Diffusion of a New Product under Network Effects:
The U.S. DVD Market

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Abstract

We formulate a model that captures the inter-dependence between hardware demand and software supply – indirect network effect - in the DVD industry. The identification of the network effect comes from the difference in software availability across two different formats: VHS and DVD. We find that a 1% increase in the number of DVD titles raises the demand for DVD players by 0.87%. Simultaneously, a 1% increase in video player ownership leads to a 0.16% increase in the variety of video titles. Our simulations show that hardware manufacturers might be able to internalize the network externality to increase total industry revenues.

JEL classification: L1, C10

Keywords: Network effects; DVD; Discrete Choice Models

1 Introduction

Network effects arise when the utility derived from the consumption of a good depends on the number of people using it. Most common examples are phone lines and fax machines. A phone line is of no use unless others are also connected to the network. Indirect network effects arise when the benefit of using a product is increasing in the use of a complementary set of goods. Typical examples of products exhibiting indirect network effects are computers (complementary with software applications) and CD-players (complementary with CD's).

In the last few years, the Industrial Organization literature has increasingly explored indirect network effects. The theory of network effects has wide applicability. Indeed, it is of fundamental importance for competition and regulation policies, business strategies, intellectual property rights, and technical change in a wide range of industries; from hi-tech ones such as IT industries (Gandal 1994) to traditional ones such as the yellow pages industry (Rysman 2004). Developments in these industries cannot be fully analyzed without an understanding of the network effects. Equally important is the fact that indirect network effects, under very general conditions, will give rise to network externalities (Church, Gandal, and Krause 2002).[1] The externality occurs when the private benefit of the marginal hardware purchaser is less than the social benefit. The marginal hardware purchaser does not internalize the welfare improving response of the software industry, where an increase in software variety will benefit the inframarginal users.

Indirect network externalities create a two-way contingency between the hardware demand and the software supply. In this paper we develop a model that captures the interdependence between hardware demand and software supply in a differentiated goods market. Specifically, we apply this model to the U.S. Digital Video Disc (DVD) player market using price and sales data on DVD players and DVD titles. We assume that the utility a consumer receives from owning a DVD player increases in the number of movie titles that are available in the DVD format. In return, an increase in the number of DVD players leads to a greater demand for movies on DVD, thus completing the cycle. The conditions under which an indirect network effect leads to a network externality are arguably satisfied in this case.[2] We use data on hardware sales and software availability to

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[1] Church, Gandal, and Krause (2002) show that indirect network effects lead to externatility when there are 1) increasing returns to scale in the production of software; 2) free entry into software market; 3) consumer preferences for the variety, not just the number, of software.

[2] Production of software involves very high fixed costs and a constant (and very low) marginal cost; thus increasing

measure the size of the network effect in the DVD player market. The data set used in this study is unique; we have close to complete coverage of the hardware market with detailed information on each separate product.[3] Additionally, we observe all movies released on DVD along with their features. This extra information proves to be essential for obtaining an unbiased estimate of the network effect.

Since hardware prices decline and software availability increases steadily over time, it is difficult to identify the effect of increased software availability on hardware adoption using time series data alone. The main source of the identification of the network effect comes from the differences in the availability of new titles on two different formats: VHS and DVD. Until very recently the number of new titles released was greater for the VHS format than for DVD.[4] Differences in software availability and the resulting differences in adoption rates allow us to estimate the network effect.

The ability to measure network effects is crucial to firms competing in these industries. It is also important from a social welfare point of view. Under certain conditions, the good or service exhibiting network effects will be under-provided or under-consumed, leading to market inefficiency. In the context of inter-dependence, integration of hardware and software industries, or price coordination among hardware firms could be socially desirable if the integrated body is able to internalize the network externality. In order to be able to analyze all these issues we construct a discrete choice model of a differentiated products market, with an explicit structure of hardware demand and software supply. The demand for a DVD player is a function of player price and characteristics and of DVD title availability. Supply of software depends on the hardware installed base and characteristics of movies.

Our results point to the existence of considerable network effects in the DVD market. A 1% increase in the number of DVD titles raises the demand for DVD players by 0.87%. On the other hand, a 1% increase in hardware installed base leads to a 0.16% increase in the number of titles released on DVD. Using our parameter estimates, we simulate the impact of cooperation among DVD player manufacturers aimed at internalizing the network externality. Our simulations provide

returns to scale in software production is to be expected. It is also safe to assume that consumer tastes for movies are heterogenous. As for free entry into the movie production industry, many books and articles have been describing how small companies could succesfully enter the movie production market. See, for example, Vogel(1998).

[3]Our data covers more than 80% of total retail sales of DVD player in the U.S. See section 3.1.

[4]By 'titles' we mean movies produced for theatrical and/or home-video screening. Today, all new movies that appear in the video rental market are released in both formats. But since VHS is a much older product, the accumulated number of VHS titles surpasses that of DVD titles by far.

mixed results. A price cut by a single manufacturer increases total industry revenues whereas an overall reduction in prices leads to a fall in industry revenues. These findings suggest that an integrated body of hardware manufacturers might not be able to exploit the network effect in order to raise their current and future gains.

The endogeneity of software availability complicates the estimation of hardware demand. Any unobserved factor that makes DVD a more popular product will lead to greater hardware sales and increased software availability. To correct this endogeneity problem we use an instrumental-variables approach. Instruments that are not correlated with hardware demand but are correlated with software supply are needed. We believe that the characteristics of titles that are released at the box office and on VHS make good instruments.

The next section reviews the related literature. Section 3 outlines the evolution of the DVD format and describes the hardware and software sides of the market. The data used in this study is also summarized in section 3. In section 4, we outline the estimation methodology and address some econometric issues. Section 5 provides the estimation results. We then experiment with a counterfactual exercise to predict the potential value of consolidation to hardware firms. The last section concludes our findings.

2   Related Literature

Starting in the 1980's, a small group of economists began to show interest in markets with network externalities. Initially, the focus of these mostly theoretical studies was on direct network externalities. Katz and Shapiro (1985) develop an oligopoly model to analyze a market with network effects. Farrel and Saloner (1985) focus on the role of firms as these decide sequentially whether to adopt a new technology (network). In the early nineties Chou and Shy (1990) and Church and Gandal (1992) extended the analysis to markets of complementary products.

Empirical studies on the subject started to appear since the mid 90's. A few of these have investigated the existence of direct network effects (Gandal (1994), Gowrisankaran and Stavins (2002), Damar (2006) among others). Gandal, Kende, and Rob (2000) is the first to investigate empirically the complementaries between hardware and software products. They use aggregate level data in the estimation of a dynamic model of the CD player industry. Similarly, Karaca-Mandic

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(2003) uses household level data on DVD player ownership to identify indirect network effects in the DVD market. Her model takes into account the fact that consumers are forward looking and may opt to delay their purchasing decisions in order to benefit from lower future prices and increased software availability. However, she makes the assumption that all DVD players are identical and hence consumers only decide when to buy a player.

Some of the previous studies deal with network effects by using models which allow for differentiated products. Ohashi (2003) and Park (2004) contruct a discrete choice model for differentiated products and estimate the size of network effects in the U.S. VCR market. But their analyses both suffer from the lack of information on software availability which is instead approximated by the lagged installed base of VCR's. Nair, Chintagunta, and Dube (2004) analyze the market for Personal Digital Assistants (PDA) and show the existence of strong network effects. Although the methodology of their paper is similar to ours, the validity of using hardware characteristics as instruments for the software variety is questionable. We believe that we construct better instruments thanks to the availability of detailed data on our software variables.

Our paper is similar to all of these in that it tries to identify network effects in a new consumer electronics industry based on static, differentiated products model. Static models have well-known limitations in estimating demand for durable goods. The problem might be even more severe in the analysis of a newly introduced product like the DVD. Despite this fact, there has been only a few attempts (see Melnikov (2001)) that incorporate dynamic demand into a discrete choice model. To our knowledge there has been no success in estimating demand and supply simultaneously in a dynamic model. Some of previous studies on durable good markets sacrifice dynamics to take into account differentiated products and incomplete competition (e.g. Berry, Levinsohn, and Pakes(1995)). While adopting a static discrete choice model of demand, our paper is superior as it uses a more convincing identification strategy (we have a more elaborate description of the software side with full information on software availability, including the characteristics). We follow Gandal, Kende and Rob (2000) in exploiting exogenous variation in the complementary market to form instruments for the network effect. We differ from them in that we have more detailed data on sales of individual models, which allows us to apply the identification strategy to an oligopoly model.

3 The U.S. DVD Industry

3.1 Hardware

In April 1997, the Digital Versatile Disc (DVD) was introduced by a consortium of hardware makers and motion picture studios as an affordable, yet markedly superior, replacement for videotapes. At the time of the introduction of the first DVD player, there were only 40 movie titles available as studios were reluctant to enter the market. Early sales of DVD players exceeded expectations and, after a brief standards war that resulted in the clear victory of the DVD, sales reached unprecedented levels. As a result, the DVD player became the fastest growing electronics product. In 2001, monthly shipments of DVD players surpassed those of videocassette recorders (VCRs). In 2007, 21 million DVD players were shipped to dealers across the U.S. Today, DVD players outsell VCR's 40 to 1. Figures 1 and 2 depict the evolution of sales and prices for the two formats between 1997 and 2004.

The radical expansion of the format was partly stimulated by a continuous decline in hardware prices. The average price of a DVD player fell from \$491 in 1997 to \$118 in 2003[5]. Strikingly, during this period the average quality steadily increased as hardware manufacturers added new features to their products. The fall in prices is, in part, due to the entry of a significant number of low-cost manufacturers such as Apex Digital Inc. which, established by the end of 1999, possesses the largest market share in units sold today. The number of manufacturers increased from 16 in 1997 to 51 in 2003.

3.2 Software

The first feature films on DVD appeared in Japan in December 1996 (*The Assassin, Blade Runner, Eraser*, and *The Fugitive* from Warner Home Video).[6] In the U.S. Warner Brothers US launched DVD titles on March 24, 1997, but the launch was limited to seven cities. Nevertheless, almost 19,000 discs were purchased in the first two weeks of the U.S. launch, a number much greater than that expected by the studio. By December 1997, over 1 million DVD discs were shipped while the number of titles climbed up to 530. Today, all movies that appear in theaters are released on

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[5]In 2007, the average price of a DVD player was \$72 (*Entertainment Industry Market Statistics*, 2007).

[6]The chronology of the DVD industry, especially the software side history, is taken from Taylor (2000). Also see the webpage version (www.dvddemystified.com/dvdfaq.html) for comprehensive information on the DVD format.

DVD as well as on VHS. By the end of 2002 there were about 23,000 titles available in the U.S. Due to the late response from the video rental market – it was September, 1999 when Blockbuster began DVD rentals in 500 stores – growth of DVD rentals was slower compared to the growth of sell-through sales. However, the rental market transited quickly to the DVD, and DVD rentals outpaced videocassette rentals by June 2003.[7] By 2007, videocassette rentals were reduced to almost zero. Figure 3 depicts the number of available titles for both formats between 1997 ad 2004.

3.3 Data

3.3.1 Hardware Data

The structural estimation of the model necessitates the use of product level sales and price data, and information on the characteristics of DVD players. Our data source comes from point-of sale scanner data through retail channels which cover more than 80% of total sales in the U.S. This unusually rich data set covers the time span from the introduction of the format in April 1997 until August 2003. From this data set we generated aggregate price and sales series for DVD players, as well as product level variables. The characteristics data were manually collected from public sources such as retailers' websites. Summary statistics and the descriptions of the characteristics can be found in table A.1 in the appendix.

We obtained total weekly sales of VCR decks from various trade magazines. We have only annual average prices of VCRs. Since the VCR market is saturated, we interpolated monthly prices, assuming that prices change at a constant rate over time.

3.3.2 Titles Data

We employ two different data sets on software availability. The DVD titles data are obtained from the DVD Entertainment Group (DEG). The data set includes all DVD titles including music videos. It has detailed information on features such as release date, genre, and MPAA rating. In our data period, on average about 60 new titles were released per month. The data are available on the DEG website.[8]

We obtained monthly data on VHS titles from the Video Software Dealers Association (VSDA).

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[7] *The Washington Times*, June 21, 2003

[8] http://www.dvdinformation.com/titles/index.html

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VSDA has the archives of VHS titles that are released since September 1998. The number of VHS titles at the time of the introduction of the DVD format (April 1997) is not available, but as of October 2003 one can search from 33,000 titles on retailers such as Amazon.com. According to the VSDA data, on average, about 60 new VHS titles come out per month. Relying on the fact that VHS was a mature and established format by 1997 we linearly extrapolated VHS title data from April 1997 to September 1998. Original data from VSDA are used for the remainder of the data range.

Our main software variety variable (MOVIES) includes only theatrical movies which are produced since 1996 and released in home video. This variable is our measure of software availability. The titles are comparable across the VHS and the DVD formats and there is complete information on their attributes. We do not observe rental or sales prices of DVD titles but this should not pose a problem since both rental and sales prices of DVD's have remained relatively steady. Changes in DVD prices cannot explain fluctuations in DVD player sales.

4   Identification of the network effects

4.1   Hardware Demand: Nested Logit Model

The simplest structure in which we can possibly describe the decision process of a consumer and identify the network effects is one that presents a choice between a VCR, a DVD player, and the no-purchase outside option in an upper nest and the choice of individual products in a lower nest. According to this nest structure, consumers first choose between buying a VCR, a DVD player, or no video product at all. If they choose to buy a DVD player, then they decide on a specific model in the lower nest. Note that over 90% of households had a VCR at the outset of DVD launch, and therefore most of VCR purchase must have been for replacement. However, the fact that the outside option includes a choice to keep and enjoy the old VCR machine would not cause a serious problem to the estimation strategy because the value of the outside option is normalized and the utilities from the other options are measured in relative terms.[9]

The necessary variation for the identification of the network effect is observed in the upper nest. We expect DVD player sales to grow relatively fast as the number of DVD titles increases. The

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[9]Note that consumer choice is not an ownership decision ("what to use") but a purchasing decision ("what to buy").

parameters on the characteristics of DVD players are identified in the lower nest. Owing to the absence of product level data, we have to make a homogeneous good assumption for VCR's. In the year 2000, a new product, the DVD-VCR combo player, has been introduced into the consumer electronics market. The combo player has two different decks which can respectively play DVD and VHS titles. The fact that the utility from a combo player depends on both the stock of VHS and DVD titles gives rise to a subtle problem in the identification of network effects. Therefore, we omit DVD-VCR combos from our sample.

The utility a representative consumer receives from purchasing a VCR or a DVD player is

$$U_{ijft} = X_{jt}\beta + \gamma P_{jt} + \eta f(N_{ft}) + \xi_{jt} + \xi_{ft} + \zeta_{ift} + \varepsilon_{ijt} \tag{1}$$

where the subscript $f \in (d,v,o)$ stands for the two video formats and the outside option, j for the jth product (let $j = 0$ for the outside option and $j = 1$ for VCR), and t for the time period. A consumer gets utility from product specific characteristics X_{jt} and (negatively) from the price of the product P_{jt}. A video player, however, does not give any utility without titles that it can play. Therefore utility also depends on a function of the number of titles in each format f, at time t, $f(N_{ft})$. Econometricians often do not observe all product attributes that consumers care about, and to this end include error terms to capture their effect on utility. The first two of these terms, ξ_{jt} and ξ_{ft} are unidimensional unobserved characteristics that represent the mean utility from a product and from a format, respectively. The latter two are idiosyncratic error terms. Heterogeneity of preference on a format is captured by ζ_{ift}. Similarly, the last term ε_{ijt} represents the deviation from the mean of a consumer's preference for a product. To complete the nested logit structure we assume that $(\zeta_{ift} + \varepsilon_{ijt})$ has a type I Extreme Value distribution with scale parameter σ. Under this formulation the probability of choosing one model takes the well-known logit form.

We acknowledge the possible endogeneity of $f(N_{ft})$ resulting from the two-way interaction between hardware and software (formally $E(\xi_{ift}|N_{ft}) \neq 0$). There might be unobserved attributes of format f such as an unobserved taste for the specific technology, which are correlated with the software availability variable. There is also reason to believe that P_{jt} might be endogenous. A product with superior unobserved features, ξ_{jt}, is more likely to have a higher price and provide a higher utility at the same time. This correlation between unobserved product attributes and price

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leads to an upward bias of the price coefficient. The within-nest share may be endogenous for the same reason.

To take into account the possible endogeneity of prices and the number of titles, we transform market shares into a linear combination of observed variables and unobserved variables following Berry (1994). By normalizing the utility from the outside option to be $U_{i0t} = \zeta_{i0t} + \varepsilon_{i0t} = 0$, we get

$$\ln s_{jt} - \ln s_{0t} = X_{jt}\beta + \gamma P_{jt} + \eta_1 f(N_{ft}) + (1 - \sigma) \ln s_{jft|B_f} + \xi_{jt} + \xi_{ft} \tag{2}$$

where $s_{jft|B_f}$ is the within group market share of product j that belongs to set B_f. We estimate the equation (2) by OLS and Instrumental Variable (IV) method to get the parameters of utility function.

4.2 Software Provision: Aggregate Level Estimation

A reduced-form equation is used to estimate the magnitude of the network effects in the other direction: the impact of the change in the installed base of players on the variety of titles.[10] Specifically, the estimation equation for aggregate software is

$$\ln N_t = \alpha + \eta_2 \ln \sum_{\tau=1}^{t} S_\tau + v_t \tag{3}$$

where the unit of time is a month, N_t is the total number of DVD title releases as defined above and S_τ is the monthly sales of DVD players. The sum of the monthly sales, $\sum_{\tau=1}^{t} S_\tau$ is the cumulative player sales or the installed base of DVD players. Note that price is missing in the software supply equation because we don't observe prices (rental or sales) of titles. We rationalize this specification by assuming that the price-cost margin remains constant across titles and time.

Our first concern is on the stationarity of our aggregate variables. Equation (3) is potentially a spurious regression equation, if the dependent and independent variables have common upward trends or unit root. In that case, we are very likely to find a significant coefficient for $\ln \sum_{\tau=1}^{t} S_\tau$, even if there is no actual relationship. In this respect, aggregate variables in the model (3) are tested for stationarity and the null hypothesis of non-stationarity is rejected.

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[10]Nair, Chintagunta, and Dubé(2004) derive a similar equation by solving for a symmetric price equilibrium under a zero profit condition.

The second concern is on the possible serial correlation of the independent variables with the error term. As Gandal, Kende and Rob(2000) suggest, we include lagged dependent variables in the regression equation to deal with this problem. An additional advantage of having lagged dependent variables is that they help us capture "direct effects" or "knowledge spillover" by controlling for previous periods' volume of sales.

4.3   Instruments

If one is only interested in parameters β and γ, $(\eta_1 f(N_{ft}) + \xi_{ft})$ together can be treated as a group fixed effect that can be eliminated. However, since our main interest is to estimate η, this approach cannot be taken and therefore we need to instrument for N_{ft}. As instruments, we use the characteristics of theatrical and VHS movies which are ready to be released on DVD. We believe that there is a relationship between certain characteristics of movies and the probability they will be released on DVD. For instance, action/adventure movies and blockbuster movies are more likely to be released on DVD, probably because DVD's contain special features such as 'behind the scenes', interactive games, and bonus cuts, which are valued more by fans of these types of movies. If indeed there exists a relationship, then we can use, for example, the ratio of action movies among all DVD candidate movies as an instrument for software availability. The decision to make a certain movie is usually made with a focus on theatrical revenue and long before video release, and therefore should not depend on the demand for DVD players.

We have run a probit regression to see if certain characteristics of movies are indeed related to the probability of DVD release. The results of this estimation verify that there is in fact a relationship between some movie characteristics and the likelihood of a DVD release. First, high budget movies are more likely to be released on DVD. The budget of a movie instead of box office score is used as a proxy for being a blockbuster movie since the box office score occasionally includes revenues from video sales and hence is clearly correlated with the error term. Second, we observe that some genres are favored by studios. Action/Adventure movies are more likely to be released on DVD whereas horror and thriller movies seem to have a lower demand as DVD titles.[11]

Valid instruments for prices are functions of the characteristics of other products since the hardware attributes are assumed to be exogenous and the existence of similar products likely keeps

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[11]The results of the probit estimation are available from the authors upon request.

the price down. The sums of the characteristics of all DVD player models and the number of models are chosen as instruments for the within-nest share.[12]

There also might be the possible endogeneity of $\sum_{\tau=1}^{t} S_\tau$ in the aggregate level estimation (3) since the variety of software and the sales of hardware are simultaneously determined. We use the sum of hardware characteristics as an instrument for the installed base in the software supply equation.

5 Results and Implications

5.1 DVD Player Demand

The results from the estimation of the product level nested logit model, which is given by equation (2), are presented below in table 5.1. The number of U.S. households is chosen as the size of the potential market for DVD players and VCRs. The market size in the first period, M_0, is set at 100 million. Consumers are assumed to exit the market once they buy a VCR or a DVD player. Thus, the market size at period t is $M_t = M_0 - \sum_{\tau=1}^{t} [Sales_t(VCR) + Sales_t(DVD)]$. This assumption of market exit captures some dynamic aspects of the problem. Under the assumption, consumers who choose not to buy a new video product become potential buyers in the next period. Hence, we can treat their behavior of no purchase as of waiting.

The first column reports the results from the base OLS estimation of equation (2). Most of the coefficients have the expected signs. Greater variety of titles has a positive effect on consumer utility and hence on hardware demand. The OLS regression results suggest that a 1% increase in the number of movies released on DVD raises the market share of a DVD player model relative to no-purchase option by 1.23%. We include dummies for the months of November and December in order to capture the "Christmas effect" - the seasonality that is observed from the data as shown in Figure 1. The positive and highly significant seasonal dummy variable (SEASON) suggests a strong Christmas effect. The large coefficient on the within-nest share (WITHIN) tells us that nesting products into categories of VCR and DVD is indeed meaningful. A DVD player model is closer substitute for other DVD player models than a VCR. The coefficients on video (component)

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[12]We believe that changes in hardware characteristics are technology (and cost) driven. Therefore they should better reflect differences in DVD player prices than changes in DVD popularity.

and audio outputs (optical, coaxial) are not significantly different from zero. Also coefficients on digital audio decoders (dolby-digital and DTS) are either negative or insignificant. The results may suggest that consumers do not give much value to those features when they choose a DVD player either because they are not informed about these attributes, or because those attributes do not increase quality significantly.

The results from the IV regressions are reported in the last two columns. Initially, only hardware characteristics are used as instruments. The results indicate that the OLS estimates for price, software variety, and the within-group share are upward biased. After applying the instruments, the coefficients become smaller in magnitude but the signs do not change. When we included software side instrumental variables (such as the cumulative number of movies in each genre and rating), we estimated even smaller but still significant coefficients. The effect of software availability on hardware demand is 0.87 and is still significantly different from zero.

The results of the first-stage regressions indicate that the instruments are highly correlated with the endogenous variables. Furthermore, a Hausman exogeneity test rejects the null hypothesis that the differences between the OLS and IV estimates are non-significant[13].

In the above regressions we use a logarithmic software benefit function, $\log(N_t)$. We also experimented with alternative software availability variables and different functional specifications. One noteworthy result is that with a quadratic specification for DVD movie titles,.while we continue to find a positive impact of variety on consumer utility we also observe that the marginal effect of an increase in titles diminishes.[14]

One can use the estimated coefficients to calculate own and cross-price elasticities for individual models. Table 5.2 presents the own and cross-price elasticities for two popular models of two of the leading DVD player brands (Sony and Panasonic) and the generic VCR model. We use the demand estimates and the mean values of the price and quantity variables to calculate the elasticities. Not surprisingly, the generic VCR model has a lower own price elasticity than both DVD player models. The main reason for a consumer to choose a VCR rather than a DVD player should be the much greater availability of titles for this format. Only 7% of the models in our dataset turn out to have lower own price elasticities than the VCR.

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[13]Results of the first-stage regressions are available upon request from the authors.

[14]Ohashi (2003) estimates network effects in the U.S. VCR market. His point estimates range from 0.63 to 1.45. Nair et. al. (2004) estimate network effects in the U.S. PDA market. Their point estimates range from 0.90 to 1.08. It is safe to conclude that our results are in line with theirs.

5.2 Software Supply

Table 5.3 shows the estimation results from the software supply equation. The first column corresponds to the OLS regression with the installed base as an explanatory variable. The coefficients on the installed base show yet another direction of the network effect. Averages of several hardware characteristics are used as instruments for player sales in the IV regressions and the results are shown in the second column. Instrumenting lowers the magnitude of the coefficients since it removes the upward bias in the estimates. As player sales increase by 1%, about 0.14% more titles are provided. For all specifications the reported standard errors are robust to unknown serial correlation of the errors.[15] The Durbin-Watson test statistic for autocorrelation after including AR(1) term are all within a band where we can say that there is no serious autocorrelation of errors.

5.3 The Role of Network Effects on the diffusion of DVD

Using equation (2), we can decompose the difference between the (log) share of total DVD sales and that of VCR's into two factors: the difference in the variety of software titles, and the differences in hardware attributes.

$$\ln s_d - \ln s_v = (1 - \sigma) \left[\ln \sum_{j \in d} e^{\delta_j/\sigma} - \ln \sum_{j \in v} e^{\delta_j/\sigma} \right] + \eta \left[\ln N_d - \ln N_v \right]$$

where d and v denote DVD and VCR, respectively. Based on this decomposition, the role of network effects on the diffusion of DVD can be calculated as[16]

$$\frac{\eta \left[\ln N_d - \ln N_v \right]}{\ln s_d - \ln s_v}$$

We have calculated this ratio for each month from April 1997, an introductory period for the DVD format, to December 2000. On average, during this period about 29% of the ratio of DVD player to VCR sales is explained by network effects. One can also see that the role of the network effects has been shrinking over time. This finding is consistent with the regression result that included a quadratic network effect specification and indicated a decreasing marginal effect.

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[15] We report Newey-West and Kernel-based autocorrelation consistent (AC) standard errors.
[16] See Ohashi(2003) for more about the decomposition

5.4 Simulation

As stated earlier, an integrated body of hardware firms may be able to internalize the network externality in a way a single firm can not. A single hardware producer among many will not find it profitable to lower the price of one its products in order to exploit the network effect. On the other hand, for an integrated hardware body that produces all of the models in the industry the potential gain of a price reduction might be much larger. In this section we simulate the effect of a one period change in the price of some products while holding all the other prices constant. We compute the change in revenues for the chosen products, the firm producing the products, and the whole industry.[17]

When a firm lowers the price of its product, there are two effects at play. First, some consumers who already decided to buy a DVD player switch from other models to the one with the reduced price. We call this the 'business stealing' effect. Second, some other consumers who were not going to buy any DVD player now find it optimal to buy the cheaper model. These purchases put the network effect into action. An increase in the installed base of DVD players induces studios to release more movies on DVD. As software variety expands, DVD players become more popular and sales of all models increase. We call this second effect the 'market expansion' effect. A single hardware firm does not have as much incentive to lower the price of its product because it will not be able to fully internalize this market expansion effect.

Our counterfactual experiment runs as follows: We perturb the equilibrium set of prices by lowering the prices of all DVD players of a single brand for just one period, holding all other prices constant. Using our results from sections 5.1 and 5.2, we simulate a change in software availability and the resulting increase in the demand for DVD players. Then, we investigate the change in revenue of the single firm and that of the whole industry.

Figure 4 shows the change in total industry revenue following a 10% reduction in the prices of all models of a firm[18]. The horizontal axis shows the timing of the price cut. When a firm lowers its prices at the 10th period (January 1998), then the total industry revenue would increase by \$1,268,100. Initially, revenues can shrink due to weak business stealing effects or a low price

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[17]We deliberately avoid mentioning profits since calculating the change in profits would require us to have marginal cost information.

[18]Here we chose SONY as the price cutting brand. Experimenting with other major brands did not lead to significantly different results.

elasticity of demand. Later, network effects generate increased revenues for the industry. Greater sales of players in the period with the price-cut induces more provision of DVD titles, and more DVD titles lead to increased DVD player purchases. Overall, change in industry revenue could be negative when network effects become effective too late to recoup the losses incurred in the early periods. The cyclical fluctuations in revenues are due to seasonal effects.

Looking at the simulation results one might wonder why none of the firms followed such a strategy instead of committing to the observed path. One explanation is that a firm might be afraid of initiating a price war. In our experiment we do not allow the other firms in the market to respond to the simulated price cut. In reality, a firm expects its rivals to react to a change in its policy. The results of this experiment suggest that, in theory, all firms in the industry might benefit from such a perturbation in prices under certain revenue allocation schemes.

On the other hand, consumer surplus increases as consumers enjoy increased software availability as well as the temporary drop in prices. We find that the surplus of the representative consumer rises by ¢6.4 over the whole period when the price cut occurs at the 10th period. This figure translates to approximately a \$640,000 gain for all households in the U.S.

As noted earlier, a consortium called the DVD Forum was founded to faciliate the development of a single DVD standard. This kind of a 'voluntary' standardization brings about several economic benefits including dissemination of information, reduction of unnecessary variety, and compatibility (Lecraw, 1984). Our simple experiment points towards a possible gain in efficiency resulting from price coordination. This confirms our belief that hardware firms can do better by making joint pricing decisions in order to exploit the network effects. Economists are usually skeptical about any form of integration since these lead to increased market concentration. Under network effects, however, consumers may benefit from the increased availability of software.

One should be careful in drawing any conclusion from our simulation. We assume that in our simulation, all decision variables except the prices of certain products stay constant. But in reality, a single firm's decisions affect the behavior of other firms. A change in market structure also incurs changes in firms' strategies on price, quality, and product line that would twist the final effect of a price-cut under network effects.

6   Conclusion

Indirect network effects arise when the benefit of a product is increasing in the use of a complementary set of goods. For instance, the utility one gets from owning a DVD player (hardware) increases in the number of titles that are available on DVD (software). At the same time demand for software depends on the number of users of the hardware. In this paper we estimate the complementarity between hardware and software in the U.S. DVD market using data on hardware sales and title availability.

We estimate a nested-logit model at the level of the individual product. The identification of the network effect comes from the differences in software availability between two different systems: VHS and DVD. The endogenous software availability variable is instrumented by various movie characteristics. Our results indicate that a 1% increase in software availability raises demand for hardware by 0.87%. Next, we estimate a software supply equation with the number of DVD titles as the dependent variable. The coefficient on the hardware installed base variable indicates the other direction of the network effect. As more DVD players are sold, more titles are released on DVD.

If left to itself, a market of complementary goods can end up in an inferior equilibrium where the hardware adoption rate and the software availability are lower than optimal. Our results show that network effects exist in the DVD market, leaving room for a negative externality of considerable size. Without more information on software provision costs, we cannot calculate the optimal size of the market. One thing we do is verify the value of integration to hardware firms. We simulate the effect of a price change while holding all future prices constant and compute the change in industry revenue. These figures give us an idea of how much of the potential benefits of the network effect is being missed by an oligopoly structure. According to our simulations, an increase in total industry revenue can be realized when the price cut occurs at early periods. Consumer surplus also increases as consumers enjoy increased software availability. These results indicate that price coordination among hardware firms may not only increase the total revenue of the firms in the industry but also the total gain to the society, although this conclusion should be taken carefully. At the new equilibrium with an increase in software availability, hardware firms may charge higher prices. Thus, the net change in consumer surplus cannot be determined without computing the set of new equilibrium prices.

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1 Tables

Table 5.1. Nested Logit Regression of Hardware Demand

	BASE	IV (HWchar)	IV (HW/SW char)
PRICE	-0.075(5.39)**	-0.089(1.23)	-0.299(3.23)**
$\log(N)$	1.227(18.70)**	1.107(7.02)**	0.867(6.20)**
WITHIN	0.959(134.69)**	0.798(13.40)**	0.828(18.28)**
SEASON	1.168(62.74)**	1.102(32.93)**	1.129(41.60)**
COMP	0.080(1.74)	0.048(0.83)	0.162(1.87)
OPT	-0.033(0.73)	-0.159(1.67)	-0.045(0.46)
COAX	-0.025(0.63)	-0.053(0.68)	-0.017(0.26)
DD	-0.042(1.38)	-0.074(1.86)	-0.085(1.31)
DTS	0.088(1.94)	0.003(0.04)	0.178(1.41)
CDR	0.142(2.88)**	0.151(1.73)	0.238(1.96)
MP3	0.123(5.29)**	0.266(2.67)*	0.093(0.80)
DVDR	0.028(0.96)	0.069(1.24)	0.096(1.89)
PROG	0.055(2.23)*	-0.007(0.07)	0.162(1.68)
REC	0.746(3.57)**	1.298(2.57)*	1.445(4.36)**
PORT	0.232(2.54)*	0.074(0.31)	0.710(2.28)*
MULTI	0.123(5.17)**	0.075(1.28)	0.188(2.88)**
Constant	-13.556(34.37)**	-13.672(16.36)**	-11.834(13.65)**
Observations	7392	7040	7040
R-squared	0.96	0.94	0.94

Robust t statistics clustered by brand in parentheses; * significant at 5%; ** significant at 1%

The first stage R^2 is 0.88 for the first IV regression, and 0.98 for the second.

Dependent variable is the difference between log of market share of a product j and the outside option.

Table 5.2. Own and Cross Price Elasticities of some products

	PANASONIC DVDA100	SONY DVPNC600	VCR
PANASONIC DVDA100	-0.89	0.0009	0.0028
SONY DVPNC600	0.0023	-0.51	0.0028
VCR	0.000002	0.0001	-0.26

Each entry corresponds to the percentage change in the market share of the model in the row with respect to a 1% change in the price of the model in the column.

Table 5.3. Software Supply Equation Estimation Results

	OLS	IV
Installed Base	0.142 (0.04)**	0.136 (0.03)**
$ln(DVD\ Movie)_{t-1}$	0.265 (0.12)*	0.279(0.11)*
Constant	-0.025 (0.54)	0.022 (0.35)
DW statistic	1.91	1.95
Observations	72	72
R-squared	0.52	0.52

Autocorrelation consistent standard errors are in parentheses; * significant at 5%; ** significant at 1%

Dependent variable is the log of monthly release of DVD movies.

Appendix: Additional Tables

Table A.1. Description of Product Attributes

Variable	Description	Obs	Mean	Std. Dev.
COMP	Component video output	8814	0.742	0.438
OPT	Optical digital audio output	8814	0.848	0.359
COAX	Coaxial digital audio output	8814	0.785	0.411
DD	Built-in Dolby Digital audio decoder	8742	0.300	0.458
DTS	Built-in Digital Theater Systems (DTS) decoder	8742	0.119	0.324
CDR	CD-R or/and CD-RW playable	8742	0.480	0.500
MP3	MP3 playable	8742	0.290	0.454
DVDR	DVD-R, a DVD recording format, playable	8778	0.148	0.355
PROG	Progressive scan	8778	0.209	0.406
REC	Recorder	8814	0.013	0.112
PORT	Portable	8814	0.078	0.269
MULTI	Value is 1 if player has multiple disc changer.	8814	0.213	0.409

Note: All variables take the value of 1 if a player has that feature and 0 otherwise.
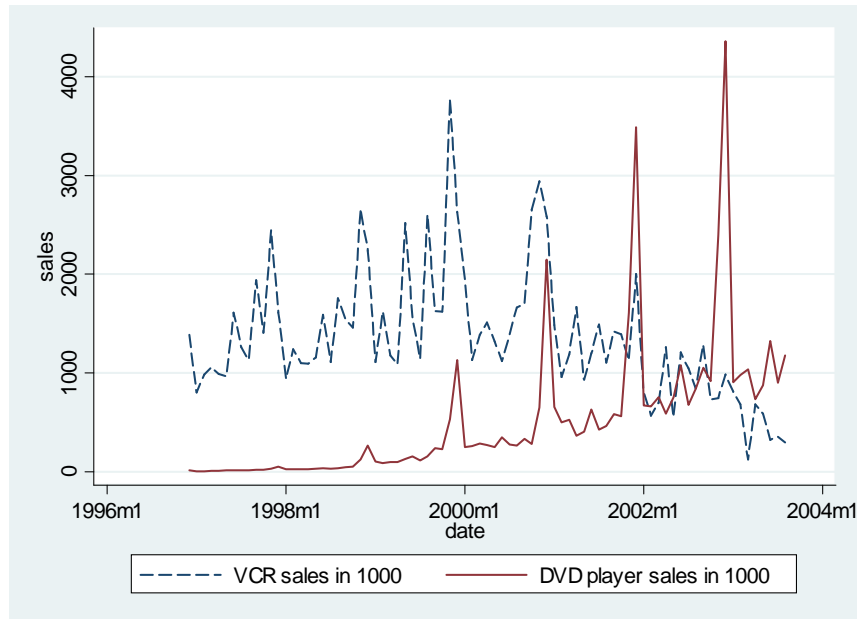
2 Figures
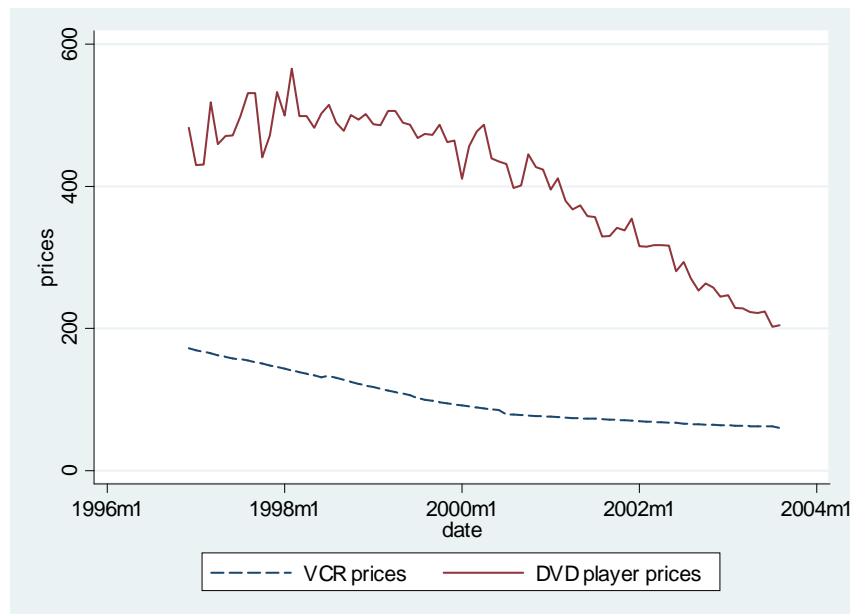

Figure 1: Monthly sales of DVD players and VCR's

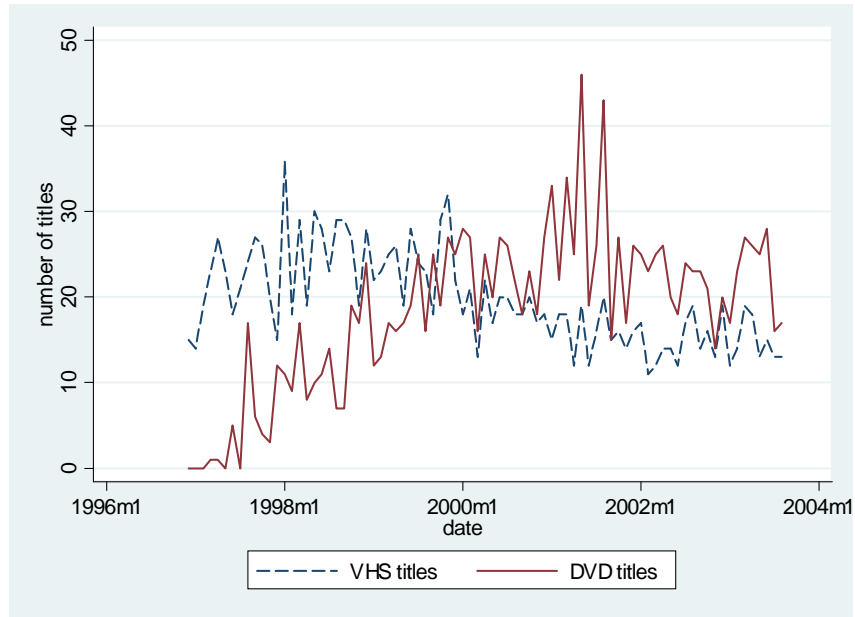Figure 2: Average prices of DVD players and VCR's
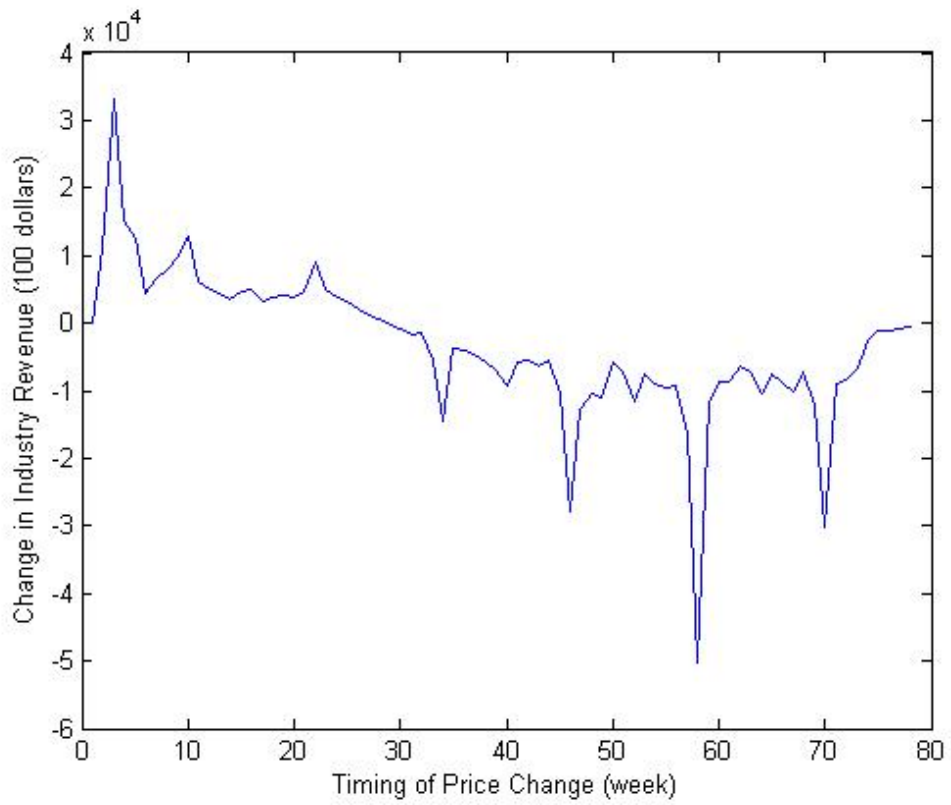
Figure 3: Number of title releases

Figure 4: Size of Industry Revenue Change by the Timing of Price Cut

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