Network Effects in Technology Adoption: The Case of DVD Players

Pinar Karaca-Mandic[1]

University of California at Berkeley
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This paper analyzes a model of consumer adoption of DVD players (the hardware-side) and movie studios' supply of movies on DVD discs (the software-side). My primary focus is the estimation of complementarities between DVD player adoption and availability of content on DVD discs. The size of the complementarities determine the level of strategic inter-dependence between hardware and software firms, and thus play an important role in designing co-marketing strategies through which hardware and software firms can align their incentives. I estimate the parameters of the hardware adoption using household level panel data. To estimate the parameters of the software model, I use a cross section of movies released at different time periods. Estimated complementarities are statistically and economically significant. The hardware-side estimation shows that a 1% increase in new DVD releases during May 2001 would increase DVD player sales by 0.5%. The software-side estimation indicates that a 1% increase in DVD player installed base in May 2001 increases the number of new DVD releases by 0.19%. Finally, I present two examples that outline the strategic implications of the estimated complementarities. In particular, I examine the amount of subsidy the movie studios would be willing to give to increase DVD player sales by 1 more unit, and the amount of subsidy the DVD player manufacturers would be willing to give to increase new DVD releases by one more unit.

Keywords: network effects, complementarity, new technology, diffusion, co-marketing strategy.

[1]Department of Economics, University of California at Berkeley. E-mail: pinar@econ.berkeley.edu. I wish to thank my advisor Aviv Nevo and my dissertation committee members Severin Borenstein and Aaron Edlin for guidance. I also received invaluable feedback from Julian di Giovanni, Tulin Erdem, Joe Farrell, Richard Gilbert, Bronwyn Hall, Ganesh Iyer, Yesim Orhun, Paul Ruud and Miguel Villas-Boas. I benefited greatly from the comments of participants at UC Berkeley Industrial Organization Lunch and Haas Business School Marketing Department seminar. I am also grateful for all the help of Jerilyn Kessel (CENTRIS), Mark McErlean (CENTRIS), Tom Edwards (NPD Intelect) and Douglas Johnson (Video Retailer Magazine) in providing me the data used in this paper. Financial support from the UC Berkeley Summer Fellowship, UC Berkeley Department of Economics Continuing Student Fellowship, UC Berkeley Dean's Fellowship and Academic Progress Award are gratefully acknowledged.

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1 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 (instead of next period), she could use the product for an additional period. On the other hand, by waiting until tomorrow, she might get a potentially higher quality product at a lower price. 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 Digital Video Disc (DVD)[2] players much if there is not a sufficient number of movie or music titles available on DVD discs.

What factors influence a movie studio's decision to release a movie on DVD discs in addition to on VHS? As long as the studio expects enough demand for the movie on a DVD disc to make positive profits, it will make the movie available on DVD disc. The installed base of DVD players is a key factor in providing the necessary demand for movies on DVD disc.

The impact of DVD content availability on DVD player adoption and the impact of DVD player installed base on the supply of content on DVD discs, known in the literature as "indirect network effects", imply 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 discs (software firms). In particular, any demand generation activ-

[2]also stands for Digital Versatile Disc

ity of the hardware firms impacts the consumer demand for the combined hardware/software product, and thus indirectly affects the software firms and vice-versa. Therefore, it might be beneficial to co-market hardware and software through which hardware firms can subsidize the software firms and vice-versa.

However, to design co-marketing strategies, one needs to know the size of the complementarities. In this paper, I first examine which factors determine a consumer's decision on when to adopt a DVD player (the hardware-side), while the primary focus is determining the impact of DVD content availability on the consumer's decision. Next, I model a movie studio's decision on whether to release its content on DVD discs with a focus on determining the impact of DVD player installed base on this decision (the software-side).

I estimate the parameters of the hardware adoption model using household-level panel data which dates back to the commercial introduction of the DVD players in the spring of 1997. This time span allows me to capture the complete adoption curve of the technology. In the data, households not only report when they adopted a DVD player, but also their average monthly rentals and purchases of movies on DVD discs. Using this information, I derive proxies for DVD content availability. These proxies have both regional and time variation. I estimate the software model using data on various characteristics of individual movie titles, whether they are released on DVD disc or not, and the DVD player installed base when they are considered for release on DVD disc.

I use instrumental variables approach to account for the potential endogeneity of the DVD content availability in hardware-side estimation, and of the DVD player installed base in the software-side estimation. On the hardware-side, I use the number of new VHS releases for different time peri-

ods, and the region/time means of various consumer demographics as instrumental variables. For these variables to constitute a valid set of instrumental variables, two requirements are needed. First,they need to be correlated with the availability of content on DVD discs. I verify this correlation. Second, they need to be uncorrelated with the unobservable factors (to the researcher) that affect the consumer adoption of the DVD players. For this second requirement, assumptions needed are that the number of new VHS releases does not respond to the demand for watching movies on DVD, and that after controlling for the consumer level demographics, the mean demographics are uncorrelated with the unobservable factors that affect a consumer's utility from adopting.

On the software-side, I use the installed base of digital cameras as an instrumental variable. I show that the digital camera installed base is correlated with the DVD player installed base. The identifying assumption is that the digital camera installed base is not correlated with the unobservable factors (to the researcher) that impact a given movie's DVD profits.

Estimated parameters are then used to compute the impacts of various marketing strategies. For example, a one-time 1% price reduction of the DVD players in May 2001 increases DVD player sales that month by 1.8%. The results indicate that correcting the endogeneity problem reduces the size of the estimated impact of new DVD releases on DVD player sales. A 1% increase in new DVD releases during May 2001 would increase DVD player sales by 1.5% using the uncorrected estimates, and by 0.5% using the endogeneity corrected estimates. For the studios which supply movies on DVD discs, a 1% increase in DVD player installed base increases the number of new DVD releases between 0.15% and 0.33%. The elasticity of new releases with respect to DVD player sales declines from 0.01 in February 2000 to 0.006

in May 2001.

I also present two examples which outline the strategic implications of the estimated complementarities. First, I examine the amount of subsidy the movie studios would be willing to give to increase DVD player sales by 1 more unit in a given month. I find that the movie studios should be willing to pay up to \$10-\$32 to increase DVD player sales by one unit in a given month. Secondly, I examine the amount of subsidy the DVD player manufacturers would be willing to give to increase new DVD releases by one more unit in a given month. I estimate that their willingness to pay ranges between \$135,000-\$2,000,000.

Although my study focuses on the network effects between DVD players and the availability of titles on DVD disc, 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. Similarly, software producers will choose not to supply software unless the hardware installed base is large enough, thereby creating significant bottlenecks.

The remainder of this paper is organized as follows. Section 2 discusses the related literature and presents the positioning of my study. Section 3 provides a framework for modeling and estimating the parameters of hardware adoption process and of software release decision. Section 4 presents the data. Section 5 discusses the econometric model with emphasis on identification, estimation method and instrumental variables. Section 6 reports the estimation results, discusses policy experiments, and presents implications from a practitioner standpoint. Section 7 concludes and discusses directions for future research.

2 Related Literature

Understanding of the determinants of new technology adoption and diffusion has received considerable attention in the economics literature. Mahajan, Muller and Bass (1990), Gupta, Jain and Sawhney (1999), Hall and Kahn (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. Song and Chintagunta (2003) build on the Melnikov (2002) model by allowing consumer heterogeneity and changing mix of consumers. They apply the model on the digital camera category, and identify different consumer segments with different preferences for the brands which leads to differences in their adoption times.

Some recent empirical literature analyzes the adoption of technologies that exhibit network effects. These newer studies not only provide evidence of the network effects, but also demonstrate strategic implications for policy makers. In an experimental setting, Gupta, Jain and Sawhney (1999) present a model for the evolution of markets with indirect network externalities with an application to the U.S. digital television industry. They find that complementarities play an important role in the acceptance of digital TV technology and provide a forecasting tool that takes into account indirect network effects.

Among the empirical studies that use actual industry data, Gandal,

Kende and Rob (2000) identify the positive feedback between hardware/software systems with an application to CD technology and discuss the implications for backward compatibility. Dranove and Gandal (2001) acknowledge the complementarity between DVD disc availability and the DVD installed base with the main focus being on presenting evidence on standard wars between DVD and DIVX systems. Park (2003) presents a dynamic structural model of consumer choice and producer pricing of a new durable technology with an application to the competition between VHS and Beta formats and analyzes the extent to which externalities contributed to the standardization of the VHS format. Nair, Chintagunta and Dube (2003) present evidence of the indirect network effects for the Personal Digital Assistant (PDA) technology.

These studies use a time-series identification strategy using aggregate data on hardware sales units and prices along with the availability of complementary product. However, for high technology products, prices typically decline over time due to decreasing costs, while the adoption of the product increases over time. Therefore, it is difficult to identify whether the increasing adoption is due to increasing network size or due to decreasing prices.

Another set of studies use cross-sectional data to identify the network effects. Rysman (2002) 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). Goolsbee and Klenow (2002) provide evidence on learning and network externalities in the diffusion of home computers by using household-level data for 1996 and 1997. The authors find that in 1997, people were more likely to buy their first home computer

in areas where a high fraction of consumers already owned computers. The main drawback of this study is that the data represent two snapshots from 1996 and 1997, making interpretation of the results difficult. The evidence that the probability of adoption is higher in regions where the installed base is larger may simply reflect the fact that the regions considered are at the increasing portion of their adoption curves instead of reflecting evidence of network effects or learning. 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.

One recent study that uses both time-series and cross-sectional data is by Gowrisankaran and Stavins (2003). The authors use a panel data set on bank adoption and consumer usage of automated clearinghouse electronic payment system (ACH) to examine the network externalities in this industry. They compare the nash-equilibrium outcome to the socially optimal outcome and find that ACH is under-used relative to its socially optimal level due to network externalities.

The data set I use also has both time-series and cross-sectional variation. However, my study is different from Gowrisankaran and Stavins (2003) in a few aspects. First, they study a direct network effect in which the benefit from using a technology increases directly as the network becomes larger (bank adoption of ACH becomes more likely as ACH is used more). Their methodology cannot distinguish whether the externality is at the consumer level (due to increased consumer usage of ACH), or at the bank level (due to more banks accepting the ACH). I study an indirect network effect in which the value of the technology increases due to a wider availability of a complementary product. Secondly, their model uses static simultaneous

decision making, and does not allow for the modeling of durable goods.

My study is the most similar to Gandal, Kende and Rob in that I model both the adoption of hardware and supply of software in a compatible standard. However, my study has a significant data advantage. First, I can model technology adoption using individual-level data. Secondly, I have both time-series and cross-sectional variation in the availability of the complementary product instead of only time variation.

3 Framework

3.1 Consumer Decision

The basic dilemma a household faces between adopting a new durable technology product today versus tomorrow is due to the trade-off between the utility from use today and lower quality adjusted price in the future. For a homogenous durable product, household i's utility from adopting the product at period t relative to the outside good[3] of using an old technology can be written as

$$U_{i,t} = -\alpha(price_t) + UsageValue_{i,t} + \sum_{\tau=t+1}^{\infty} \beta^{\tau-t} E_{it} UsageValue_{i,\tau} \quad (1)$$

where α is the marginal utility of income, β is the discount factor and E_{it} is the expectations operator for household i at period t.[4] Now, assume that for any time period $\tau \geq t+1$, $E_{it}UsageValue_{i,\tau}$ is the same for a DVD player independent of when it is purchased. This assumption implies, for example, that a high quality product purchased at $t+1$ and a low quality product purchased at t has the same expected usage value for $t+1$ and afterwards.

[3]Utility from outside good can be written as
$U_{i0,t} =_{it}$ where Y_{it} is household $i's$ income at time t.

[4]Unfortunately modeling DVD players as a homogenous good ignores brand effects and consumer expectations on quality and brand availability. I make this assumption because I don't observe the brand of the DVD player consumer purchases. Moreover, I only observe transaction prices averaged across all brands.

Another implication is that the product does not ware off.

Then, from period t's perspective, the utility relative to the outside good, from adopting at period $t+1$ instead of t is

$$E_{it}U_{i,t+1} = -\beta\alpha(E_{it}price_{t+1}) + \sum_{\tau=t+1}^{\infty} \beta^{\tau-t} E_{it} UsageValue_{i,\tau} \quad . \tag{2}$$

A household would adopt at t instead of $t+1$ if $U_{it} > E_{it}U_{i,t+1}$, which can be written, under the assumed specifications for $U_{i,t}$ and $E_{it}U_{i,t+1}$, as

$$UsageValue_{it} > \alpha(price_t - \beta E_t price_{t+1}) \quad . \tag{3}$$

Assuming rational expectations ($E_t price_{t+1} = price_{t+1}$), this condition simplifies to

$$UsageValue_{it} > \alpha(price_t - \beta price_{t+1}) \quad . \tag{4}$$

This condition states that the household would rather adopt today if the expected usage value by having the good an additional period today outweighs the benefit of waiting until tomorrow and taking advantage of lower prices. The household will adopt at the smallest t that satisfies condition (4).

Consider household i in region r at time period t. For this household, let

$$UsageValue_{irt} = \alpha_0 + \alpha_2 S_{rt} + \alpha_3 D_i + \gamma_{rt} + \mu_{irt} \tag{5}$$

where S_{rt} is the content availability on DVD discs at region r at time t, D_i are household demographics, γ_{rt} are time and region specific unobservables capturing unobserved quality perception of the DVD technology, and μ_{irt} represent unobserved consumer heterogeneity that are identically, independently distributed across households.[5] Some examples of the demographic variables are the number of adults/teenagers/kids in the household, income

[5]One can think of μ_{irt} either as an unobserved consumer heterogeneity on usage value of DVD players, or as consumer heterogeneity on perception of disc availability S_{rt}. Currently I am assuming that for a given household in region r at time t, every household has the same perception of S_{rt}. Instead one can model household i's perception as $S_{rt} + \mu_{irt}$.

level of household, employment type, whether the household owns its own home or not etc. Moreover, household's ownership of other digital and high technology goods such as camcorder, pc, digital camera and subscribership to digital cable can be used to proxy for whether the household is a digital technology lover or not. Then, equation (4) becomes

$$\alpha_0 + \alpha_1(price_t - \beta price_{t+1}) + \alpha_2 S_{rt} + \alpha_3 D_i + \gamma_{rt} + \mu_{irt} > 0 \quad . \tag{6}$$

By specifying

$$y^*_{irt} = \alpha_0 + \alpha_1(price_t - \beta price_{t+1}) + \alpha_2 S_{rt} + \alpha_3 D_i + \gamma_{rt} + \mu_{irt} \quad , \tag{7}$$

equation (6) can be re-written as

$$y^*_{irt} > 0 \ . \tag{8}$$

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 is no more choice situations for that household.

3.2 Software Release Decision

A studio produces a certain number of movies to be released every month on VHS. Among those movies, the studio decides which ones to also make available on DVD discs.[6] By making title k available on DVD disc, studio earns the profit,

$$\pi_k = X_k\theta + \nu_k \ , \tag{9}$$

where X_k are the characteristics of the movie. A studio releases the title on DVD disc if

$$\pi_k \geq 0 \quad . \tag{10}$$

[6]During the period of my study (between February 2000 and June 2001), not every VHS movie is released on DVD.

The researcher cannot observe the profit function π_k, but she can observe whether the movie is released on DVD disc or not.

Movie characteristics X_k can be divided into two groups. The first group contains movie specific characteristics such as its studio and its domestic box office revenue. The second group contains characteristics that are common for all movies that were released on DVD disc at the same time period. These variables include the installed base of DVD players at the time of release.

Similarly, the unobservable ν_k is assumed to be separable into a component that is movie-specific and a component that is specific to the introduction time and rating of the movie. Movie specific unobservables could capture factors such as whether the movie received any awards, and whether it stars a famous actor/actress. The part of the unobservable that is common for all movies of a given rating released at a given time is further decomposed into a component that is the same for all movies with the same rating across all time periods, and deviations from this mean rating effect for a given time period. The rating specific unobservable could potentially include consumer demand for watching movies with a certain rating. The time specific deviations from these rating effects could include factors such as changes in consumer demand for different ratings over time, technological shocks that affect the cost of movie production on DVD discs, or other cost shifters that the researcher does not observe.

4 Data

The primary data source used in this paper is provided by Communications, Entertainment, and Technology Research and Information Service (CENTRIS)).[7] For the period between April 1997 (corresponding to the intro-

[7]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

duction of DVD players in the U.S. market) and June 2001, I observe around 200,000 households. I have the following information for each household: detailed set of demographics, whether the household owns a DVD player, a VCR, a DVD-ROM, a camcorder, a pc, a digital camera and a digital cable. Additionally, for each household reported to own a DVD player or a DVD-ROM, I have information on the number of discs rented and number of discs purchased within the 30 preceding days of the survey. Starting in January 2000, each household that reported to own a DVD player was also asked about the length of their ownership of the product, giving their exact adoption time. I restrict my analysis to the monthly surveys between June 2000 and June 2001 in the top 25 designated market areas (DMAs) represented in the sample. These restrictions yield a sample size of 22,175 households. Since CENTRIS data do not provide information on the price of DVD players, I unfortunately cannot observe transaction prices for each household. Instead, I use monthly average price data for DVD players provided by NPD Intelect.[8]

I also use a trade magazine called Video Retailer[9] to extract information on monthly VHS and DVD title releases by studio, rating, and box office revenue. This information is available starting February 2000.[10]

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.

[8]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.

[9]Video Retailer is supported by the trade organization Video Software Dealers' Association (VSDA)).

[10](http://www.videoretailer.com/worksheetarch.htm (accessed during November'01 and January'02))

As a measure of content availability on discs, S_{rt}, a proxy is constructed from the CENTRIS and Video Retailer data. First, I compute the ratio of active to non-active renters of DVD movies by month for each region using responses of the households from each month's CENTRIS survey. An active renter is defined as a household with DVD technology (a household who owns either a DVD player or DVD-ROM) that has rented at least one movie on DVD disc within the last 30 days preceding the survey. This measure is assumed to proxy regional market activity for DVD content. The problem with this measure is that it is aggregated for each time period and region from individual responses. Since different sets of individuals are surveyed at different time periods, further noise is added to this variable. Therefore, I smooth this measure with a linear fit for each region, and interpret it as a market activity index.

Next, using the data from the Video Retailer Magazine, I compute a measure of monthly content availability in terms of actual new DVD video releases starting with releases on February 2000.[11] Note that this measure represents the national monthly availability of content on DVD discs. I interact this national content availability measure with the regional market activity index measure constructed using the household level data. The overall measure of DVD content availability for a given region and time, S_{rt}, is the interaction of the market activity in that region and the national monthly new releases on DVD discs.[12]

For the software-side, an observation is a movie title and the dependent variable is a 1/0 variable taking the value 1 if the movie is released on DVD

[11]Earlier monthly release information for DVD movies is not available from the Video Retailer magazine.

[12]I use the number of monthly new releases instead of cumulative number of movies available on DVD since it is reasonable to assume that a new adopter cares more about watching new releases rather than older movies.

disc. To construct this variable, I use the monthly order sheets of Video Retailer magazine. I examine each movie released on VHS for a given month and determine whether it was also released on DVD disc that month.[13] For the independent variables, each title's characteristics such as its studio, rating, domestic box office revenue are available from the Video Retailer. The data consists of around 1000 movies released on VHS between February 2000 and June 2001 and their characteristics. In February 2000, approximately 60% of the VHS movies were also released on DVD while in June 2001, about 90% of them were also available on DVD.

Table 1 reports summary statistics across different regions for February 2000 and May 2001. As Table 1 points out, mean market activity index has increased from 0.39 in February 2000 to 0.67 in May 2001. This implies that 29% of technology owners in February 2000 rented at least one movie on DVD disc, while this percentage increased to 40 in May 2001. Similarly, while the average owner rented 1 movie on DVD disc during February 2000, average owner rented 2 movies on DVD disc during May 2001. Table 1 also reports differences across a sample of regions in their market activity index. As expected, metropolitan areas such as New York-New Jersey-Long Island and Los Angeles-Riverside-Orange County have larger market activity indices compared to Pittsburgh or Athens-Atlanta.

Figure 1 presents the adoption curves of various digital technology products computed from the household level data. Data suggest that the take-off time of digital cable, digital camera and DVD players are about the same, and all three technologies are still at the increasing portion of their adoption curves as of May 2001. By May 2001, approximately 15 million U.S. house-

[13]For the monthly order sheets that I have examined, titles not released on DVD during the same month as the VHS release were not offered on DVD at a later month's order sheet.

holds owned a DVD player, and about 10 million owned a digital camera.

5 Econometric Model

5.1 Identification

The goal of the empirical methodology for the hardware-side is to estimate the parameters of equation (8) and to identify price sensitivity and the complementarity between adoption of DVD players and content availability on DVD discs. To identify the impact of DVD content availability on DVD player adoption, I compare households in a given region with the same demographics who purchased at different times, and relate such differences to different prices and content availability over time. Furthermore, I also compare households with the same characteristics who bought at the same time but in different regions and relate the differences in the number of adopters to the regional differences in content availability on DVD discs.

One important concern in estimating the adoption equation (8) is the fact that content availability S_{rt} is potentially an endogenous variable. It is possible that some of the unobservables to researcher in y^*_{irt} are in fact observable to suppliers of content on discs (studios which make decisions of releasing certain videos on DVD discs, and/or the local video retailers who decide whether to carry more DVD titles). In particular, content suppliers most likely have a good idea about γ_{rt} (demand shocks, economic shocks and/or region/time specific channels that affect quality perception of the product such as marketing and advertising). To the extent that content availability responds to γ_{rt}, variable S_{rt}, which captures content availability, will be correlated with γ_{rt}, which is part of the error term. To deal with the problem of correlation between S_{rt} and γ_{rt}, I propose a set of instruments that are correlated with S_{rt}, but uncorrelated with γ_{rt}. These instruments

are discussed in detail in Section 5.3.

The possible correlation of DVD player prices and γ_{rt} is also a concern. However, there are two reasons that lessen this concern. First, it is a reasonable assumption to characterize DVD player manufacturing as a competitive industry.[14] Second, 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 changes in consumers preferences or perceptions. 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 price of consumer DVD players. I will further discuss this issue in Section 5.3 .

To identify the impact of the DVD player installed base on the suppliers' decisions in making content available on DVD discs, I compare movies with identical characteristics released on VHS format at different months, and relate the differences on whether they were also released on DVD discs to differences in DVD player installed base at the month of their potential release. The concern is that the DVD player installed base is an endogenous variable, and is correlated with the time specific unobservables of the profit function. Recall that these unobservables could include factors such as technological shocks that affect the cost of movie production on DVD discs and other cost shifters. Households' adoption behavior will respond to these shocks, making DVD player installed base to be correlated with these unobservables. To deal with this correlation, I use instruments that are correlated with the DVD player installed base, but are uncorrelated with the time-specific unobservables that enter the profit function. I discuss the

[14] As a sample for DVD player models, DVD Entertainment Group lists at least 10 manufacturers and 90 models on July 25, 2001. By mid-2003, 60 different brands, and 250 models were available. (http://www.dvdinformation.com, accessed during April 2003.)

software-side instruments in section 5.3.

5.2 Estimation Method

If endogeneity was not an issue, parameters of equation (8) could be estimated directly using maximum likelihood estimation under certain assumptions on the error $\gamma_{rt}+ \mu_{irt}$. However correlation between observable S_{rt} and unobservable γ_{rt} prevents us from doing so. Therefore, I use an estimation method that takes this correlation into account.

The estimation method is an application of Berry, Levinsohn and Pakes (1995) and Berry (1994) to disaggregate data. This approach is implemented to disaggregate data by Goolsbee and Petrin (2002) and Petrin and Train (2002). 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. I estimate the former component using the interaction of region and time fixed effects in the discrete choice model. The estimated fixed effects then incorporate both the unobservables, γ_{rt}'s, and the observables that do not vary within a region and time. As a second step, one can then regress these fixed effects on region/time specific observables such as S_{rt} and $(price_t - \beta price_{t+1})$ using standard instrumental variables approach while accounting for the covariance among fixed effects.

The specific estimation procedure is as follows. I first use a binary probit model to estimate

$$y^*_{irt} = \delta_{rt} + \alpha_3 D_i + \mu_{irt}, \tag{11}$$

where

$$\delta_{rt} = \alpha_0 - \alpha_1(price_t - \beta price_{t+1}) + \alpha_2 S_{rt} + \gamma_{rt} \ . \tag{12}$$

I capture $\delta_{rt}'s$ with the interaction of region and time dummy variables.

As a second step, I use the estimated $\widehat{\delta_{rt}}$ from the first step and estimate

$$\widehat{\delta_{rt}} = \alpha_0 - \alpha_1(price_t - \beta price_{t+1}) + \alpha_2 S_{rt} + \gamma_{rt} \tag{13}$$

using generalized two-stage least squares[15] with the appropriate instrumental variables. To use this estimation method, one needs to be able to estimate fixed effects consistently in the first step. In my application, the asymptotics come from having a large number of observations for each region/time pair.

To implement the same estimation approach for the software-side, I first estimate a binary probit model of 1/0 release decision on time/rating fixed effects and individual movie characteristics. Next, I regress the previously estimated fixed effects on DVD player installed base and rating dummy variables using generalized two-stage least squares estimation.

5.3 Instruments

For the hardware-side estimation, the appropriate instrumental variables need to be correlated with the DVD content availability, but uncorrelated with the unobservables to which DVD player adoption might be responding. Recall that the latent utility model for DVD player adoption is

$$y^*_{irt} = \alpha_0 + \alpha_1(price_t - \beta price_{t+1}) + \alpha_2 S_{rt} + \alpha_3 D_i + \gamma_{rt} + \mu_{irt} \quad . \tag{14}$$

This equation can be written as

$$y^*_{irt} = \alpha_0 + \alpha_1(price_t - \beta price_{t+1}) + \alpha_2 S_{rt} + \alpha_3 D_i + \gamma_r + \Delta\gamma_{rt} + \mu_{irt}, \tag{15}$$

where γ_r represent region specific unobservables that are constant over time. These γ_r can be captured with region dummy variables. The residual $\Delta\gamma_{rt}$ for a given region in this context is then the changes in unobservables over time. Therefore, the instrumental variables should be correlated with S_{rt},

[15] One needs to use a generalized least squares method to account for the standard errors of the dependent variable that is estimated from a previous regression.

but uncorrelated with $\Delta\gamma_{rt}$. As discussed in Section 4, the measure of DVD content availability S_{rt} for region r at time t is the interaction of the region's market activity for DVD disc usage at time t computed from household level data and the national new releases of movies on DVD discs for t.

I use a set of three instrumental variables. The first instrumental variable is the national releases of new VHS movies. Every month, studios release a certain number of movies on VHS format. Among these movies, studios decide which ones to also make available on DVD discs. Therefore, the number of new VHS movie releases should be correlated with the number of new DVD movie releases. Figure 2 illustrates the correlation between monthly VHS and DVD releases. Assuming that the decision to make a movie available on VHS does not respond to the demand for watching movies on DVD, number of new VHS releases would not respond to the unobservables in consumers' DVD adoption such as advertising and marketing activities that promote DVD technology. VHS releases would be correlated with these unobservables if there is a feedback effect between DVD titles and VHS titles. For example, if the introduction of the DVD technology increased overall demand for movie watching and made studios release more movies on VHS, then the number of new VHS releases would not be a valid instrument. However, I cannot reject the null hypothesis that the number of monthly VHS releases do not increase after DVD releases became easily available.[16]

Two additional instrumental variables exploit both cross-sectional and time-series variation. For each region r and time period t, I use the mean

[16]Starting February 2000, video retailers have been able to order DVD movies using standard order sheets of the Video Retailer Magazine as they have long been doing with the VHS movies. For the period between September 1998-June 2001, 64.39 movies on average were released on VHS while between February 2000-June 2001, 63.12 movies were released on VHS suggesting that the widespread availability of DVD movies did not increase the number of VHS movies released overall. I cannot reject the null hypothesis that the number of monthly VHS releases do not increase after February 2001. (t-stat of 16 degrees of freedom is -0.9)

age and proportion of highly educated (college and higher) households I have in the sample as instrumental variables. Given that a household is dropped from the sample after adoption, constructed measures for period t are then the mean demographics of households who did not adopt by the end of period $t-1$ (those with choice value "0" for period $t-1$).

However, changes in these mean demographics proxy the changes in the demographics of the new adopters. Among those households whose demographics are included for constructing means at period t, some adopt at period t. These households are dropped from the sample when constructing means at period $t+1$. Therefore, for a continuous variable like "age", if we see that the mean age of the sample for a given region increases from period t to period $t+1$, this indicates that younger people adopted at period t and they are dropped from the sample, leaving older people to be included in the sample for $t+1$. More specifically, this would mean that the mean age for those who adopted in period t is smaller than the mean age of the sample in period t. Similarly for a 1/0 variable that indicates "high level of education", the larger the decrease we see in the proportion of highly educated people in the sample from period t to $t+1$, the larger the proportion of highly educated people who adopted at period t.

These demographic composition changes could potentially be correlated with the changes in regional DVD content availability. For example, younger people probably watch more movies. Therefore, one would expect the regional market activity for DVD discs to be larger in regions where there is more tendency for younger people to buy DVD players. Similarly, educated people are presumably more interested in using high technology products, making them use their DVD players more intensely. Again, local retailers probably bring in more DVD movies to their stores in regions where there

is more tendency for highly educated people to buy DVD players. Therefore, DVD content availability is expected to increase with an increase in mean age (new adopters are younger), and with a decrease in the proportion of highly educated households (a larger proportion of the new adopters are highly educated). The first stage regression result presented in Table 3 provides evidence for this conjecture. The identifying assumption is that the means across r and t of "age" and "high education" are not correlated with unobservables $\Delta\gamma_{rt}$ since we include these demographics at the household level estimation as D_i's in equation (15).

In general, special marketing activity and advertising probably occurs the most during the holiday seasons, and regions with more electronics chain stores are impacted more from these advertising and promotions. I control for holiday seasons with quarterly dummy variables, and for the region specific unobservables, such as existence of many electronics stores, with regional dummy variables.

As mentioned before, one might be concerned that in equation (15), variable $(price_t - \beta price_{t+1})$ is also correlated with $\Delta\gamma_{rt}$. Individual transaction prices or regional prices are not observed in the data. I only observe an average transaction price (aggregated across different brands) for each month. Therefore, concern is the correlation $(price_t - \beta price_{t+1})$ with the portion of $\Delta\gamma_{rt}$ that is common for all regions. As the industry reports argue, decline in prices of DVD players is due to the mass production of DVD-ROM drives and plummeting costs of audio/video decoder chips.[17] 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. I could not find systematic data on the price of audio/video decoder chips,

[17] Taylor (2001)

but instead use semiconductor chip price index published by the Bureau of Labor Statistics to support the same argument. As Figure 3 illustrates, these two series both follow a decreasing trend. Moreover, if there is any strategic pricing of DVD players due to seasonal effects, quarterly dummies used in the utility specification should control for these effects.

For the software-side identification, the instruments need to be correlated with the DVD player installed base, but uncorrelated with the unobservables in the profit function for a given movie. After controlling for rating-specific unobservables using rating dummy variables, remaining unobservables are deviations from the mean rating effect over time. As discussed earlier, these unobservables could capture changes in demand for different ratings not accounted for by the national DVD player installed base, technological shocks that affect the cost of movie production on DVD discs, or other cost shifters.

The instrument I use is the installed base of digital cameras, which is computed by aggregating responses from the household level data. Digital cameras became available commercially around the same time as DVD players.[18] Given that both digital cameras and DVD players are digital technologies, it is reasonable to expect that their installed bases are correlated. I present evidence of this correlation in Table 5 (B) which is discussed further in Section 6. For the DVD technology, there is a feedback effect through DVD content availability, which further enhances the adoption of DVD players, but there is no such direct complementarity for digital cameras. Consequently, the adoption curve of digital cameras most likely sketches the adoption curve of a typical digital technology net of the effects of any other direct complementarities. Therefore, we do not expect the adoption of digital cameras to respond to unobservables in the profit function of studios who supply movies

[18]NPD Intellect started collecting sales and price data both for digital cameras and for DVD players on January 1998.

on DVD discs.

6 Results

The sample of analysis includes 22,175 households that are surveyed in top 25 DMAs between June 2000 and May 2001.[19] Using each household's adoption time, I create a panel for a given household over time where a household's choice variable takes the value "0" for all the periods up to the adoption time, and "1" for the period of adoption. The household is dropped from the sample after adoption. Therefore, I am modeling the probability of adoption given that the household has not adopted yet.

Table 2 (A) reports the estimation of equation (11) i.e., the first stage estimation of the hardware-side using probit specification. The dependent variable is the 1/0 choice variable, and the independent variables include demographic variables D_i's, and the fixed effects δ_{rt}'s that are the interaction of region and time dummy variables. As discussed earlier, these fixed effects incorporate both the unobservables, γ_{rt}'s, and observables that do not vary across households at a given region and time. Such observables are the DVD content availability S_{rt}, and average price difference $(price_t - \beta price_{t+1})$. Because a given household is observed for different time periods until adoption, μ_{irt} in equation (11) that controls for household heterogeneity is correlated across time periods for a given household. Standard errors are corrected for this "household group effect". As the results indicate, most of the demographics are statistically significant, and they have the expected sign. For example, older people have lower probability to adopt, households that own other technology products such as digital camera, digital cable and pc have

[19] Although DVD players were introduced during April 1997 in the U.S., the data do not show significant ownership until the end of 1999. Therefore, I limit the analysis to start on February 2000, which is also the first date when monthly DVD release data are available from Video Retailer magazine.

higher probability to adopt, and finally households with higher income have higher probability to adopt.

I next use the estimated fixed effects to estimate equation (13), and report the results in Table 2 (B). The covariates included are region and quarterly time dummy variables along with DVD content availability S_{rt} and price difference ($price_t - \beta price_{t+1}$) of DVD players. As mentioned before, the DVD content availability measure used is the interaction of new monthly DVD releases with regional market activity (the ratio of active to non-active renters smoothed for each region). To correct for the endogeneity of DVD content availability, I use the three instruments discussed in Section 5.3. For both the OLS and 2SLS regressions, DVD content availability and price difference are statistically significant. Coefficient on DVD content availability is positive, and the coefficient on price difference is negative. Given that the OLS coefficient on DVD content availability is the true coefficient plus some spurious correlation between the unobservable and DVD content availability, estimating the OLS is expected to result in an upward bias of the DVD content availability coefficient. As expected, endogeneity correction using the 2SLS regression reduces the size of this variable's coefficient.

Table 3 reports the first stage regression of DVD content availability on instrumental variables and other exogenous variables. The coefficient on all three instrumental variables are statistically significant, and they have the expected signs as discussed in Section 5.3.

As a specification test, I use Hausman (1983) test of overidentifying restrictions. The Chi-squared test statistic with 31 degrees of freedom has a value of 14. I cannot reject the over-identifying restrictions at 5% level.

As another specification test, instead of using the three instrumental variables together, I estimate equation (13) using one instrumental variable at

a time, and construct a Hausman test. The null hypothesis is that the estimates obtained using three instrumental variables and the estimates obtained using one instrumental variable are both consistent, but the estimates with three instrumental variables is more efficient. The alternative hypothesis is that the estimates with three instrumental variables is inconsistent. For each of the three instrumental variables, I test the model with one instrumental variable alone against all three instrumental variables together, and could not reject the null hypothesis. Therefore, I report the more efficient results obtained using three instrumental variables.[20]

Table 4 displays the parameter estimates of equation (13) using different sets of instrumental variables. The results are robust to using mean number of adults as an additional instrumental variable, or using different functional forms of the three instrumental variables.

Table 5 reports estimation results of the software-side. Table 5 (A) reports the probit estimation where the dependent variable is the 1/0 decision of whether a movie is released on DVD disc or not, and the independent variables are the movie specific characteristics and rating/time fixed effects. As expected, a movie with higher domestic box office revenue has higher probability to be released on DVD disc. Table 5 (B) reports the generalized two stage least squares estimation of the estimated rating/time fixed effects on rating dummy variables, quarterly dummy variables and DVD player installed base. Endogeneity correction reduces the coefficient on DVD player installed base as expected.

To understand the economic significance of the estimated coefficients on DVD content availability and price difference, I compute their marginal ef-

[20]Hausman test for the model with new VHS releases as the only instrument against the model with all three instruments has a p-value of 0.99 while the other two cases have p-values of 1.

fects. These marginal effects report the changes in the probability of adoption as the variable of interest changes by one unit. Next, by multiplying the marginal effects with the number of households who did not buy a DVD player by the end of period $t-1$, one can compute the changes in DVD player sales during period t.[21]

Figure 4 (A) demonstrates magnitude of the price elasticity of DVD player sales. The magnitude of the price elasticity is decreasing over time. A 1% increase of DVD player prices decreases DVD player sales by 4.9% in February 2000, and by 1.8% in May 2001.

Figure 4 (B) represents the elasticity of DVD player sales with respect to new DVD releases. The figure also compares the results with and without the endogeneity correction. As the coefficient estimates in Table 2 (B) suggested, accounting for endogeneity of the DVD content availability reduces the impact on DVD player adoption. A 1% increase in new DVD releases during May 2001 would increase DVD player sales by 1.5% using the uncorrected estimates, and by 0.5% using the endogeneity corrected estimates. In terms of the impact of an additional DVD movie release, the endogeneity corrected elasticity figures imply that the DVD player sales would increase by 0.9% in May 2001.

Figures 5 (A) and 5 (B) demonstrate the relative impacts on DVD player sales, of reducing DVD player prices versus increasing new DVD releases. This comparison is particularly important for DVD player manufacturers who have to decide whether to invest in strategies that impact the final price to consumers, or in strategies that impact the usage value of the product through the complementarity effect. Figure 5 (A) shows the necessary percentage decline in DVD player prices to have the same impact on DVD player

[21] I assume 100 million households as the potential market size.

sales as a 1% increase in new DVD releases. Figure 5 (B) shows by how many dollars DVD player prices should decrease to achieve the same increase in DVD player sales as a 1 unit increase in new DVD releases. As the panels indicate, the impact of new DVD releases on DVD player adoption relative to that of DVD player prices is increasing over time. To induce the same impact on DVD player sales as a 1% increase in new DVD releases, DVD player prices would have to decrease by 0.07% in February 2000, while in May 2001, a 0.29% decline of DVD player prices would be required. Similarly, to achieve the same increase in DVD player sales as a 1 unit increase in new DVD releases, DVD player prices would have to decline by \$0.5 in February 2000 while the required decline in May 2001 is \$0.95.

Figure 6 displays the economic significance of the software-side estimation. In particular, Figure 6 (A) displays the percent increase in new DVD releases from a percent increase in DVD player installed base in a given month. The elasticity ranges between 0.15% to 0.33%, and it does not seem like there is a clear pattern in how the elasticity varies over time. Figure 6 (B), on the other hand, displays the percent increase in new DVD releases from a percent increase in DVD player sales for various months. With the exception of the holiday season of 2000, there seems to be a slight decline in the elasticity of new releases with respect to DVD player sales. The elasticity declines from 0.01 in February 2000 to 0.006 in May 2001.

Figure 6 (C) shows the necessary percent increase in DVD player installed base to induce the release of an additional movie on DVD. The required percentage increase is declining over time. For example, in February 2000, a 14% increase in DVD player installed base would be necessary for a unit increase in new DVD releases, while in May 2001, a 9% increase would have been sufficient. This is not surprising, given that the DVD player installed

base is increasing over time.

6.1 Strategic Implications

The results discussed above present evidence that the complementarities play a significant role both in the consumer decision to adopt DVD players, and in the movie studios' decision to supply movies on DVD discs. The strategic inter-dependence between the DVD player manufacturers (hardware firms) and the movie studios that supply content on DVD discs (software firms) imply that any demand generation activity of the hardware firms impacts the software firms indirectly and vice-versa.

Therefore, both the hardware firms and the software firms could benefit from co-marketing strategies designed to align their incentives. These co-marketing strategies could take the form of bundling DVD players with free DVD movies, or offering movie rental/purchase coupons and rebates for purchasers of DVD players. Alternatively, hardware firms can directly subsidize software firms to release additional movies on DVD, and/or software firms can directly subsidize hardware adoption. Below, I present an analysis to quantify how much software firms would subsidize the hardware firms and vice-versa.

How much subsidy would the movie studios be willing to give to increase DVD player sales by 1 more unit at a given time period?

A studio decides whether to release a movie on DVD disc or not based on a set of covariates, including the DVD player installed base at the time movie is considered for release. To estimate the studio gains from a unit increase in DVD player installed base, I simulate the change in expected profits of a representative movie caused by an increase in DVD player installed base. This exercise is equivalent to computing the compensating variation for as-

sessing consumer gains in a discrete choice framework presented in Small & Rosen (1981).

The major difficulty arises in computing a monetary unit for the studio gains. For the demand-side models, consumer's utility from a product is generally a function of the product's price, and the coefficient on the price variable (which has the interpretation of the marginal utility of income) allows for converting the consumer gains from a policy change into monetary units. There is no covariate in the software model that allows an estimate analogous to the marginal utility of income. To obtain a monetary unit for the studio gains, I follow an indirect approach. I use industry figures and the box office revenue of a movie to estimate the revenue movie would generate on DVD if it is released on DVD, and scale the simulated expected profit and the change in expected profit to match this monetary figure.

Recall that the covariates in the reduced form profit equation for a given movie are the box office revenue of the movie, DVD player installed base at the month the movie is considered for release, dummy variables for the production studios, movie ratings, and quarterly dummy variables. First, by using a given movie's domestic box office revenue, I make a back-of-the-envelope calculation to estimate the revenue a studio would generate by releasing that movie on DVD disc. Einav (2003) reports that the contracts between movie studios (producers and distributors) and movie theaters are fairly standard. Movie studios either pay the distributors 90% of the box office revenues net of the theater expenses, or 70% of the gross box office revenue. Adams Media Research reports that 21% of a movie's revenue is generated by the domestic theatrical performance.[22] Given these numbers, and using the movie's box office revenue, I calculate the total domestic rev-

[22]US Film Revenue by Pipeline, 2002. Given to author on May, 2003.

enue a movie generates. Adams Media Research also claims that home video (which includes DVD and VHS) represents about 61% of the total domestic revenue. According to figures compiled by Ernst & Young for the DVD Entertainment Group, DVD accounts for 30% of a studio's retail revenue from sales and rentals.[23] These figures imply that $1 domestic box office revenue corresponds to $0.61 DVD revenue[24]. This conversion allows for the calculation of DVD revenue in monetary units given the domestic box office revenue of a movie. Next, I convert the simulated expected DVD profit for each movie into monetary units by scaling it to match the DVD revenue the movie would generate if it is released on DVD. The details of this calculation are presented in the Appendix.

Figure 7 (A) demonstrates the increase in the movie studio revenues from a unit increase in DVD player sales in a given month. Assuming that a marginal DVD player owner does not increase the cost of a movie, the figure indicates that the movie studios should be willing to pay up to $10-$32 to subsidize a unit increase in DVD player sales depending on the month. Movie studios' incentives to subsidize DVD player adoption seem to be significantly larger during the holiday season of 2000.

The potential increase in DVD player sales given such a subsidy can be computed using the marginal effect of a price reduction on DVD player sales. The price elasticity of DVD players presented in Figure 4 (A) can be used to compute the increases in DVD player sales from a $1 price reduction. If the consumers can be segmented into a group who would buy the product without the price reduction, and another group who would buy only with a

[23] www.factbook.net/wbglobal-rev.htm (accessed on May 12, 2003)

[24] (0.7) Box Office Rev.=(0.21) Total Rev.
Home Video Rev.= (0.61) Total Rev.
DVD Rev. = (0.3) Home Video Rev.
Then, DVD Rev.
= [(0.3)*(0.61)*(0.7)/(0.21)] Box Office Rev.

price reduction, the subsidy can be offered only to the latter group. In that case, DVD player sales can increase by 28% in February 2000, and by 16% in May 2001. With the exception of the holiday season of 2000, I find a slight decrease over time in the percentage increase in DVD player sales that can be achieved using the subsidy amounts presented in Figure 7 (A).

If consumers cannot be segmented as above, and that the price reduction should be offered to all consumers, I find that the subsidy per new buyer becomes very small that it could not initiate new purchases. For most months I examine, to be able to initiate new purchases by those consumers who would not buy without a price reduction, a maximum of 10-20% of the buyers who would buy anyways at regular prices can be offered a discount. In May 2001, NPD reports that 487,052 DVD players were sold at an average price of $190. If 90% of these players were sold at the regular price of $190, while 10% were sold at a discounted price using the subsidy of the movie studios, the maximum discount per DVD player unit would be $7, and it would be sufficient to increase total DVD player sales that month by 6%.

How much subsidy would the DVD player manufacturers be willing to give to increase new DVD releases by one more unit at a given time period?

DVD player manufacturers can sell the same number of units at a higher price if the consumers are compensated through an increase in the number of new DVD releases. Figure 5 (B) shows the amount by how much the DVD player prices can increase and keep consumers at the same utility given a unit increase in new DVD releases. From Figure 5 (B), a $0.95 price decline in May 2001 would have the same impact on DVD player sales as a 1 unit increase in new DVD releases. Then, if the number of new DVD releases increases by 1 unit, DVD player prices can potentially increase by $0.95

and still generate the sales of 487,052 DVD players. This implies that the DVD player manufacturers' total profits would increase by $462,000 without impacting their cost.[25] Then, DVD player manufacturers would be willing to subsidize the movie studios up to $462,000 to have an additional new DVD release in May 2001. Figure 7 (B) displays, for different months, the amount of increase in DVD player manufacturers' revenues from a unit increase in new DVD releases. Manufacturers' willingness to pay for an additional new DVD release increases over time. In February 2000, they would be willing up to $135,000, while in May 2001, they would be willing up to $462,000.

Without much information on the cost of releasing a movie on DVD, it is difficult to say whether the movie studios would accept such a subsidy and release one additional movie on DVD. A back-of the-envelope calculation using rough cost figures suggests that they would. Industry sources report that the ballpark cost of producing a 2-hour Hollywood quality movie on DVD disc with motion menus, multiple audio tracks, subtitles, trailers and a few information screens is about $20,000. Moreover, it costs $1,000 to master, and $0.75 to replicate a DVD movie.[26] Consider the following strategy: DVD manufacturers could get together and contract with one movie studio to release an additional movie on DVD[27], and bundle that additional DVD release with the 487,052 DVD players they sell during May 2001. Using the rough cost figures above, the per-disc cost of producing the movie on DVD is $0.79.[28] Given that the manufacturers can charge an additional

[25]If I had information on the cost of producing a DVD player, I could compute the manufacturers' gain directly by observing that the increase in new DVD releases would induce more sales of DVD players at a given price, and thus would increase the total profits of DVD player manufacturers.

[26]The source of these cost figures is the May 27, 2003 version of the official Internet DVD FAQ for the rec.video.dvd usenet newsgroups, compiled by Jim Taylor. http://www.dvddemystified.com (Accessed on May 27, 2003).

[27]A movie that the studio would release on VHS anyways, but not on DVD.

[28]To compute the per-disc cost of producing the movie on DVD, I divide $21,000 (the ballpark cost of $20,000 and the mastering cost of $1,000) by sales unit of 487,052. Then

$0.95 per player if the new DVD releases increase by 1 unit, manufacturers could compensate the studio for the cost of producing the additional DVD title, and share the remaining per DVD player profits of $0.16 with the studio. This implies that the profits of the movie studios and of DVD player manufacturers in aggregate could increase by $78,000 during May 2001, while keeping consumer surplus at the same level. The same strategy could of course be repeated for additional movie titles.

7 Conclusion

In this paper, I first analyze a model of consumer adoption of DVD players and movie studios' release of movies on DVD discs, and determine the factors that influence these processes. Next, I examine the impact of various marketing strategies on DVD player adoption, and on the release of new DVD movies. I also discuss strategic implications for DVD player manufacturers, and for the movie studios in designing co-marketing strategies through which they could align their incentives.

To estimate the parameters of the hardware adoption model, I use a household level panel data set. To estimate the parameters of the DVD movie release model, I use a cross section of movies released at different time periods. My primary focus is the identification of complementarities between DVD player adoption and availability of content on DVD discs. Given the endogeneity problem, I use the approach of instrumental variables.

The results indicate that correcting the endogeneity problem reduces the size of the estimated complementarities. In terms of elasticities, a 1% increase in new DVD releases during May 2001 would increase DVD player sales by 1.5% using the uncorrected estimates, and by 0.5% using the endogeneity

I add the per-disc replication cost of $0.75.

corrected estimates.

On the software-side, for the studios which supply movies on DVD discs, a 1% increase in DVD player installed base increases the number of new DVD releases between 0.15% and 0.33%. The elasticity of new releases with respect to DVD player sales declines from 0.01 in February 2000 to 0.006 in May 2001.

Using these estimates, I find that the increase in movie studio revenues from a unit increase in DVD player sales ranges between \$10 and \$32. On the other hand, an additional movie on DVD increases the DVD player manufacturers' profits by \$127,000-\$2,000,000. These results can be used by manufacturers of DVD players, movie studios which release titles on DVD discs, or other policy makers that are interested in the diffusion of DVD technology.

As for future extensions, consumer adoption model can be expanded in many directions. Quality, wear/tear and brand effects could be included in the model. Consumer heterogeneity could be structurally modelled to help better understand the changing mix of consumers. The assumption of rational expectations could be relaxed to allow for different expectations mechanisms. The usage value from the product could be allowed to vary with which product the consumer adopts. Finally, a fully dynamic model could model consumers as forward looking agents, and take into account expectations on future prices, quality and brand availability.

Conditional on the availability of price and quantity data on various movies released on DVD discs, one could examine the supplier decision of releasing movies on DVD by using a structural model (possibly dynamic) instead of by using a reduced form profit function. Such data would also allow for modeling the consumer demand specifically for watching movies

on DVD. 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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9 Appendix

The change in expected DVD profits of movie k is given by

$$\Delta_k = \int_{\pi^0_{release}}^{\pi^f_{release}} prob_{k,release}(W_{k,release}, W_{k,don'trelease})dW \tag{16}$$

where $\pi^o_{release}$ and $\pi^f_{release}$ are the values of the profit function before and after the policy change respectively. In practice $\pi_{don'trelease}$ is normalized to zero.

For the probit specification, the probability of is given by

$$prob_{k,release}(\pi_{k,release}, \pi_{k,don'trelease}) = \Phi(\pi_{k,release} - \pi_{k,don'trelease}) \tag{17}$$

where $\Phi(.)$ is the cumulative normal distribution function. Because the integral in equation (16) does not have a closed form, it has to be simulated. In practice, for each time period t, I simulate the expected profit for a representative movie at period t before and after the policy change. Then,

$$\Delta_k = (prob^f_{k,release}\pi^f)_{simulated} - (prob^o_{k,release}\pi^o)_{simulated}$$

where the subscripts f and o denote the values after the policy change and before the policy change respectively. However, this simulated value does

not have a meaningful unit, and thus it has to be scaled to have a monetary unit. Note that the change in expected DVD profit of movie k from a policy change can also be written as

$$\Delta_k = prob^f_{k,release}(TR^f_k - TC^f_k) - prob^o_{k,release}(TR^o_k - TC^o_k)$$

where TR is the total revenue and TC is the total cost of releasing the movie on DVD. Using the industry statistics, I first estimate, for a given movie k, the dollar value of TR^o_k , given the box office revenue of the movie. Next, I construct a scaling factor

$$\varphi_k = \frac{prob^o_{k,release}(TR^o_k)}{(prob^o_{k,release}\pi^o)_{simulated}} \quad . \tag{18}$$

Then, the change in expected revenue is $\Delta_k\varphi_k$. Note that this scaling makes the strict assumption that TC^o_k and TC^f_k are proportional to TR^o_k and TR^f_k respectively with the same proportionality factor.

TABLE 1 - SUMMARY STATISTICS

Across regions	Feb-00		May-01	
	Mean	Std. Dev	Mean	Std. Dev
new DVD releases	43	0	59	0
ratio of active to non active renters (market activity index)	0.39	0.12	0.67	0.062
DVD content availability measure (market activity index*new DVD releases)	17	5.3	39.59	3.67
mean DVD movie rentals per owner	1.04	0.35	2.06	0.2
mean DVD movie purchases per owner	1.28	0.35	1.8	0.49

	Market Activity Index For Different Regions	
Designated Market Area (matched to Census Metropolitan Area)	Feb-00	May-01
New York, New Jersey, Long Island	0.39	0.56
Pittsburgh	0.25	0.55
Athens, Atlanta	0.31	0.47
Los Angeles, Riverside, Orange County	0.42	0.72
San Francisco, Oakland, San Jose	0.31	0.72
Chicago, Gary, Kenosha	0.42	0.63
Boston, Worcester, Lawrence	0.44	0.67

TABLE 2 - HARDWARE-SIDE ESTIMATION

(A)
FIRST STEP

Regressors	Dependent Variable: adopt/ don't adopt
	probit
interaction of region & time dummy variables (fixed effects)	yes
number of adults	0.08** (0.01)
number of teens	0.016 (0.013)
age	-0.013** (0.0009)
own house	-0.066** (0.024)
full time work	0.1** (0.022)
high income	0.26** (0.037)
own camcorder	0.15** (0.021)
subscribe to digital cable	0.14** (0.03)
own pc	0.23** (0.03)
own digital camera	0.2** (0.026)
at least college degree	0.016 (0.022)
mid-level income	0.12** (0.036)
log likelihood	-8313.8
number of obs.	142342

Notes
1. Standard errors are corrected for household group effect.
2. ** : significant at 5%

(B)
SECOND STEP

Regressors	Dependent Variable: Fixed Effects from the First Step (1) OLS	(2) 2SLS
DVD content availability	0.02** (0.0019)	0.01** (0.0045)
DVD player price difference	-0.009** (0.0009)	-0.008** (0.001)
region dummy variables	yes	yes
quarterly dummy variables	yes	yes
number of obs	352	352
first stage R-squared		0.57

Notes
1. Robust standard errors are reported. Standard errors are also corrected for covariance among the dependent variable, fixed effects, and for the two stage IV estimation.

TABLE 3 - FIRST STAGE REGRESSION

Regressors	Dependent Variable DVD content availability
new VHS releases	0.31** (0.06)
mean age	3.49** (0.5)
mean college and higher	-36.9** (18.4)
price difference	0.04 (0.03)
region dummy variables	yes
quarterly dummy variables	yes
number of obs.	352
R-squared	0.57

TABLE 4 - ALTERNATIVE SETS OF INSTRUMENTAL VARIABLES

instrumental variables	Set 1 **(currently used)**	Set 2	Set 3	Set 4	Set 5
1. new VHS releases	**yes**	yes	yes	yes	yes
2. mean age	**yes**	yes	yes	-	-
3. mean college and higher	**yes**	-	yes	-	-
4. mean adults	**-**	yes	yes	-	-
5. interaction of 1 & 2	**-**	-	-	yes	yes
6. interaction of 1 & 3	**-**	-	-	yes	yes
7. interaction of 1 & 4	**-**	-	-	-	yes
8.price difference, region & quarterly dummy variables	**yes**	yes	yes	yes	yes
First Stage F-test :					
Ho: coefs. on IVs are jointly zero	**F(3,320)=19**	F(3,320)=24	F(4,319)=18	F(3,320)=20	F(4,319)=18
p-value	**0**	0	0	0	0
First Stage R-squared	**0.57**	0.58	0.58	0.56	0.58
Second Stage Results					
coefficient of DVD content availability	**0.01****	0.0098**	0.0011**	0.0096**	0.0092**
	(0.0045)	(0.0046)	(0.004)	(0.0049)	(0.0046)
coefficient on price difference	**-0.008****	-0.008**	-0.008**	-0.008**	-0.008**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)

TABLE 5 - SOFTWARE-SIDE ESTIMATION

FIRST STEP

(A)

Regressors	Dependent Variable: release on DVD DVD or not
	probit
interaction of rating and time dummy variables (fixed effects)	yes
domestic box office revenue	0.0088** (0.0025)
studio dummy variables	yes
log likelihood	-482.11
number of observations	995

Notes
1. ** : significant at 5%

SECOND STEP

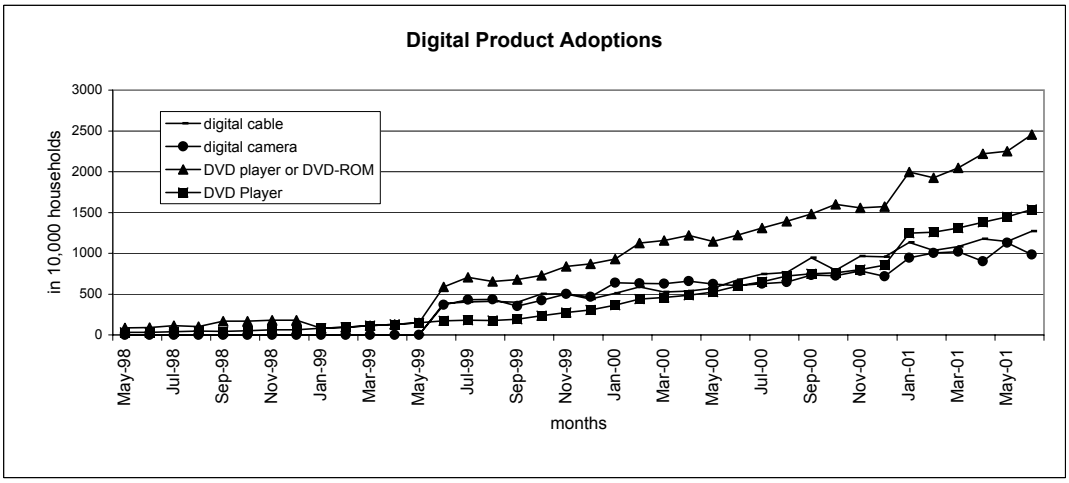
(B)

Specification 1 (DVD Installed base varies by time)

Regressors	Dependent Variable: Fixed Effects from First Step (1) OLS	(2) 2SLS
DVD Player Installed Base (1 m. hh.)	0.075** (0.018)	0.066** (0.018)
R-rating	0.9** (0.26)	0.91** (0.26)
G-rating	0.3 (0.3)	0.29 (0.29)
PG13-rating	1.01** (0.29)	1.02** (0.28)
Non-rated	0.1 (0.27)	0.11 (0.27)
quarterly dummy variables	yes	yes
number of obs.	59	59
first stage t-stat for digital camera installed base		20.70
first stage R-squared		0.91

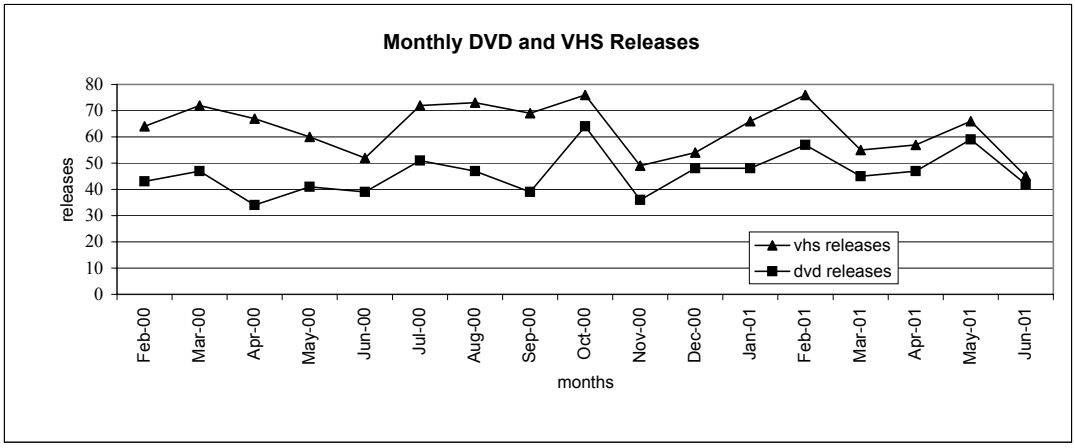
Notes
1. Rating dummy for PG-rating is dropped.
2. Robust standard errors are reported. They are also corrected for the covariance among the dependent variable, fixed effects, and for the two stage IV estimation.

FIGURE 1



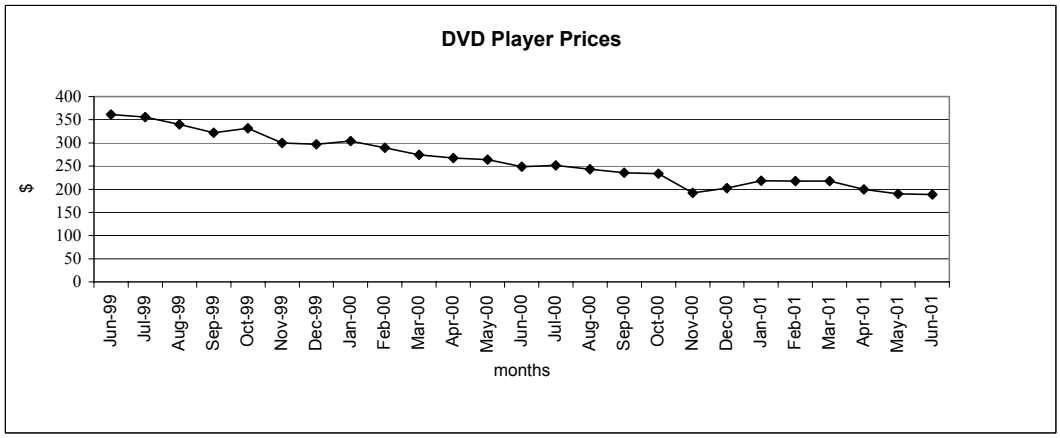
Source: CENTRIS surveys

FIGURE 2

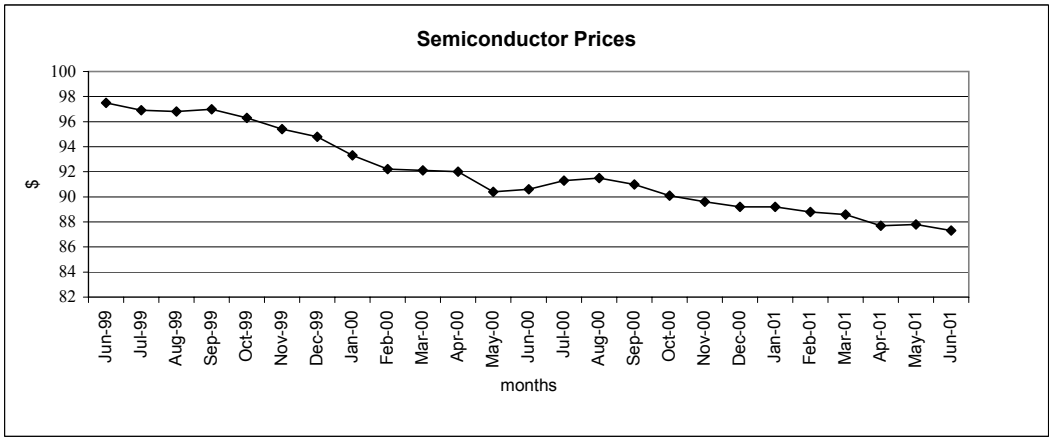


Source : Video Retailer Magazine

FIGURE 3



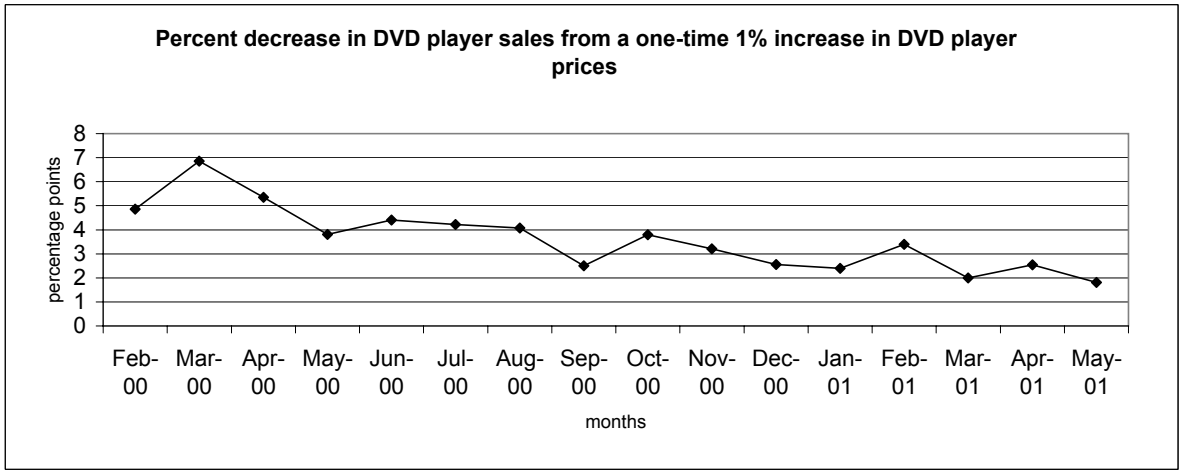
Source : NPD Intelect



Source :Bureau of Labor Statistics

FIGURE 4: HARDWARE-SIDE ELASTICITIES

(A)



(B)

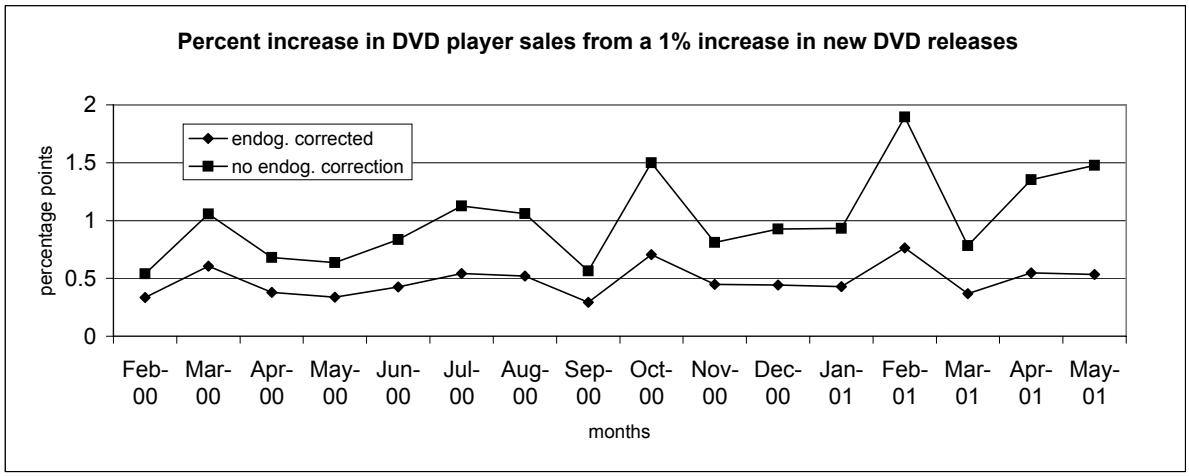
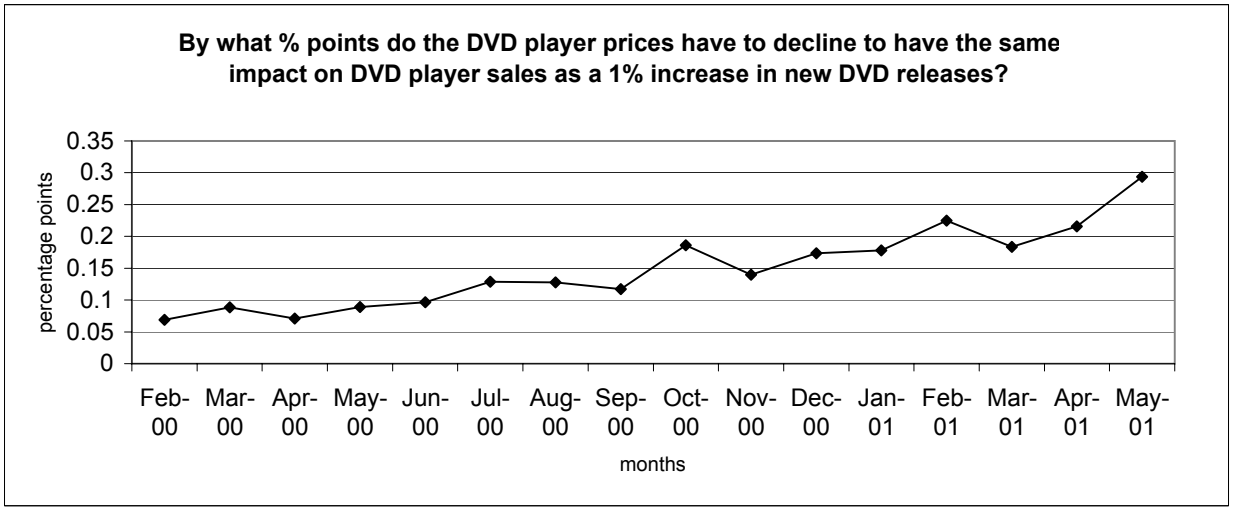


FIGURE 5: HARDWARE-SIDE RELATIVE EFFECTS OF PRICE VS. COMPLEMENTARITY

(A)



(B)

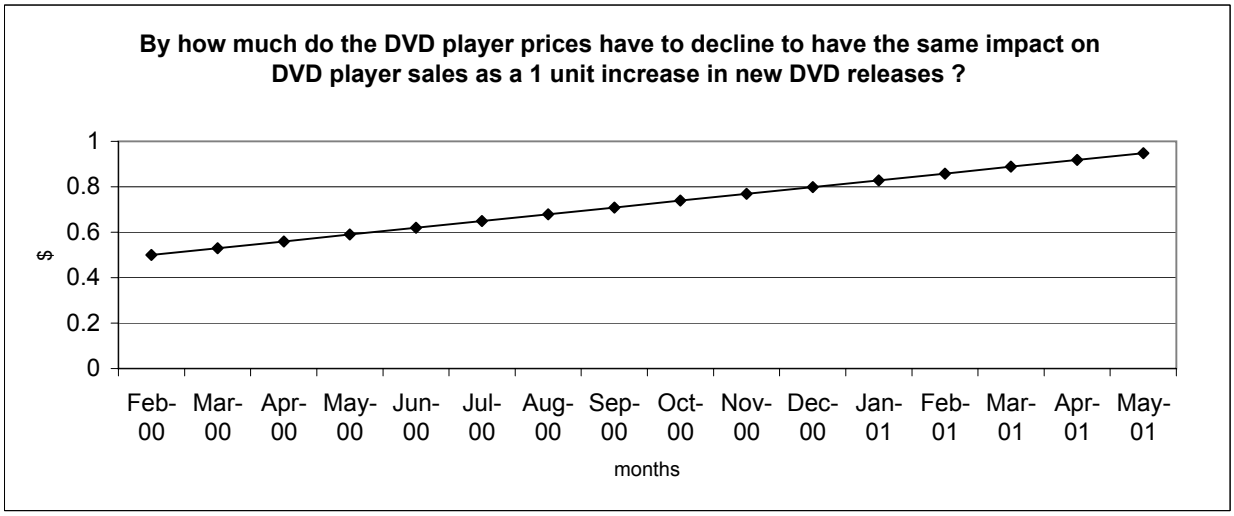
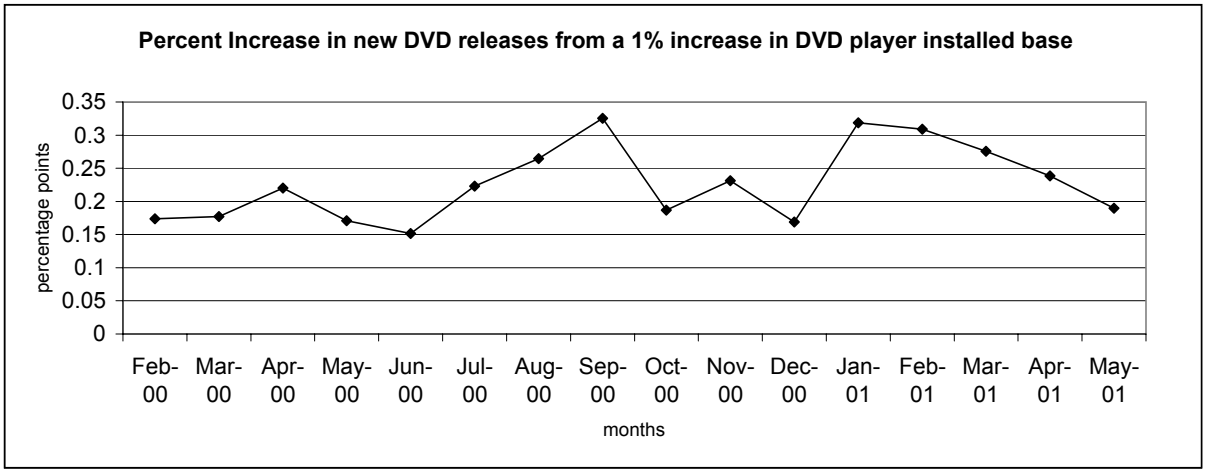
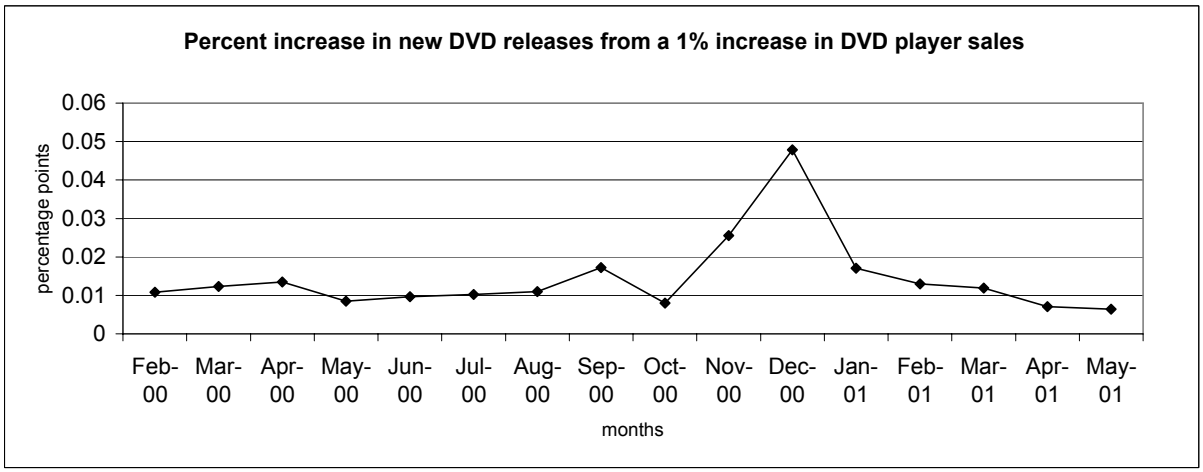


FIGURE 6 : SOFTWARE-SIDE

(A)



(B)



(C)

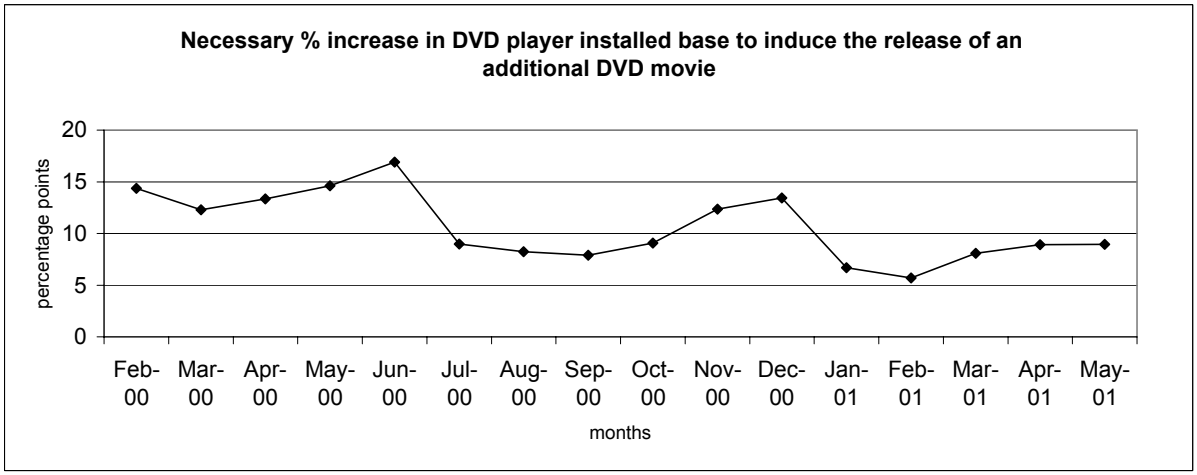
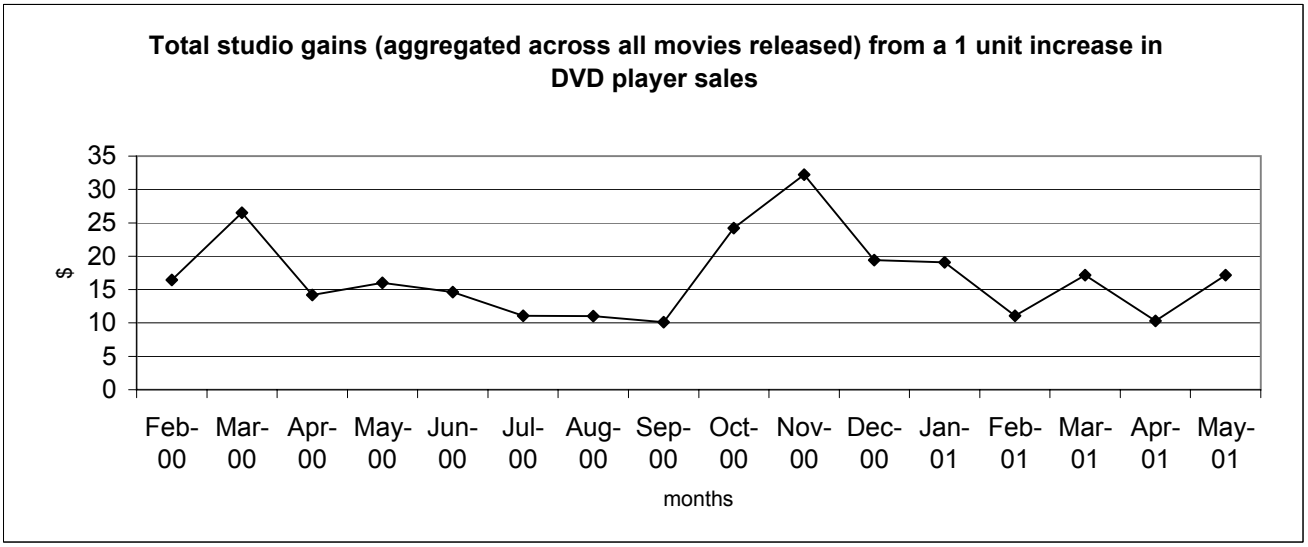


FIGURE 7 : SOFTWARE AND HARDWARE GAINS

(A)



(B)