices could increase if there is an additional movie released on DVD in a given month. Based on the estimates reported in specification (8) of Table 4, an additional movie release in a given month allows for DVD player prices to go down by \$0.15, and still generate the same DVD player sales. In May 2001, approximately 2.6 million DVD players were sold, implying that the hardware firms jointly could have gained profits of about \$390,000 from an additional release. Similarly, during the holiday season of November 2000-December 2000, about 2.8 million DVD players were sold, suggesting that hardware firms' joint gains could have been \$428,000 higher if an additional DVD movie were available in each of these months. Given that a ball-park cost for producing a Hollywood-quality two-hour DVD movie with motion menus, multiple audio tracks, subtitles, trailers, and a few info screens is about \$20,000 (Taylor, 2001), subsidizing software firms for the release of an additional movie on DVD most likely would have paid off.

Another similar policy experiment can be conducted for the DVD movie rental availability. Again, using the estimates reported in specification (8) of Table 4, it is predicted that an increase of 1% in the DVD movie rental inventory per household in May 2001 (from an average of 200 to 202 movies per 10,000 households) can allow hardware firms to increase prices by \$0.19. This estimate suggests that, the hardware firms' profits could have been higher by \$490,000 for the 2.6 million DVD players sold that month.

Strategies between the hardware and software firms could take the form giving free DVD movies, or offering movie rental/purchase coupons and rebates along with purchases of DVD players. For example, Sony, which had the advantage of owning movie studios, released its first \$900 model in April 1997 including four free DVD titles: Clint Eastwood's "In the Line of Fire", a children's movie "Fly Away Home", a Tony Bennett concert and a Sesame Street special.⁹ Another co-marketing campaign ran between November 15 and December 21 of 1999, and it involved eight major companies. Through this campaign, consumers who bought Toshiba DVD players at the major retailer stores such as the Best Buy, The Wiz and the Good Guys would receive 5 free DVD movies from New Line Home Video and Warner Home Video. Moreover, they would receive 13 DVD movie rental coupons redeemable at Hollywood Entertainment or West Coast Entertainment.¹⁰ A bigger multi-firm campaign followed between February

⁹ February 27, 1997, The Associated Press.

¹⁰ "Historic Promotion of DVD Products Unites Industry Leaders; Key Retailers and Manufacturers Launch Breakthrough DVD Program for Holiday Buyers", November 11, 1998 Business Wire.

2000 and May 2000, and gave 5 free DVD movies to purchasers of DVD players from a large set of manufacturers.¹¹

VII. Conclusion

This paper presents evidence that complementarities play an important role in the consumer decision to adopt DVD players. The empirical strategy's strength relies on its possibility of identifying complementarity both from cross-sectional and time series variations. For new technology products with decreasing production costs and declining prices over time, the cross-sectional variation in adoption decisions as well as in the complementary product proves very advantageous. Moreover, the availability of household-level data allows for controlling for a rich set of demographic factors that may influence technology adoption.

Estimates imply that increases in both the number of regionally available DVD movie rentals and the number of national DVD movie releases significantly increase new DVD player sales. Counterfactual analyses reveal that DVD player manufacturers could achieve profit gains from subsidizing DVD content providers to release more movies on DVD. It is highly likely that any demand generation activity of the hardware firms also positively influences the software firms indirectly, a mechanism not modeled and estimated in the paper. To conduct a more complete analysis of the potential strategies for hardware firms and software firms, future work could also incorporate a supply-side model where in availability of DVD content is modeled as a function of DVD player installed base. This paper does not undertake that task primarily due to data limitations on

¹¹ DVD player manufacturers included JVC, Panasonic, Philips, Pioneer, Samsung, Sony, Thomson Multi-Media (RCA, Proscan, GE), Toshiba and Zenith, while movie studios involved were Columbia TriStar, Metro-Goldwyn-Mayer, New Line Home Video, Universal Studios Home Video and Warner Home Video.

the supply-side and the difficulty of finding appropriate instruments that have both a time-series and cross-sectional variation to identify such a model.

As future research, conditional on data availability on the model and brand of DVD players, consumer adoption model could be expanded to include more interesting dynamic expectations on quality of product, prices and brand availability. The study could also be made richer by incorporating a model of DVD player manufacturers. Brand specific quantity and price data along with brand characteristics of DVD players could be used to obtain a more precise estimate on price elasticity, to understand the consumer valuation of various product characteristics, and to examine manufacturers' strategic entry and product location choices.

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Table 1: Household-Level Descriptive Statistics

	Mean	Std. Dev.
Respondent and Household Characteristics		
% Male respondent	47.55%	
Age of respondent	43.89	15.98
Household size	2.78	1.43
# Adults in the household (18 or older)	2.02	0.82
# Teenagers in the household (12-17)	0.31	0.69
# Older kids in the household (6-11)	0.24	0.60
# Kids in the household (under 6)	0.21	0.55
% Married or Living with Partner	76.54%	
Ethnic Background		
% Asian	1.60%	
% White	83.98%	
% Black	9.87%	
Work, Educational, Income Demographics		
% working full time	60.10%	
% working part time	10.99%	
% unemployed	2.81%	
% retired	14.84%	
% home maker	6.42%	
% student	2.17%	
% disabled	2.30%	
% with at least college education	56.32%	
% with at least \$50,000 income	40.33%	
% own home	71.30%	
Ownership of Technology Products		
% own DVD player	5.01%	
% own VHS	0.95%	
% own camcorder	35.52%	
% own digital cable	8.46%	
% own personal computer	63.05%	
% own digital camera	9.74%	

Note: The sample includes 47,893 unique households

Table 2: Descriptive Statistics of Content Availability by Designated Market Areas

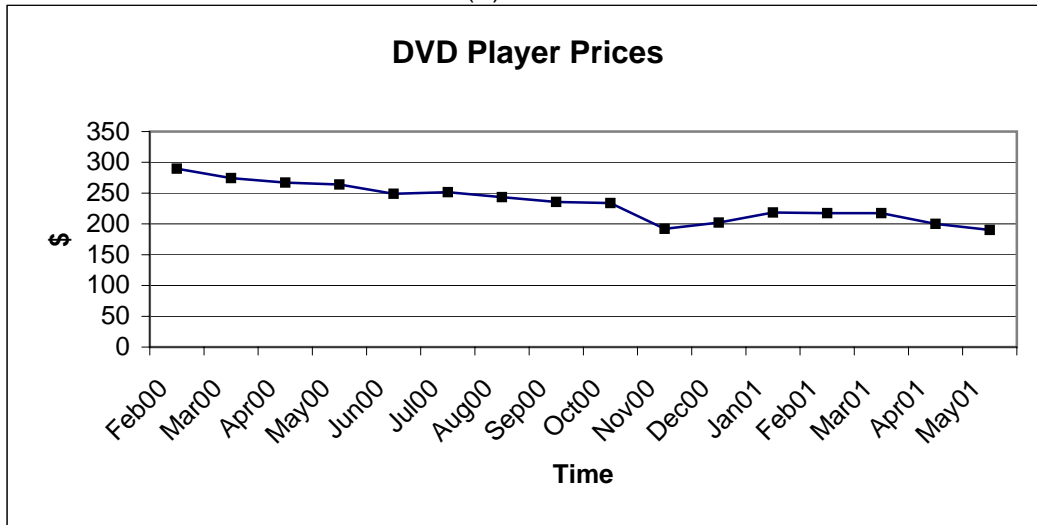
	Feb-00		May-01	
	Mean	Std. Dev.	Mean	Std. Dev.
Video Retail Stores				
# Video Retail Stores (from Yellow Pages)	77.70	82.66	79.35	83.56
Average monthly VHS movie orders per store	153.92	91.32	179.18	89.05
Average monthly DVD movie orders per store	6.92	5.80	45.01	30.74
Content Availability by Designated Market Area				
DVD movie rental inventory of stores	455.53	621.57	11982.20	14429.26
VHS movie rental inventory of stores	18542.04	18528.73	194569.70	187065.50
DVD movie rental inventory per 10,000 households	8.45	10.24	235.54	249.09
VHS movie rental inventory per 10,000 households	354.65	306.77	3700.03	28875.93
Content Availability Nationwide				
Number of new titles released on DVD nationwide	42	0	60	0
Number of new titles released on VHS nationwide	64	0	66	0
Inventory of movie titles released on DVD nationwide	42	0	760	0
Inventory of movie titles released on VHS nationwide	124	0	1086	0

Notes

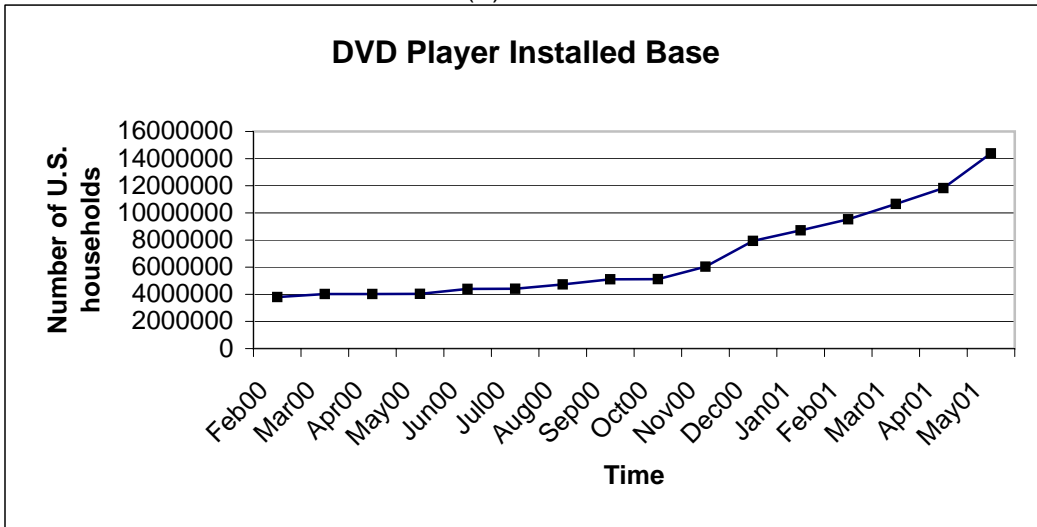
1. The statistics are based on observations from 138 DMAs
2. Inventory measures are cumulative and they take February 2000 as the base year

Figure 1: Trends in DVD Player Prices and Installed Base

(A)



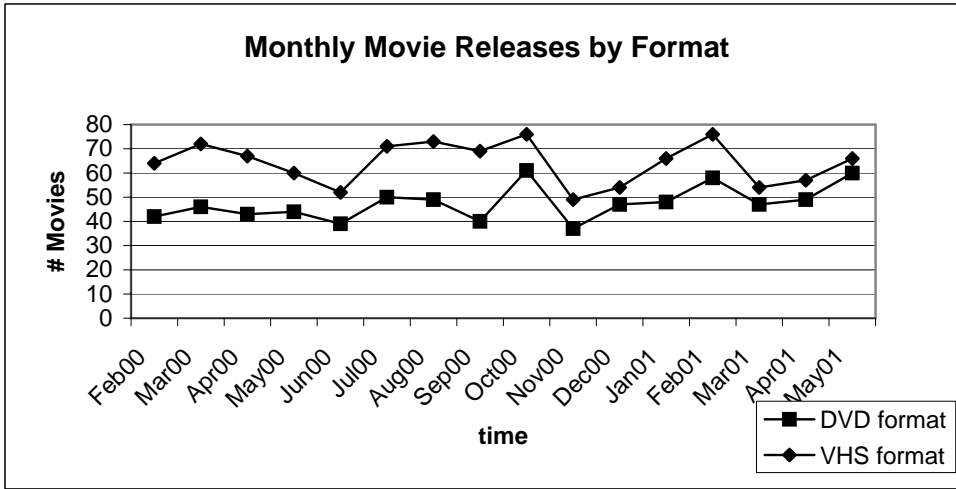
(B)



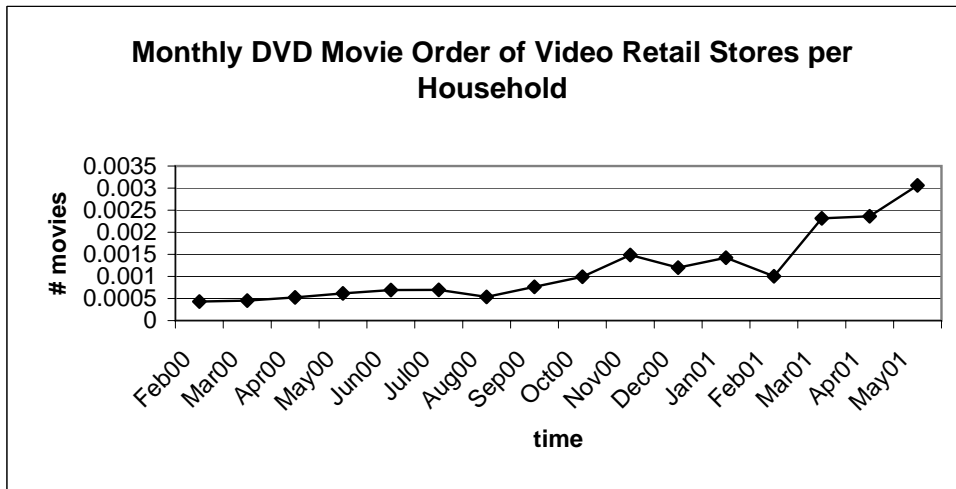
Source: NPD Intellect for DVD player Prices, and author's own tabulations from Centris data for DVD player installed base and sales

Figure 2: Trends in Content Availability

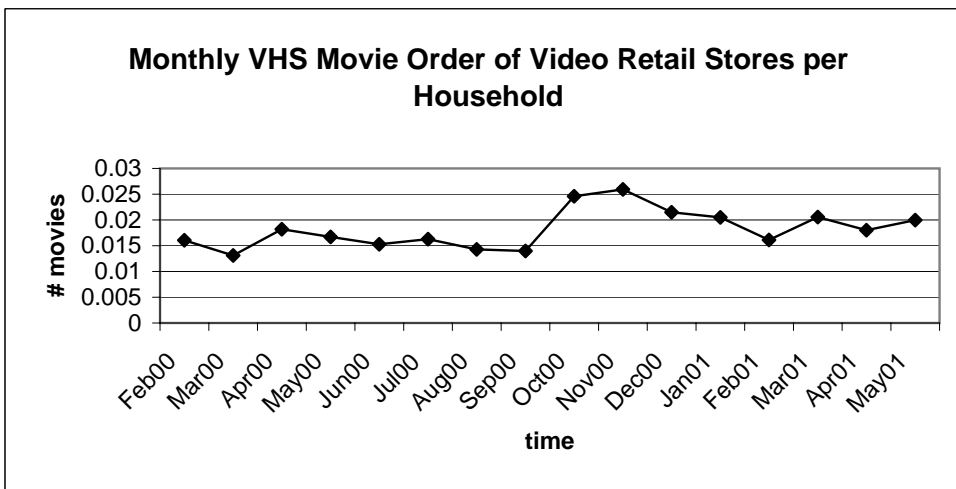
(A)



(B)



(C)



Source: Data from the new movie releases come from the Video Retailer Magazine, and the data for the video retail store inventories come from tabulations by RENTRAK.

Figure 3: Distribution of % DVD Player Ownership Across Time and DMAs

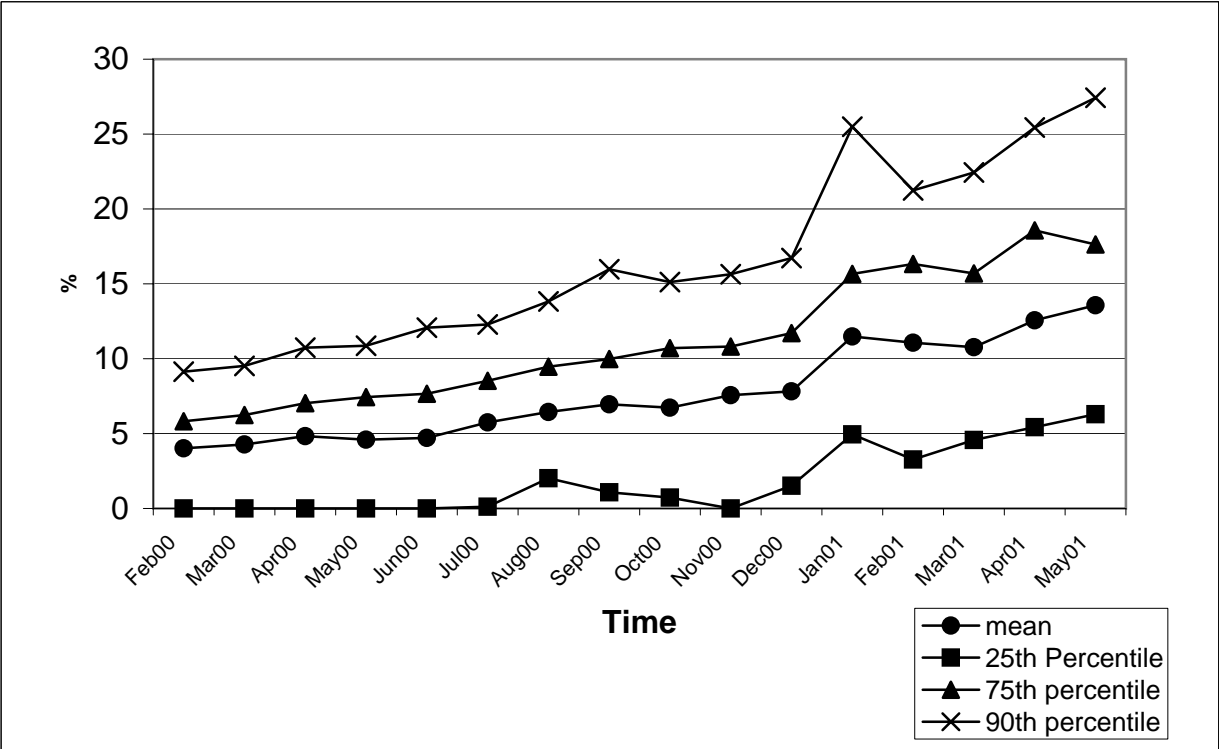


Figure 4: Distribution of Regional DVD Movie Rental Inventory Across Time and DMAs

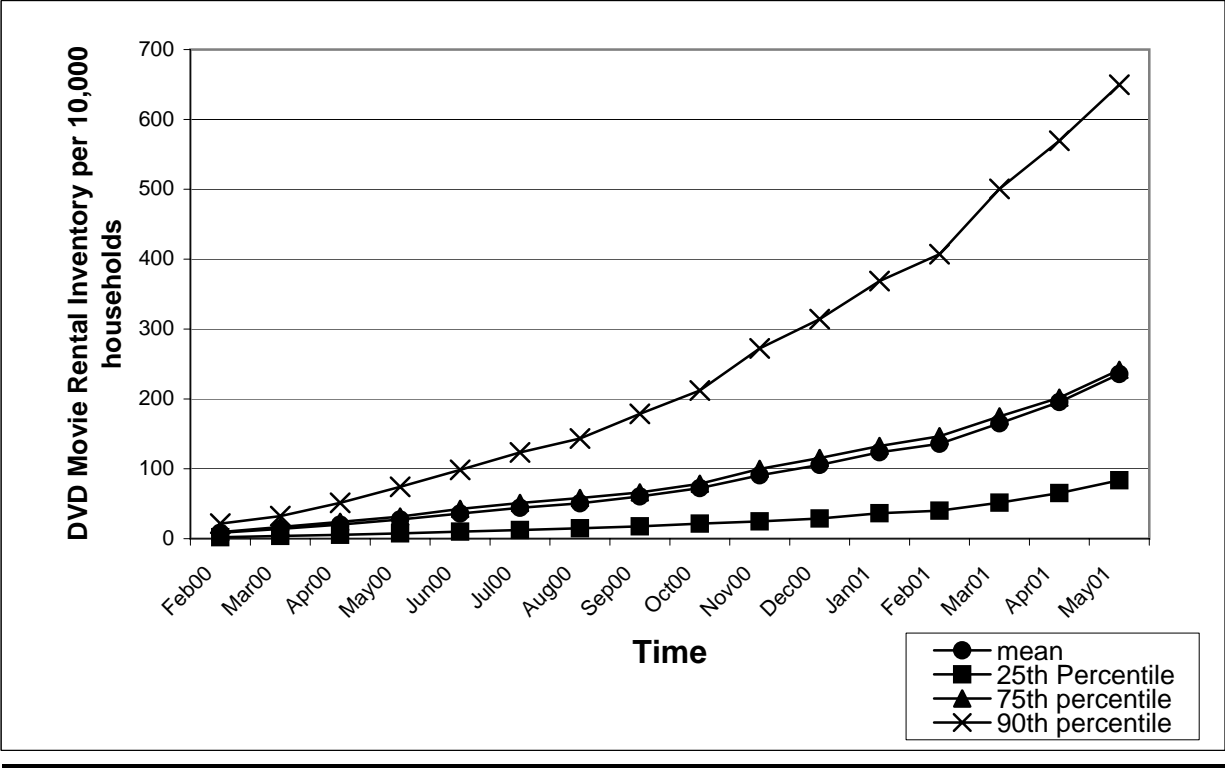
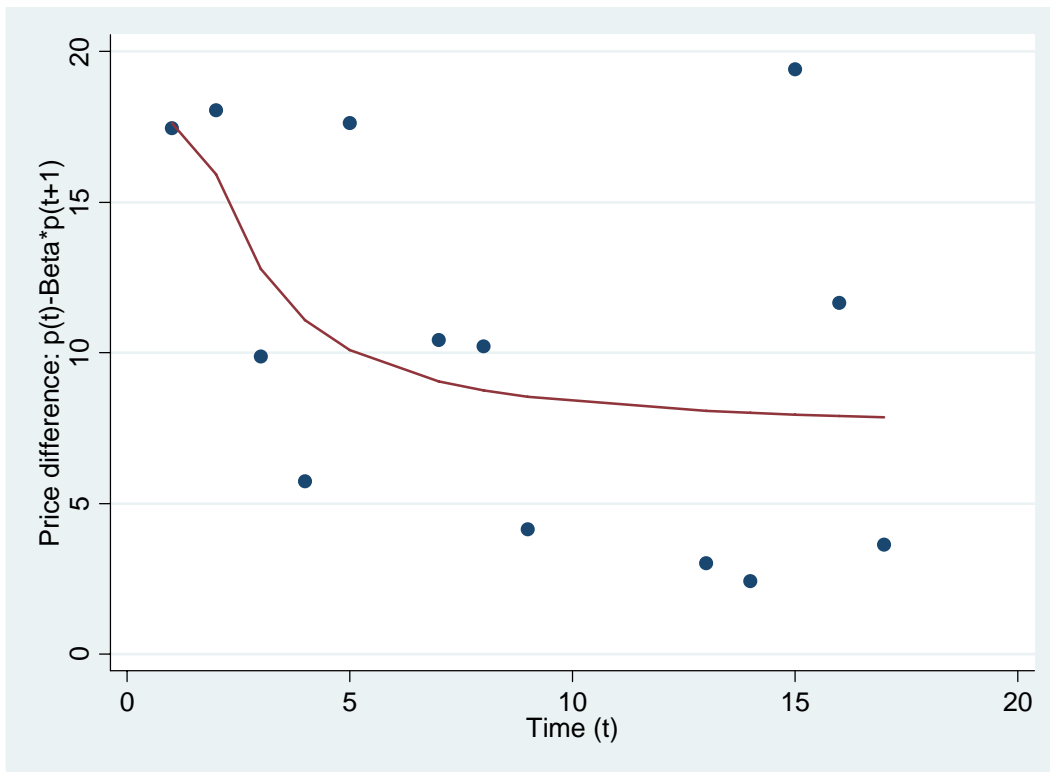


Figure 5: Variation in Price Differential over the study period (February 2000-May 2001)



Note: Observation in time zero corresponds to the difference of DVD player prices between January 2000 and February 2000 adjusted by a discount factor set at 0.99

Table 3: First Step Estimation: Probit of Adoption on Household-Level Variables

	Mean Coefficient Estimate	Std. Dev of the Mean Coefficient	Mean Marginal Effect
Age of Respondent	-0.009	0.011	-0.002
Household Size	0.378	0.209	0.091
# Teenagers (12-17 yrs. old) in the Household	-0.65**	0.205	-0.084
# Kids (0-11 yrs. old) in the Household	-0.894**	0.209	-0.098
Married or Living with Partner	-0.533**	0.062	-0.075
Asian	0.298**	0.070	0.069
White	0.445**	0.067	0.111
Male	0.023	0.062	0.004
Home Owner	-0.234**	0.067	-0.040
Working Full Time	1.438**	0.250	0.481
Working Part Time	1.709**	0.249	0.581
At Least College Educated	-0.062	0.053	-0.012
At Least \$50,000 Household Income	0.765**	0.057	0.218
Retired	1.398**	0.097	0.465
Student	1.552**	0.092	0.524
Home Maker	1.85**	0.097	0.628
Disabled	2.247**	0.070	0.738
Own Camcorder	0.385**	0.054	0.093
Subscribe to Digital Cable	0.207**	0.052	0.046
Own PC	0.431**	0.059	0.107
Own Digital Camera	0.194**	0.049	0.043
Month fixed effects	included		
Notes			
1. Original probability of adopting having not adopted yet in the whole sample is 0.02			
2. ** Denotes statistical significance at 5% significance level			

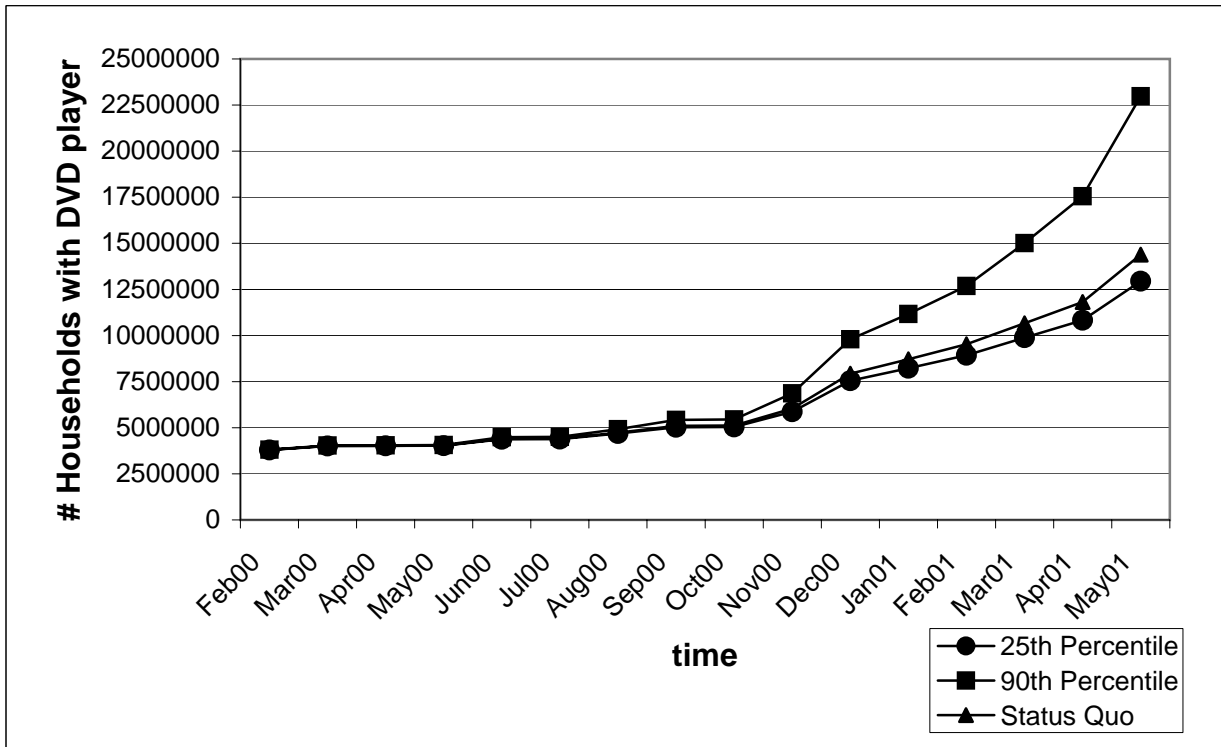
Table 4: Second Step Estimation: OLS and IV estimates of region-time interactions estimated in the first step on region-time varying variables

	OLS						IV	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Regional DVD Rental Inventory per Household	7.13*** (1.77)	5.62*** (1.80)	5.96*** (1.79)				7.01*** (2.17)	8.38** (3.87)
Lagged Regional DVD Rental Inventory per Household				7.24*** (1.84)	5.55*** (1.93)	5.84*** (1.91)		
National DVD Release Inventory	0.0015*** (0.00019)	0.0051*** (0.0017)	0.0096*** (0.003)	0.0015*** (0.0002)	0.0052*** (0.0017)	0.0094*** (0.0033)	0.0013*** (0.0002)	0.0012*** (0.0002)
Price Difference	-0.0041*** (0.0006)	-0.0058*** (0.0007)	-0.0067*** (0.0009)	-0.0041*** (0.0006)	-0.0058*** (0.0007)	-0.0066*** (0.0009)	-0.0082*** (0.0013)	-0.008*** (0.0013)
DMA fixed effects	included	included	included	included	included	included	included	included
Quarterly time fixed effects	included	--	--	included	--	--	included	included
Linear Time Trend	--	included	included	--	included	included	--	--
Quadratic Time Trend			included			included		
Number of Observations	879	879	879	879	879	879	813	813
Endogenous Variables								
Regional DVD Rental Inventory per Household							no	yes
National DVD Release Inventory							yes	yes
Price Difference							yes	yes
Wu-Hausman statistic								F(1,724)=0.19
Ho: Regional DVD Rental Inventory per Household is exogenous								p-value=0.66
Notes:								
1. Newey West standard errors with two lags are reported in parentheses								
2. All specifications use GLS with weights constructed from standard error of the dependent variable from the previous estimation								
3. Specification (7) uses national VHS Release Inventory and Semi-Conductor Price Index as instruments								
4. Specification (8) uses Regional VHS Rental Inventory per Household, National VHS Release Inventory and Semi-Conductor Price Index as instruments								
5. *** and ** denote statistical significance at 1% and 5% significance levels respectively								

Table 5: First Stage of the Instrumental Variables Estimation

	Two endogenous variables (Specification 7)		Three endogenous variables (Specification 8)		
	National DVD Release Inventory	Price Difference	Regional DVD Rental Inventory per Household	National DVD Release Inventory	Price Difference
Regional DVD Rental Inventory per Household	106.74*** (33.77)	-11.27 (10.86)			
Regional VHS Rental Inventory per Household			0.01*** (0.0015)	5.49 (3.96)	14.05*** (4.75)
National VHS Release Inventory	0.73*** (0.003)	-0.06*** (0.007)	1.6e-05*** (1.97e-06)	0.73*** (0.003)	-0.06*** (0.006)
Semi Conductor Price Index	-4.46*** (0.27)	2.05*** (0.38)	0.0004*** (0.00014)	-4.45*** (0.28)	2.85*** (0.46)
DMA fixed effects			yes	yes	yes
Quarterly time fixed effects			yes	yes	yes
Number of Observations	813	893	893	813	893
R-squared	0.99	0.17	0.75	0.99	0.18
F-test for joint significance of instruments	F(2,725)=71995	F(2,805)=45.62	F(3,805)=33.33	F(3,725)=50847	F(3,805)=41.93
p-value	0.00	0.00	0.00	0.00	0.00

Figure 6: DVD Player Installed Base Under Different Regional DVD Rental Inventory Scenarios



Note: The "25th percentile" scenario assumes that all DMAs have the same movie rental inventory which is set at the status quo 25th percentile level across all DMAs (presented in Figure 4). Similar analogy for the "90th percentile" scenario follows.

Figure 7: Number of New Adopters Under Different Scenarios

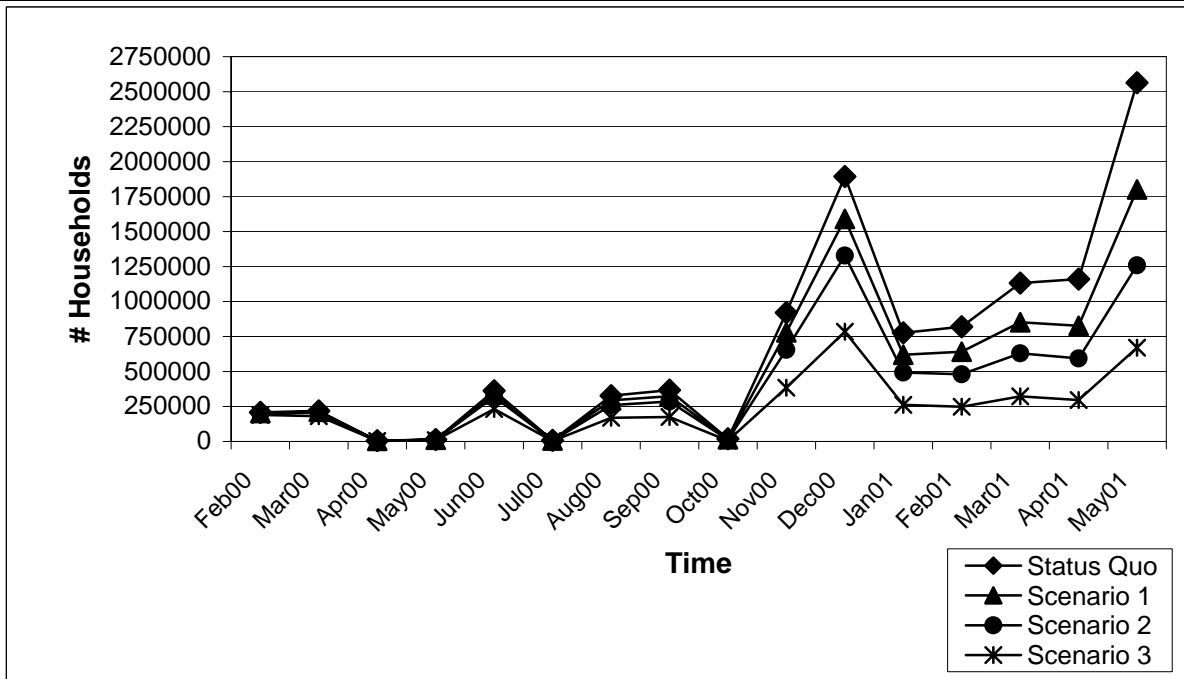
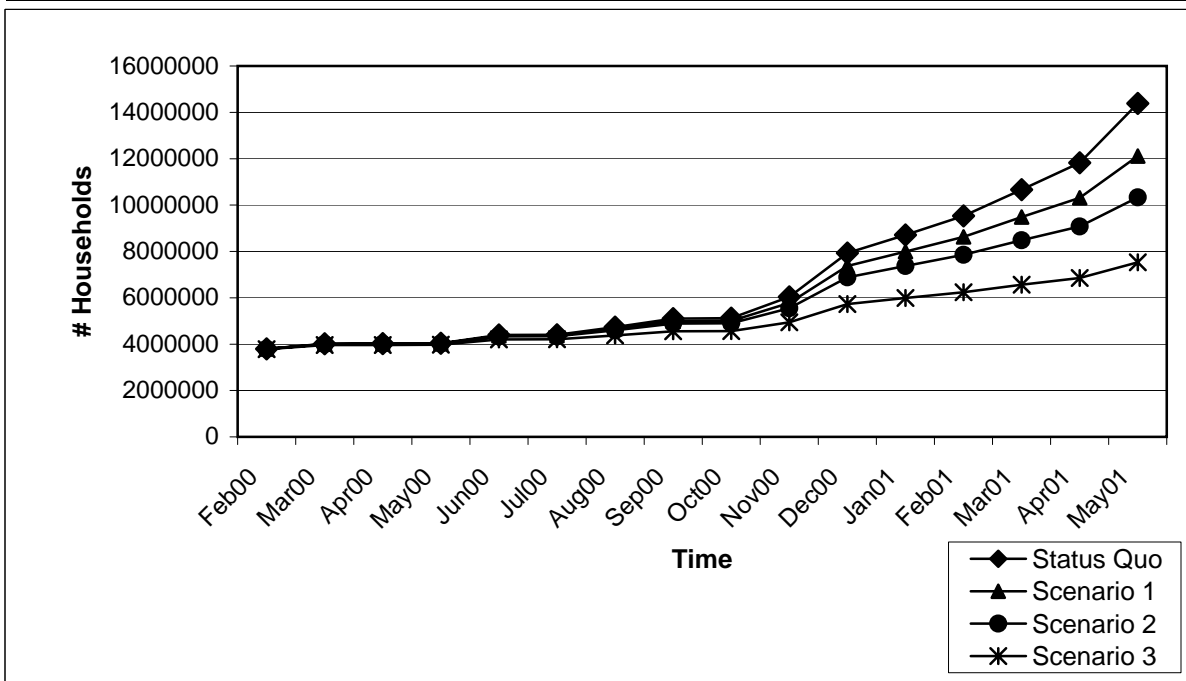


Figure 8: DVD Player Installed Base Under Different Scenarios



Scenario 1: no rental availability

Scenario 2: no rental availability and no release growth

Scenario 3: no rental availability and 50% less new releases