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INDIRECT NETWORK EFFECTS AND THE PRODUCT CYCLE: VIDEO GAMES IN THE U.S., 1994–2002*

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We examine the importance of indirect network effects in the U.S. video game market between 1994 and 2002. The diffusion of game systems is analyzed by the interaction between console adoption decisions and software supply decisions. Estimation results suggest that introductory pricing is an effective practice at the beginning of the product cycle, and expanding software variety becomes more effective later. We also find a degree of inertia in the software market that does not exist in the hardware market. This observation implies that software providers continue to exploit the installed base of hardware users after hardware demand has slowed.

I. INTRODUCTION

Many high-tech products exhibit network effects, wherein the value of the product to an individual increases with the total number of users. Often these effects operate indirectly through the market for a complementary good. For example, the value of a CD player depends on the variety of CDs available, and this variety increases as the total number of owners of CD players increases. Other examples include DVD players and discs and computer hardware and software. In this paper, we estimate indirect network effects in the market for video game systems. A system consists of a video game console (hardware) and game titles (software). The console itself does not have any value apart from facilitating the use of software. Other factors such as console price and quality being equal, a consumer would prefer to buy the console that offers a wider variety in game titles.

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Understanding indirect network effects is crucial for understanding why products like these succeed or fail. Moreover, since high-tech products tend to have short product cycles, it is also important to understand how the implications of indirect network effects differ over the course of the product cycle. Penetration pricing is often mentioned as a useful strategy in these kinds of markets.[1] By offering a low introductory price, a firm selling hardware can build up an installed base of consumers which will lead to more software provision and a higher willingness to pay for hardware later in the cycle. It is also regarded as crucial for platform providers to have a broad selection of software available in order to promote console sales and raise royalty revenues.

The purpose of this paper is to measure the effects of software variety and hardware price throughout the evolution of a network industry. The modern U.S. video game market provides an ideal opportunity to study this issue for two reasons: (a) the presence of indirect network effects is apparent; (b) because of the short product cycle and intense inter- and intra-generational rivalry, we observe multiple incompatible systems in the market, providing us with sufficient data variation for analysis. To investigate the effectiveness of the business strategies, we must investigate the causal relationship between the hardware installed base and software title variety. Both the installed base and software variety are, in the end, endogenously determined as market outcomes. In order to address the endogeneity problem, we explicitly characterize the indirect network effect as an interaction between console purchases made by consumers and software supply chosen by game providers.

To date, there has been only a handful of empirical papers studying indirect network effects. Among them, some estimate network effects only from the installed base of consumers. These include Bayus and Shankar [2003], Ohashi [2003], and Park [2002]. These papers essentially model indirect network effects as though they were direct—i.e., consumers benefit directly from the existence of other consumers,[2] rather than indirectly through the market for a complementary good. The work that deals explicitly with such markets includes Gandal, Kende and Rob [2000], who focus on the compact disc player market in order to explain the diffusion process of a single technology with network effects; Dranove and Gandal [2003], who estimate indirect network effects of DVD and Divx players; and Nair *et al.* [2004] on personal digital assistants (PDAs). These papers analyze a one-shot standards war, not a situation like ours in which technologies are evolving and one standard is dominant for some period of time but is

[1] See, for example, Shapiro and Varian [1999].

[2] The direct network effect model is most appropriate for something like a telephone network. As more consumers use telephones, the value of the telephone to an individual consumer increases because it is possible to call more people. It is as if the quality of the telephone is increasing in the number of consumers.

eventually overtaken by a superior standard. This unique feature of the video game market helps us look at the evolution of console market shares and software availability for multiple technologies. Following an approach of Nair *et al*. [2004], our empirical model draws extensively from the results of the theoretical work of Church and Gandal [1992; 1993] and the extension in Park [2002]. Our paper contains three differences from Nair *et al*. [2004] in identification strategy. The first difference is due to the nature of the market under study. While Nair *et al*. [2004] analyze the developing phase of the product cycle, our study period covers both developing and declining stages of consoles. Thus we need to account for this nonlinearity of product evolution. The second difference is that we do not use observed product characteristics as instruments to control for unobserved characteristics. In the video game market, observed characteristics may be positively correlated with brand image or other attributes for which we do not have data. The last difference is that we create cost-side instruments using the fact that U.S. game consoles are the same as Japanese consoles. These instruments are similar to those proposed by Hausman [1996], but likely to be free from a criticism of Bresnahan [1996].

We find that lowering price is particularly effective near the beginning of the product cycle: demand for hardware is particularly elastic with respect to price at the beginning of the cycle.[3] Furthermore, we find that the elasticity of demand for hardware with respect to the available variety of software is relatively low at the beginning, and higher in the middle of the product cycle. Thus, while it is generally regarded as crucial to have some software available in order to launch hardware successfully, we find that on the margin an additional title does not have nearly as much effect on hardware demand at the beginning of the cycle as it does later. At the end of the cycle, when a hardware standard is becoming out-of-date relative to newer competitors, the elasticity of hardware demand with respect to both price and software variety is low.

We also uncover a degree of inertia in the software market that does not exist in the hardware market. As a console becomes obsolete, both the installed base and software variety decrease. By characterizing the hardware and software decisions explicitly, we obtain the additional insight that growth of the hardware installed base diminishes first, and software provision slows down only after a lag. This finding implies that software providers continue to exploit the installed base of consumers after hardware demand has slowed.

The organization of the paper is as follows. Section II describes important features of the U.S. video game market and gives descriptive statistics from

[3] Even if hardware is priced most aggressively near its introduction, the price may be highest then because the marginal production cost is much higher than later in the product cycle.

our data set. Section III presents the model used to analyze the indirect network effect. The model characterizes two economic activities in the U.S. video game market: hardware adoption and software provision. Section IV describes the data and instruments used in the estimation. In the construction of the instruments, we use the fact that all the game systems in the data were manufactured in Japan during the period. Section V discusses the estimation results. Using these results, Section VI describes the role of indirect network effects in the competition between video game platforms in the period from 1994 to 2002. Section VII concludes. A technical appendix follows.

II. THE MODERN U.S. VIDEO GAME MARKET

The U.S. market for home video game systems has grown enormously in recent years. In the period of our study, console sales more than doubled, from 6 million units in 1994 to 13.1 million in 2001. Total revenues for the industry were $9.4 billion in 2001, larger than total box-office revenues in the movie industry ($8.4 billion in 2001).[4] Table I shows market structure in the U.S. video game market during the period from 1994 to 2002 (because of data availability, the last year of our sample includes data only for the first quarter of the year. We discuss the data sources in Section IV(i)).

A video game system consists of hardware (the video game console) and software (game titles). Games are produced on cartridges or discs for use with the console. Hardware firms (like Nintendo) design and manufacture hardware and charge licensing fees to firms producing software; we will also refer to hardware firms as *platform providers*. Hardware producers generally produce some of their own software, and many independent firms produce software for one or more consoles. For the leading consoles, the vast majority of titles are produced by independent software publishers.

In Table I, we present eight major game systems in order of the total units sold in the sample over seven years. Figure 1 is a simple way to verify the presence of indirect network effects. The figure plots yearly pairs of installed base and software variety for five major consoles in the period from 1994 to 2002. Installed base is represented as the cumulative number of console units sold up to a given time, and software variety is the number of game titles that receive sales in the market. In any given year, we calculate a share by console type for each of the variables. Generally, the size of the installed base of hardware users and the amount of software variety available are positively correlated for any given technology. As a console increases in popularity, both variables increase; as a console becomes out-of-date and is overtaken by competition, both variables decrease.

[4] 'Recession? Don't Tell the Video Game Industry,' *New York Times*, May 24, 2002.

TABLE I
U.S. VIDEO GAME MARKET 1994–2002 QI

Platform Types (format)	Introduction Year	Platform Provider	Main console characteristics: CPU bits	MHZ	RAM (M bytes)		1994	1996	1998	2000	2002 Q1
PlayStation (CD-ROM)	September 1995	Sony	32	33.87	2	% Console units sold		28.83	61.38	39.17	12.87
						Mean Console Price (USD)		235.15	138.79	99.59	109.31
						% software variety		9.31	32.20	51.94	51.61
						%variety offerd by platform provider		19.04	20.45	18.20	15.08
N64 (Cartridge)	September 1996	Nintendo	64	93.75	4	% Console units sold		24.99	31.27	30.59	1.54
						Mean Console Price (USD)		199.61	138.06	105.23	84.42
						% software variety		0.20	5.62	15.41	14.65
						%variety offerd by platform provider		80.00	24.16	18.99	20.74
Genesis (CD-ROM)	September 1989	Sega	16	7.60	0.072	% Console units sold	57.87	18.56	5.31	0.67	
						Mean Console Price (USD)	117.59	94.13	46.87	19.90	
						% software variety	42.02	42.08	25.52	10.30	3.60
						%variety offerd by platform provider	28.63	29.88	34.94	26.56	19.40
PlayStation 2 (DVD-ROM)	October 2000	Sony	128	294.91	32	% Console units sold				13.41	56.38
						Mean Console Price (USD)				297.47	298.33
						% software variety				0.69	12.75
						%variety offerd by platform provider				2.22	8.37
Super Nintendo Entertainment System (Cartridge)	September 1991	Nintendo	16	3.6	0.128	% Console units sold	36.43	15.88	1.61	0.01	
						Mean Console Price (USD)	115.01	121.99	75.47	52.87	
						% software variety	32.15	34.96	20.23	8.66	3.33
						%variety offerd by platform provider	8.47	10.36	16.67	25.44	17.46
Dreamcast (CD-ROM)	September 1999	Sega	128	200	16	% Console units sold				16.14	0.05
						Mean Console Price (USD)				182.79	50.25
						% software variety				7.39	13.49
						%variety offerd by platform provider				19.59	22.09
Saturn (CD-ROM)	May 1995	Sega	32	28	4	% Console units sold		10.49	0.44	0.01	
						Mean Console Price (USD)		233.98	77.86	31.65	
						% software variety		7.71	15.50	5.57	0.58
						%variety offerd by platform provider		31.45	30.07	35.64	0.00
Nintendo Entertainment System (Cartridge)	January 1986	Nintendo	8	1.8	0.002	% Console units sold	4.75	0.66	0.001		
						Mean Console Price (USD)	55.57	49.51	20.16		
						% software variety	25.83	5.75	0.94		
						%variety offerd by platform provider	11.50	25.60	35.29		
						Industry console sales (M units)	5.65	7.09	12.41	8.11	1.37
						Total No. Variety	1234	1480	1494	1678	473

Notes: The platforms are in order of the total units sales in the period of 1994-2002. The eight platforms covered 99.4 % of the U.S. home video game market.
The data of 2002 are up to the first quarter. To conserve space, the table presents the information every two years. % Console units sold is the console market share in the industry. % software variety is the share in the total number of software titles available in the market, and % variety offered by platform provider is the share in the total number of software titles offered by platform provider.

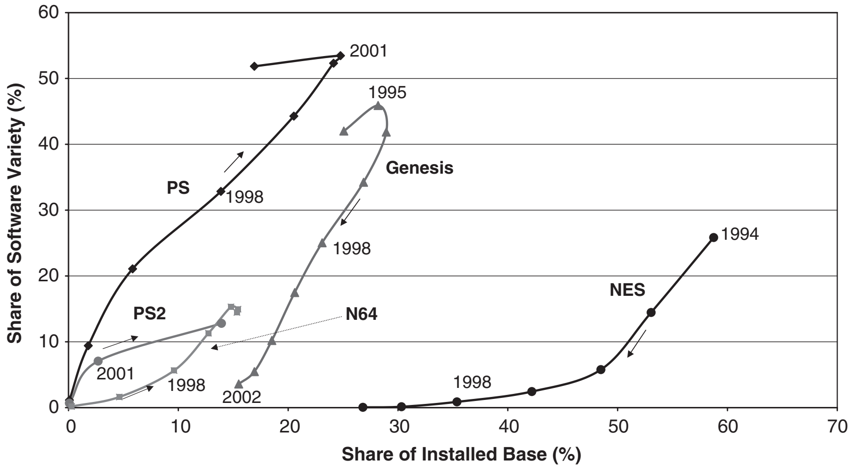

Figure 1
Rivalry in the Major Five U.S. Video Game Systems, 1994–2002

The significant market growth in the U.S. video game market was accompanied by considerable upgrading of console quality, leading to a rapid turnover of systems. At the broadest level, three technical factors determine the quality of the systems as presented in Table I: instruction word length (in bits) of either the central processor (CPU) or graphics processor (GPU), clock speed (in MHz), and the amount of RAM (in megabytes). The instruction word length is a measure of the maximum complexity of a single command sent to the processor, clock speed measures the number of such instructions that can be processed per second, and RAM provides temporary storage of information as a game is being played. The earliest machine in our sample was the Nintendo Entertainment System (NES), introduced in January, 1986. The NES was an 8-bit console that ran at 4 MHz and had 8 kilobytes of RAM. The technical characteristics of early systems restricted on-screen objects to two dimensions with a narrow range of colors. They were upgraded considerably in later consoles: comparison of the NES console with the Sony PlayStation 2 (PS2), introduced in October, 2002, tells us that instruction word length increased by 16 times; clock speed by 164 times; and lastly, RAM increased by 16,000 times! The latest game systems can create improved graphics with faster and more complicated play.

Since the late 1980's, game makers have introduced new game systems approximately every five years to satisfy the needs of consumers who look for more powerful games to play. The considerable quality upgrading leads to frequent console turnover, along with significant market growth. Table I indicates that market growth was also stimulated by aggressive pricing by console providers: for the first three years of the console introductions, the average price cut was about 28.4% per year, whereas the price drop for older consoles was modest at 7.5%. The console prices in general continued to drop even into the period when console sales were in decline. The estimation of console demand must take account of this rise and fall of popularity in the console life cycle.

For any given year in the sample period, there have generally been two dominant consoles and a few fringe players. At the beginning of the sample period, the Sega Genesis and the Super Nintendo Entertainment System (SNES) dominated the console market (see Table I). They were quickly replaced by the Sony PlayStation (PS) and Nintendo N64. By the end of the sample period, PS2 sales were growing fast (to date, the PS2 is the leading console and has sold approximately 60 million units worldwide[5]). All the game systems in Table I were originally developed in Japan[6] and sometimes sold under different names there.[7] We use this fact to construct instruments to control for endogeneity of some variables in Section IV(ii).

Table I also presents information on the software market. To save space, the table lists the information every two years, while the data used for the subsequent analysis are monthly as described in Section IV(i). The third row for each platform (% software variety) indicates the share in terms of the number of game titles sold. The total number of game titles is provided at the bottom row in the table. Software publishers provide finance for game development, manage relations with hardware providers, and perform packaging and marketing for game titles. Marketing of game titles entails extensive advertising and promotion at trade shows, such as the Consumer Electronic Show and the Electronic Entertainment Expo. A software publisher may either develop games in-house or subcontract game development to independent developers. Platform providers also publish some software titles themselves, but these 'first-party' titles comprise a modest share of the software variety available for their own consoles (see % variety offered by platform provider in the table). A simple calculation from Table I shows that the software share provided by platform providers starts with an average of 27.7% in the year of a console's introduction, immediately declines to 21.5% in the following year, but hits another high of 26.6% six years after the console release. From this point, the share declines. Some titles are available on multiple platforms; however, this is true for only 17% of the titles in our sample. Converting a game from one system to another has required additional development time and cost, and

[5] 'Playing Mogul,' *New York Times*, December 21, 2003.

[6] During our sample period, American-made consoles were not strong competitors. The 3DO system, introduced in 1993, never captured more than 2% of the market. Microsoft's Xbox was introduced in November, 2001, and was not well established by the end of the sample period.

[7] For those systems that have different names, we list Japanese names as follows with corresponding English names in parenthesis: Nintendo Famicon (NES); Super Famicon (SNES); and Sega Mega-Drive (Genesis).

contractual agreements with platform providers sometimes demand exclusivity to one game system.

An independent publisher pays a royalty fee to a platform provider for every unit of a game title sold. Software licensing fees are the primary source of revenue for hardware producers. Although data on hardware cost are not available, it is widely speculated that all of the major consoles have been sold at a price near marginal cost. According to Brandenburger [1995] and Hagiu [2004], there is good reason why it is in the interest of a hardware provider to keep the price of the hardware itself low and profit through software sales instead.[8] When deciding whether to buy a console, consumers face uncertainty about the quality of the game experience they will be getting and about future software prices. A low hardware price signals the platform provider's confidence that the consumer will want to buy games. There is also a holdup problem: once a consumer buys a console, he is captive to that platform to some extent and can be induced to pay a lot for games. Knowing this, consumers are willing to pay less for the hardware. Although we do not explicitly model uncertainty, our estimation results are consistent with the theoretical predictions described above. The results discussed in Section V imply that lowering hardware prices is effective, especially early in the product cycle.

III. A MODEL OF INDIRECT NETWORK EFFECTS

This section describes the estimation model we use to analyze indirect network effects in the U.S. video game market in the period from 1994 to 2002. Based on the descriptive statistics illustrated in Figure 1, this section seeks to establish the causal relationship between the hardware and software markets. The model comprises two main components, hardware adoption and software provision, and the indirect network effect is characterized by the interaction of these two components. We use a canonical model often used in the literature to describe the hardware and software markets. Our empirical model of indirect network effects is similar to that of Nair *et al.* [2004], and thus we refer the mathematical derivation of our model to Nair *et al*. [2004] and the unpublished appendix (available at the *Journal*'s editorial web site). We first describe hardware adoption and then turn to software entry. Section IV addresses the endogeneity issue and introduces instru-

[8] The story of the 3DO Multiplayer reinforces this view. The company owned the rights to the most technologically advanced console on the market at the time. However, any firm could produce a Multiplayer. As with other platforms, software producers had to pay a royalty to 3DO. This royalty was unusually low ($3 per unit, as compared to approximately 5 times this for SNES). The hope was that the low royalties would foster a large variety of software, and that consumers would buy the console because of this. However, since hardware producers could not subsidize hardware production with profits from software royalties, the price of the hardware was high (two to three times the price of other consoles on the market at the same time). Even though the quality of the console was undisputed, consumers were unwilling to pay the high price of hardware.

ments used in the estimation. Section V discusses the estimation results for the model presented in this section.

III(i). *Hardware Adoption*

Following the theoretical work on indirect network effects, including Church and Gandal [1992; 1993] and Chou and Shy [1990], our model is based on consumer preferences for hardware and software. As discussed above, a video game system consists of a console and compatible game titles. Since a console itself has no stand-alone benefit, a consumer who purchases a console must purchase game software written for that system. We capture this aspect of preferences by using a symmetric constant elasticity of substitution (CES) utility function. This specification assumes that a consumer values all available game titles equally. Though tractable, this specification is not entirely consistent with the U.S. video game market. According to Coughlan [2001], only a handful of game titles shared a majority of the industry revenues: the top 5% of the titles made more than 50% of the software industry revenue in our sample period. Furthermore, more than 50% of the revenues for a particular game title were typically made in the first year after the game release. It is, however, difficult to extend this CES specification to incorporate heterogeneity of game titles. We instead use a measure of heterogeneity in game titles as an instrument to achieve identification in Section IV. Hardware adoption in our model is thus assumed to depend only on the number of game titles provided (where the quality of each title is assumed to be the average quality of all titles), the price of games, and the price and other characteristics of consoles. Since we do not intend to make contributions to the theoretical work on indirect network effects, but rather are interested in testing an implication of the model often used in the literature, we leave the derivation of the underlying model setup to the unpublished appendix.

We use the television household as the purchasing entity, where each household has a unit demand for a video game system.[9] Video games are normally played by individuals whose ages range from 10 to 30 years old. Demographic data are, however, not available in our data set. Using an implication of the theoretical result, we assume that a representative

[9] In this paper, we use data for console games only, and all consoles require the use of a television as a monitor for game play. There is also a significant market for video games that can be played on a personal computer. However, this is commonly regarded as a different market by those in the industry, since console games are generally played in the living room rather than at a desk and thus are more likely to be regarded as entertainment. Certain genres of games, most notably educational, are more popular in the PC format than in any console format. Also, because there are no security measures built into PC hardware, piracy is more of a problem for PC games than for console games. The number of titles available in the PC format at any given time has generally been large, but the total sales volume is relatively small (less than 30% of the total market in 2001) and declining. It would be very difficult to incorporate PC data because of the inherent problems in tracking PC sales and imputing some percentage of PC use to game play.

household maximizes the following utility function at time t by choosing console j among $J_t + 1$ alternatives, one of which is the option of not purchasing a console:

$$u_{jt} = \beta_0 + x_j\beta_x + \beta_p p_{jt} + \omega N_{gt} + \xi_{jt} + \varepsilon_{jt}, \tag{1}$$

where u_{jt} is a representative household's utility from consuming console j that belongs to format g, and N_{gt} is the number of titles available for format g. We use different indices, g and j, to account for the backward compatibility of the PS2. Since the PS2 can be used to play PS games, but not vice versa, the PS2 *format* includes both the PS and PS2 *consoles*, whereas the PS format includes only the PS console. The price of console j at time t (adjusted by the CPI) is p_{jt}, and β_0 contains a constant term and other control dummies discussed in Sections IV and V.

We have data on three observed characteristics in Table I: data width, clock speed and RAM. We denote console j's observed characteristics by a vector x_j. Utility from these observed qualities is, however, realized only through the presence of software titles: the quality is constrained by the console technology, x_j, for some games but not others. Thus the vector of coefficients, β_x, would change over time with consumers' perception of the game quality. Since the quality of game software is not observable, $x_j\beta_x$ captures the average benefit from the console technology, and the deviation from the average is captured by an error, ξ_{jt}, where $E(\xi_{jt}) = 0$. The unobserved error also reflects important factors that lead consumers to purchase a particular console that are not present in the data. A process of building console image, perhaps partly stimulated by advertising, may be one example of such a factor. In an effort to control for the time-varying consumer tastes, we include console dummies and allow for them to change over time. Note that console dummy variables substitute for the use of $x_j\beta_x$ because x_j does not change within a console. Section V explains the estimation method in detail.

The indirect network effect is captured by N_{gt}. This linear specification is supported by our preliminary empirical analysis.[10] We estimate only an indirect network effect, not a direct effect. There would be a direct network effect in the video game market if consumer utility, and thus console demand, depended on the number of consumers who own the same console. This would be the case if, for example, console users derived value from borrowing games from other users of the same console. Such an effect may be present in a local region, but with the country-level data at hand, we believe the indirect effect to be of far more significance.

[10] A previous version of the paper used a Box-Cox transformation for the number of game titles, i.e., $(N_{gt}^{\lambda} - 1)/\lambda$, where λ is to be estimated. This transformation allows for logarithmic (when $\lambda = 0$) and linear (when $\lambda = 1$) specifications. We rejected the logarithmic case, but not the linear case, and thus impose the latter restriction in the subsequent analysis.

We impose assumptions on ε_{jt} that generate a standard nested logit model. The number of potential buyers at time t is the number of TV households that have not previously bought a console. Each potential buyer first decides whether to purchase a console. If the household decides to buy, it then chooses which console to buy (and households that do not buy a console choose the outside option). Following Berry [1994], a linear regression model for this two-stage logit is derived as follows:[11]

$$\begin{aligned}\ln(\mathrm{s}_{jt}) - \ln(\mathrm{s}_{0t}) &= \beta_0 + x_j\beta_x + \beta_p p_{jt} + \omega N_{gt} + \sigma \ln(s_{jt|B(t)=1}) + \xi_{jt} \\ &\equiv \delta_{jt} + \sigma \ln(\mathrm{s}_{jt|B(t)=1}) + \omega N_{gt},\end{aligned} \tag{2}$$

where s_{jt} is the share of the potential hardware market captured by console j during period t, and $s_{jt|B(t)=1}$ is console j's share of the portion of the market that does purchase video game systems in period t; thus $s_{jt|B(t)=1}$ is equal to $\mathrm{s}_{jt}/(1-\mathrm{s}_{0t})$, where s_{0t} is the market share of the outside option at time t. The mean utility of the outside option is assumed to be zero. Otherwise it should be incorporated in the constant term of the demand equation. We estimate the above model in Section V. We turn now to the estimation model of software entry.

III(ii). *Software Entry*

We now describe the determination of variety in game titles. When more consumers buy a particular console, software firms have more incentive to produce games designed for that console. We assume that there are many software firms that can potentially produce game titles for any particular console. According to Coughlan [2001], software firms normally publish more than one game title for a particular console. For example, Electronic Arts, the largest software publisher, published nearly 6.3% of the overall game titles during our sample period. To simplify the estimation model, however, we assume a single-product software firm provides its game title to a console j. Software production exhibits increasing returns to scale and free entry. Those consumers who purchase game titles already own a console. Each consumer in the installed base of console j has a CES demand for software s. Under the above assumptions, the symmetric Bertrand equilibrium determines the degree of available variety in game titles as:

$$N_{jt} = A_j(IB_{gt})^{\gamma}, \tag{3}$$

where A_j is console j's specific constant. We adopt the usual definition of the installed base, and define IB_{gt} as $\Sigma_{q=1..t-1} M_q s_{jq}$, where M_q is the potential market size for video game consoles at time q. The indices j and g are the same, except that when j is PS, IB_g equals the sum of IB_{PS} and IB_{PS2} to

[11] The derivation is available in the unpublished appendix.

account for the backward compatibility of PS2. Church and Gandal [1992; 1993], Chou and Shy [1990], and Nair *et al.* [2004] use the same assumptions on the software market listed above to derive the equilibrium degree of software variety. In the empirical implementation, we thus use the following reduced-form model:

$$\ln(N_{jt}) = \alpha_j + \gamma_1 \ln(IB_{gt}) + \gamma_2[h\_age_{jt}] + \gamma_3[\ln(IB_{gt})h\_age_{jt}] + \eta_{jt}, \tag{4}$$

where η_{jt} is a mean-zero error. The model includes a console fixed effect, $\alpha_j \equiv \ln(A_j)$. By definition, the size of the installed base, IB_{gt}, never declines throughout the console lifetime. Other factors being equal, an older console is usually less attractive for game providers to supply titles, since such a console embodies older technology. Thus, the sensitivity of the installed base to the variety in titles, represented by γ in (3), may be different for an old console as opposed to a new one. In order to consider this vintage effect, we include an age variable for console j at time t, h_age_{jt}, in equation (4), and allow it to interact with the installed base variable. This age variable counts the number of years after the console release at t. Accounting for the vintage effect is important in our analysis, because the data cover the initial as well as final stages of the lifecycle for some consoles.

The rest of the paper analyzes equations (2) and (4). As is common with models of network effects, our model has multiple equilibria, and we discuss this issue in the appendix. This paper essentially assumes that the data and estimation result correspond to the stable equilibrium.

Before we turn to the estimation method, it is useful to discuss how the model presented above identifies elasticities in the market. We address two issues, hardware supply and dynamics. To estimate the price and variety elasticities of hardware adoption, it is more efficient to jointly estimate hardware demand in addition to supply equation by using cross-equation restrictions imposed by an imperfect-competition model. If the supply equation is misspecified, however, the resulting estimates would not be efficient, and even worse, not consistent. Under dramatic changes in the market with uncertain product life and lack of appropriate cost proxies, it is difficult to specify a hardware supply model for video game consoles. Since we are interested in obtaining consistent estimates of the demand model, this paper estimates only the hardware adoption equation.

The model presented in this section is a static model. Since a video game console is durable, it may be more appropriate to use a dynamic model to describe the market. The major issue of dynamics in the video game market concerns the timing of both hardware adoption and software entry. In the hardware market, consumers decide to purchase a console based on their expectations of the future popularity of the console. We can think of two types of console buyers: (i) those who have not purchased video games before; and (ii) those who own older game systems. At each point in time, the first consumer type compares the net benefit of purchasing a game system to the value of the outside option, and the second type compares it to the net benefit of sticking with the older system. While the dimensionality of the problem makes it very difficult to model dynamic behavior that fully accounts for this trade-off, we try to capture it in the empirical implementation. We include console-time interaction dummies that proxy for console-specific events affecting expectations. To account for type (ii) consumers, we allow for the installed base to depreciate, so that the outside market share changes with the flow of returning consumers. Although we cannot uncover the underlying decision-making process in the choice of purchase timing, we believe that our reduced-form static treatment still gives us consistent estimates of the hardware adoption process.

The timing of product launch in the software market is another issue. Forward-looking software publishers base their entry decisions on expectations about future growth of console sales. For example, if uncertainty exists as to the future profitability of a console, a publisher may wait before introducing software compatible with the console, or may wish to supply another console. Although modeling the product launch decision is beyond the scope of this paper, we try to capture this feature by including console dummies that proxy for differences in profitability across console types that influence expectations, and also by including console age interacting with installed base to capture publishers' anticipation of the console market size at a given point of the console lifecycle. While we believe that estimation results based on (4) still hold in a dynamic setting, we need to interpret the results with caution.

IV. DATA AND ESTIMATION

IV(i). *Data*

Our data on console sales and the number of available game titles come from the NPD Group, a market research firm. NPD Group collects data from approximately two dozen of the largest game retailers in the United States. These retailers account for approximately 65% of the U.S. market; from the data, NPD formulates estimates of figures for the entire U.S. market. These estimates do not take into account sales to rental outlets such as Blockbuster.

We have monthly data for the period from January, 1994, to March, 2002. Important statistics in the hardware market are presented in Table I, and definitions of variables and summary statistics are in Table II. We excluded the two latest consoles, the Nintendo Game Cube and the Microsoft Xbox, due to small sample sizes (both of these consoles were introduced late in 2001). It is important to use monthly rather than annual data because of the short life cycle of hardware, and the even shorter life cycle of software titles

TABLE II
DEFINITIONS AND SUMMARY STATISTICS FOR THE VARIABLES

Descriptions	Mean	Std. Error	Min	Max
Console sales (quantity units in thousand) by month	148.16	285.35	0.00	2795.16
CPI-deflated console price in the U.S. (January 1978 U.S. dollars = 100)	1.01	0.69	0.13	3.84
The number of game titles for a system	320	272	2	1244
Installed base by format (million households)	12.88	9.26	0.03	35.78
Age of console system (years)	6.01	4.10	0.08	16.08
CPU/GPU (bits)	51.6	47.5	8.0	128.0
Clock speed (MHz)	83.3	101.5	3.6	295.0
RAM (mega bytes)	14.0	14.5	0.1	36.0
Current nominal exchange rate of $U.S./Japanese Yen	111.45	11.83	84	145
CPI-deflated console price in Japan (Yen)	16560	9562	1513.3	42500
Average age of software titles by console system (months)	26.40	20.96	0.67	83.91
Average lifetime of software titles by console system (months)	51.63	16.85	8.41	85.79

Sample means of year dummies		Sample means of console dummies	
1994	0.07	PS	0.16
1995	0.10	PS2	0.03
1996	0.13	Genesis	0.19
1997	0.15	Saturn	0.14
1998	0.13	DreamCast	0.06
1999	0.13	NES	0.11
2000	0.15	SNES	0.17
2001	0.13	N64	0.13
2002	0.02		

Sample size: 1055

(an individual title has positive sales for approximately 30 months, on average).

For game consoles, we have retail revenues and retail quantities sold, broken down by console. We calculated the average retail price of a console from the data of revenues and quantities. Each game console system has a unique version and no updates. The console price in our data thus averages over retail prices of the console from various regions in the United States. We use the consumer price index (all urban consumers: all items less food and energy) to adjust the nominal resale price. The data on technical characteristics of the various consoles, noted in Section II, were collected from console manufacturers' websites.[12] For game titles, we know when an individual title receives sales, broken down by console. In addition, game titles are categorized by publisher (the firm that markets the title; publishers may develop games themselves or contract with independent game developers).

We define the potential video game market as the number of people who had a TV but did not have a video game system prior to their purchase. The number of U.S. households with at least one television set in the study period

[12] See *www.nintendo.com*, *www.playstation.com*, and *www.sega.com*.

comes from the Census Bureau's 2003 *Statistical Abstract of the United States*. The size of the installed base by console and by month is obtained by the cumulative console sales up to the previous month. The installed base at the beginning of 1994 is obtained from Bayus and Shankar [2003], which reports the installed base (in millions) of NES (25.7), SNES (4.8), and Genesis (7.6). Although the numbers are somewhat inconsistent with those reported in Brandenburger [1995b] for SNES (8.5) and Genesis (10.6), we use the data from the former. Use of the Brandenburger [1995b] data does not effectively change the results reported in the subsequent sections. Demand for upgrading (i.e., switching from old to new consoles) may be a concern due to rapid quality improvement. It is, however, impossible to read the magnitude of upgrading demand from the dataset. To check the significance of our concern regarding the presence of upgrading demand, we consider the possibility that the installed base depreciates at an annual rate of 5%. The base specification assumes that the installed base size equals the sum of past sales ($IB_{gt} = \Sigma_{q=1..t-1} M_q s_{jq}$). In an alternative specification, the definition of the installed base of format g becomes $\Sigma_{q=1..t-1} \delta^{(q-1)} M_q s_{jq}$, where δ is the depreciation rate.[13] This assumption essentially allows those consumers who own older consoles to purchase another game system. The outside market share thus changes with the flow of returning consumers.

IV(ii). *Instruments*

This subsection addresses identification issues in the base estimation model of hardware adoption and software entry. The estimation models are equations (2) and (4) as defined in Section III. We first discuss the estimation of (2) and then turn to the estimation of (4).

Hardware adoption. Much of the previous literature makes the identifying assumption that x_j and ξ_{jt} are not correlated with one another. Although it helps greatly by reducing the number of instruments needed in the estimation, this assumption may not be accurate in that observed characteristics could be positively correlated with brand image or other attributes for which we do not have data. Because of this concern, we use console dummy variables to control for unobserved attributes. Section III(i) discusses the possibility that brand images and consumers' perception of observed quality could change over time. To account for this concern, we include different console dummies by year, along with year fixed effects in the estimation. Although our data are of monthly frequency as described in Section IV(i), we could not obtain meaningful estimates by including monthly dummies due to the lack of cross-sectional variation with only a few consoles in the market.

[13] Since the data are of monthly frequency, we set δ as 0.9957 (i.e., exp(log(0.95)/12)).

Even after controlling for brand and time dummies, the deviation from the mean in some variables may still be correlated with the mean-deviation of ξ_{jt}. We are concerned that three variables are correlated with console *j*'s error, ξ_{jt}: They are within-group share, price and software variety. An obvious variable that is plausibly correlated with ξ_{jt} is $\ln(s_{jt|B(\mathrm{t})=1})$, since $s_{jt|B(t)=1}$ contains part of the dependent variable, s_{jt}. Console prices, p_{jt}, may be endogenous, because if ξ_{jt} is correctly perceived by consumers and suppliers in the market, a console with a better image may induce higher willingness to pay, and thus sellers may be able to charge higher prices in an oligopolistic market. The last endogenous variable in the hardware adoption is the variety in game titles, N_{jt}. This concern comes from the interaction with the software entry model (4), and the autocorrelation on ξ_{jt}. An increase in console demand at t–1, because of the change in the unobserved error, would inflate the installed base at t, leading to an expansion of the variety. Thus ξ_{jt} and N_{jt} are positively correlated with each other in the presence of the autocorrelation in ξ_{jt}.

We use various sets of instruments to account for the endogeneity of the three variables. We employ two instruments from the cost side. They are constructed by using the fact that all the consoles in the data were imported from Japan. One instrument is monthly exchange rates between the Japanese Yen and the U.S. dollar (from *International Financial Statistics*, 2002). Since most of the manufacturing processes occurred in Japan during the period, the U.S. retail price of a console should have been affected by exchange rates between Japan and the United States. We use a lag of one year for the exchange rate, because the console introduction date in the U.S. was usually one year behind that of Japan. Note, however, that this instrument is an industry aggregate, and does not vary by console type. The use of this instrument thus only helps identify the hardware demand through the variations of the instrument over time.

The other cost-side instrument is the console retail price in Japan. The data are from various semi-weekly issues of the Famicon bulletin (in the period from January, 1992 to December, 1998) and from Nikkei Newspaper (from June, 1996 to March, 2001). We cross-checked the overlapped period to find that the price levels are similar across the two sources. We again take a lag of one year for the console prices in Japan, in view of the difference in the release dates between Japan and the United States. Since almost all consoles in the data were manufactured and sold in Japan, the Japanese console price would contain cost shocks, as well as effects of consumers tastes for unobserved quality in Japan. Thus, if Japanese gamers' tastes differ from American tastes, the Japanese console retail prices serve as a cost-side instrument for retail prices in the U.S. market. Some evidence suggests that such a difference in tastes does exist.[14] The identifying assumption made

[14] 'New Riddle for Xbox: Will it Play in Japan?' *New York Times*, February 18, 2002.

here is reminiscent of that made in Hausman [1996] in his study of the ready-to-eat cereal industry. The identification condition is that all demand shocks are uncorrelated across cities in the country. While some papers (for example, Bresnahan [1996]) criticize this identifying assumption because of the importance of national advertising and fads for some products, our assumption of uncorrelated demand shocks across countries may be more reasonable, especially for the countries where cultural traits are very different.

Because of our unique data source detailed in Section IV(i), we have instruments available from the software side. First, we use the monthly average age of software titles provided to a console. Popular titles tend to stay in the market longer and attract more consumers to the associated console. Thus we expect that a console with more older titles achieves a larger within-market share, $\ln(s_{jt|B(t)=1})$. Note that the monthly average age of software titles does not simply represent a time trend by console, due to significant entry and exit of game titles. We also use console age as an instrument. This instrument is measured by the number of months that passed since the console introduction. The squared and interaction terms of the instruments mentioned above are also used.

Software entry. Our concern here is endogeneity of the installed base in (4). If software entry associated with console j is accelerated due to an unobserved shock in the software market at $t-1$ (η_{jt-1}), this shock would induce new console adoption and boost the share of the console (s_{jt-1}), and hence the installed base in the next period (IB_{gt}). Thus if η_{jt} is correlated with η_{jt-1}, endogeneity in IB_{gt} arises. We use as an instrument the monthly average age of software titles provided to a console, the same instrument used in hardware adoption. We can think of cases where the average software age correlates with the entry error. If potential entrants perceive the presence of many older titles as a sign of a profitable opportunity, the instrument would be positively correlated with η_{jt}. On the other hand, if they see it as a result of tough competition (i.e., that young titles cannot survive in a market), the instrument would be negatively correlated with the error. Thus the direction of the bias by use of this instrument, if it exists, could go either way. We therefore rely on the statistical test of overidentifying restrictions to check if the instruments are orthogonal to the error. Section V reports that the test would not reject the orthogonality condition. We also include in the set of instruments the square of console age and the interaction terms of console and software ages.

V. ESTIMATION RESULTS

This section presents estimation results of the hardware adoption and software entry equations discussed in the previous section. We first estimate the equations independently using a two-stage least squared (2SLS) method, and then estimate them jointly.

It is known that the 2SLS method can produce severely biased estimates, if the instruments are weak. We thus check the explanatory power of instruments, conditional on the included exogenous variables in the first stage of the 2SLS method. We obtain an F-statistic for each of the endogenous variables discussed in Section IV(ii). To conserve space, Table III reports the average value of the F-statistics. We find that all the instruments used in this paper are not weak at the 99% confidence level of F-statistics. The estimated coefficients in the table are obtained by regressing the dependent variable onto the exogenous and fitted values of endogenous variables.

Hardware adoption. Table III shows two estimation results from the hardware equation. The first specification (H1) controls for time and console effects, in addition to the interaction of the two.[15] We include the interaction terms to account for the dynamic nature of the industry, as discussed in Sections III(i) and IV(ii).

We use the instruments introduced in Section IV(ii) to control for the endogeneity in console price, software variety, and within-group market share. Since we have more instruments than we need to identify an equation, we can test whether the additional instruments are uncorrelated with the error by using the J-statistic (i.e., the statistic for overidentifying restrictions). The J-statistic finds that the model (H1) fits well. In order to check for the presence of autocorrelated errors and the resulting endogeneity problem for software variety addressed in Section III(ii), we supplement the estimation with a test on whether the residuals are autocorrelated. We construct the AR(1) coefficient in the table by first estimating a coefficient of the lagged residual for each console, and then aggregating them by using console market share as a weight. The aggregated coefficient is found to be at a modest level of 0.48, indicating a need to control for software variety.[16] The estimated coefficients on price and the network effect are significantly different from zero.

Table IV shows the demand elasticity with respect to price by console (E_p in the first row for each console), and its standard error.[17] The standard errors in the table are obtained by the delta method. We discuss the whole study period below, but to save space, we present the elasticity values only every two years in Table IV. The elasticity is estimated at -1.07 on average.[18] Though the elasticity values differ substantially across consoles,

[15] We include the console-year interaction dummies when the console received more than one million units of sales for the year. This method makes 27 interaction dummies.

[16] Taking a simple average in the aggregation of the AR(1) coefficients does not change this result much.

[17] The elasticity for console j at time t is $[\beta_p (1\text{–}\sigma)]\, p_{jt}\, [1 - \sigma s_{jt|B(t)=1} - (1-\sigma)s_j]$.

[18] The yearly elasticity (for both price and software variety) is calculated as follows: we first obtain elasticities by console and by month, and then aggregate them by taking a simple average.

TABLE III
ESTIMATION RESULTS ON HARDWARE ADOPTION (2) AND SOFTWARE ENTRY (4)

	(H 1) 2SLS		(H 2) OLS		(S 1) SLS		(S 2) OLS		(J) SLS	
Variables	Est.	Std.	Est.	Std.	Est.	Std.	Est.	Std.	Est.	Std.
Hardware:										
Price	– 0.71**	0.25	– 0.50**	0.15	–		–		– 0.71**	0.22
Number of Game Titles	0.41*	0.17	0.43**	0.09	–		–		0.41**	0.13
Within Group Share	0.35**	0.09	0.60**	0.03	–		–		0.35**	0.06
Software:										
ln(IB)	–		–		2.94**	0.20	1.47**	0.04	2.94**	0.21
ln(IB)*Hardware Age	–		–		0.44**	0.12	– 0.01	0.01	0.44**	0.12
Hardware Age	–		–		– 7.58**	2.05	– 0.24	0.23	– 7.58**	2.08
No. Observations	493		493		562		562		1055	
R-squared	–		0.96		–		0.87		–	
1st stage F stats	1.40E + 03**		–		8.71E + 04**		–		1.71E + 04**	
J statistics (D.F.)	13.70 (9)		–		0.35 (1)		–		14.05 (10)	
AR(1) Coefficient	0.48**		0.43**		0.92**		0.97**		–	

*Significance at the 95-percent confidence level.
**Significance at the 99-percent confidence level.
The dependent variable for the hardware adoption is the logarithm of console market share minus the logarithm of the outside share.
The console market share is defined as the fraction of the TV households that do not have game systems by a given time.
The hardware equation includes year dummies, console dummies, and their interactions, which are not reported here. The instruments for hardware adoption are exchange rate (USD/JY), console prices in Japan (CPI adjusted), hardware age (the months passed since the console introduction), and monthly average software age. The squared and interaction terms of the instruments are also used. The number of game titles are divided by 100 for the presentation purpose.
The dependent variable for the software entry is the logarithm of the number of game titles provided to a console. The software equation includes year and console dummies, which are not reported in this table. The instruments used for software entry are monthly average software age, and monthly hardware age. The squared and interaction terms of the two age variables are also used. Heteroskedasticity-robust standard errors are used in the table.

Table IV documents that the console demand becomes less price elastic with the age of console. The elasticity in the first year of introduction was on average estimated at – 1.92, and it increased with console age until the value reached – 0.52 when the console had been in the market for seven years.[19, 20]

Table IV also shows the elasticity of demand with respect to software variety (E_s in the third row for each console).[21] While the demand is found to be elastic at 1.89 on average, the elasticity values vary a lot across the consoles, from a high point of 5.51 for PS2 down to 0.75 for Saturn.

[19] Only four consoles survived for seven years within the sample period: PS, Genesis, Saturn and SNES.
[20] This result is driven in part by the fact that the potential number of buyers is declining over time.
[21] The elasticity for console j at time t is $[\omega/(1-\sigma)]N_{jt}\,[1-\sigma s_{jt|B(t)=1}-(1-\sigma)s_j]$.

TABLE IV
ELASTICITIES OF HARDWARE ADOPTION AND SOFTWARE ENTRY

Platforms	Demand Elasticities with respect to:	1994	1996	1998	2000	2002 Q1
PlayStation	Price (Ep)		– 2.15	– 1.06	– 0.79	– 0.92
	std. error (Ep)		0.77	0.37	0.28	0.29
	Software variety (Es)		0.67	2.25	4.50	5.56
	std. error (Es)		0.45	0.97	1.90	1.04
	- Es/Ep		0.31	2.12	5.67	6.02
	Entry Elasticity wrt IB		3.29	4.16	5.03	5.72
N64	Price (Ep)		– 1.74	– 1.21	– 0.85	– 0.76
	std. error (Ep)		0.48	0.44	0.30	0.28
	Software variety (Es)		0.02	0.42	1.37	1.67
	std. error (Es)		0.89	0.27	0.61	0.77
	- Es/Ep		0.01	0.34	1.61	2.21
	Entry Elasticity wrt IB		3.02	3.72	4.59	5.28
Genesis	Price (Ep)	– 1.01	– 0.88	– 0.45	– 0.18	
	std. error (Ep)	0.36	0.32	0.17	0.07	
	Software variety (Es)	2.43	3.40	2.20	1.03	
	std. error (Es)	1.04	1.46	0.94	0.44	
	- Es/Ep	2.39	3.87	4.83	5.56	
	Entry Elasticity wrt IB	5.03	5.90	6.77	7.64	
PlayStation2	Price (Ep)				– 2.47	– 1.93
	std. Error (Ep)				0.44	0.34
	Software variety (Es)				5.55	5.31
	std. error (Es)				2.10	1.02
	- Es/Ep				2.24	2.75
	Entry Elasticity wrt IB				3.00	3.51
Super Nintendo Entertainment System	Price (Ep)	– 1.08	– 1.14	– 0.73	– 0.49	
	std. error (Ep)	0.39	0.41	0.27	0.18	
	Software variety (Es)	2.03	2.84	1.79	0.87	
	std. error (Es)	0.90	1.25	0.79	0.40	
	- Es/Ep	1.88	2.49	2.43	1.77	
	Entry Elasticity wrt IB	4.16	5.03	5.90	6.77	
Dreamcast	Price (Ep)				– 1.61	– 0.45
	std. error (Ep)				0.59	0.26
	Software variety (Es)				0.64	1.56
	std. error (Es)				0.41	0.76
	- Es/Ep				0.40	3.45
	Entry Elasticity wrt IB				3.29	3.98
Saturn	Price (Ep)		– 2.32	– 0.76	– 0.30	
	std. error (Ep)		0.85	0.28	0.10	
	Software variety (Es)		0.60	1.39	0.55	
	std. error (Es)		0.49	0.64	0.27	
	- Es/Ep		0.26	1.82	1.85	
	Entry Elasticity wrt IB		3.43	4.30	5.17	
Nintendo Entertainment System	Price (Ep)	– 0.59	– 0.50	– 0.20		
	std. error (Ep)	0.22	0.18	0.18		
	Software variety (Es)	1.86	0.50	0.08		
	std. error (Es)	0.81	0.25	0.43		
	- Es/Ep	3.16	1.00	0.39		
	Entry Elasticity wrt IB	6.62	7.50	8.37		

Note: The elasticities are calculated based on estimates from (H1) and (S1) in Table III. The standard errors are calculated by the delta method. The data of 2002 are up to the first quarter. To conserve space, the table presents the information every two years.

In a market with strong indirect network effects, it is crucial to make sure that a new game system is widely adopted. Two ways a platform provider can do this are by lowering the price of hardware and by encouraging software entry. One interesting question is to measure the relative effectiveness of these two strategies. Following the idea of Gandal, Kende and Rob [2000], we calculate a ratio of E_p and E_s. This ratio measures the effect of console price equivalent to a 1% increase in software variety (in absolute value). The result is in Table IV (under -E_s/E_p). The ratios suggest that, as far as consumers are concerned, a 1% increase in game titles is equivalent to a 2.3% price cut in the market, aggregating across years and consoles. In general, the ratio starts low with the introduction of a new console, increases to as large as 2.80 (for PS and Genesis), and eventually declines as the console retires from the market.

Section IV(ii) discusses that, without regard for the endogeneity, the price, variety, and within-group share coefficients would be biased upward. In order to check the severity of the endogeneity concern, we estimate the model (H1) with the assumption that the explanatory variables are exogenous. The result with the exogenous variables is under (H2). The comparison with the result in (H1) points to the elimination of the endogeneity biases, although the differences of the OLS and 2SLS estimates of price and variety coefficients are not significantly different from zero. The OLS estimate on price (-0.50) is 30% higher than the 2SLS estimate (-0.71), but the 2SLS yields an estimate on software variety close to the corresponding OLS estimate (0.43).

Lastly, we estimate the model under the assumption that the console installed base depreciates at an annual rate of 5%, as described in the data section. The estimation results (not shown in the table) are very close to those of (H1), indicating that the results in (H1) are robust to the size of the outside market share.

Software entry. We now turn to results of estimating the software entry model, equation (4). The estimation results are under (S1) and (S2). Our preliminary analysis finds that the specification that leaves out the hardware-age variable from (4), by assuming $\gamma_2 = \gamma_3 = 0$, does not fit well. The specification (S1) thus includes hardware age as an explanatory variable. The J-statistic shows that the model fits moderately well with the instruments. The high and significant average autocorrelation coefficient in η (0.92) indicates the need to use instruments for installed base. Comparison with the OLS result in (S2) shows that the instruments successfully control for the bias in the installed base coefficient, from 1.47 (OLS) to 2.94 (2SLS). The direction of bias in the coefficient is difficult to predict, because we also include a hardware age variable in the estimation: hardware age traces a trend of installed base, and the two variables are correlated at the level of 0.77. The F-statistic indicates that the instruments are not weak. Holding the hardware age constant at the mean (3.6 years), a 1% increase in the installed base expands the software variety on average by 4.52%. The result also shows that, holding the installed base size at the mean value, an older console would be less attractive for software providers to launch game titles: a console with an additional year in the market would lose 2.6% of its software titles. Table IV indicates that the elasticities of software variety with respect to the installed base (under Entry Elasticity wrt IB) are estimated to be 5.05 on average. Based on the estimation results in Tables III and IV, we discuss implications of network effects in the U.S. video game market in the next section.

In the alternative specification in which the installed base depreciates at an annual rate of 5%, the coefficients of installed base and its interaction with hardware age are smaller than those of (S1). Nevertheless, the main results in Section VI hold qualitatively with this specification.

Joint estimation. The specification (J) in Table III reports the joint estimation results from (2) and (4). Although we do not have cross-equation restrictions, the joint estimation produces more efficient estimates when the errors from the hardware and software equations are correlated. We calculate the generalized method of moment (GMM) estimators, with an optimal weighting matrix constructed from the 2SLS residuals from the specifications (H1) and (S1). We find that the obtained estimates are almost the same as those in (H1) and (S1), but their standard errors are somewhat reduced for the hardware equation, and do not change much for the software. Nevertheless, the values of standard errors calculated by the estimates in (J) are similar to those in Table III, which we discussed in this section.

VI. IMPLICATIONS OF THE INDIRECT NETWORK EFFECT

This section describes how the indirect network effect identified in the previous section plays a role in video game system competition in the period from 1994 to 2002. As discussed in Section III(ii), we have estimated a static model. Although a dynamic model would better describe the evolution of the market, estimating such a model is not feasible in our context. While we cannot explicitly draw dynamic conclusions from our estimation results, we can draw static conclusions for different points in the product cycle: we thus examine a snapshot of the market at different points in time. We also extrapolate somewhat to dynamic conclusions in this section, but only where it seems relatively safe to do so. Our dynamic speculations are consistent with the static estimation results and are intuitively appealing.

To analyze the relative strength of each console, we take deviations in (2) and (4) from the averages to obtain the following equations:

$$\Delta \ln(s_{jt}) = \omega \Delta N_{gt} + \Delta[\sigma \ln(s_{jt|B(t)=1}) + \delta_{jt}] \tag{5}$$

and

$$\Delta \ln(N_{jt}) = \Delta[k(IB_{gt},\ h\_age_{jt})]\gamma + [\Delta\alpha_j + \Delta\eta_{jt}]. \tag{6}$$

We take the first three explanatory variables in (4) and define $k(IB_{gt}, h\_age_{jt})$, and assume that $\Delta y_{jt} \equiv y_{jt} - y_t$, where y_t is the average of y_{jt} across consoles available in the market in a given year t. The deviation in the console market shares and software provision can be decomposed into the network effect (the first term) and the non-network effect (the second term). We use the estimates under (J) presented in Table III to explore the importance of the network effect in explaining the market outcomes relative to the industry average (i.e., the left hand side of the equations).

We first discuss implications from console adoption, equation (5). Figure 2 presents the relationship between the relative market shares and the difference in network effect for five selected consoles.[22] The figure confirms that the software variety predicts well the changes in the relative strength of console market share: when more game titles enter the console market relative to the industry average, the consoles sell better than the average.

Besides a fairly strong positive correlation, we also see a generally clockwise pattern in the change of deviation in market share (i.e., $\Delta\ln(s_{jt})$) versus deviation in software variety (i.e., $\omega\Delta N_{gt}$). As long as ω is positive, the observation of a clockwise pattern is not affected by the estimation results obtained in the previous section. Consider the data points for the Sega Saturn. From 1997 to 1998, the deviation in market share for this console decreased, but the deviation in software variety was close to constant. That is, the relative market share for the Sega Saturn decreased significantly but the change in the relative amount of software variety lagged behind. From 1998 to 1999, the market share decreased further and software variety decreased as well. We take this to be an indication of inertia in the software market. Even after the growth of the installed base has slowed down, software publishers continue to develop new titles in order to reap profits from the established installed base. At some point, however, new software development tapers off, causing a further decrease in relative market share (i.e., a decline in the growth rate of the installed base). In the declining stage of the product cycle, market shares are more sensitive to the network effect than in the growth stage.[23]

We also analyze the deviation in the installed base from the average (i.e., $\Delta[k(IB_{gt}, h\_age_{jt})]\gamma$) versus the deviation in software variety (i.e., $\Delta\ln(N_{jt})$) from equation (6). Since hardware age essentially traces a trend of the size of the installed base (and the correlation coefficient between the two variables is 0.77), it is difficult to separate the two variables in k and discuss the impact of the installed base.

[22] A figure for the other consoles is given in the published appendix, on the *Journal*'s web site.

[23] An exception is a small increase in the market share for the Sega Genesis in 1999. This is probably due to the consumer response to a large price cut. Sega cut the price of the Genesis by more than half in 1999 (see Table I).

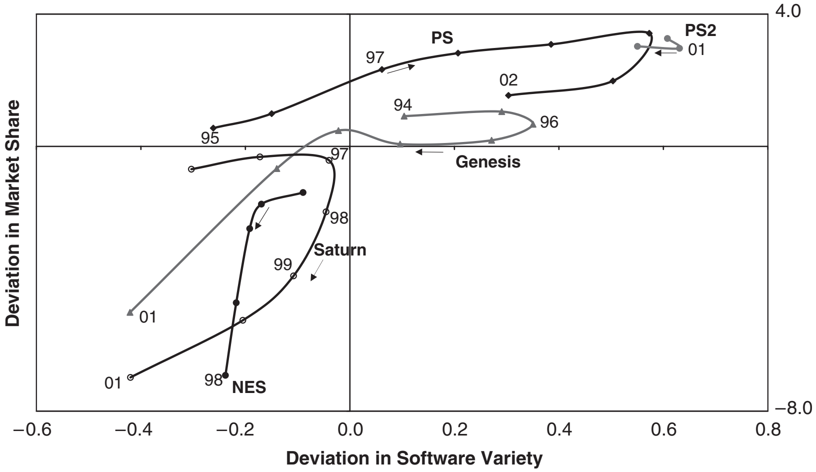

Figure 2
Network Effects in the Hardware Market: Selected Consoles

The relationship between $\Delta\ln(N_{jt})$ and $\Delta[k(IB_{gt},\ h\_age_{jt})]\gamma$ further confirms our finding made with Figure 2 (the figure that shows the relationship is available in the unpublished appendix): As a console ages, superior technology emerges, and growth in the installed base of the technologically inferior platform begins to decline. The relative number of software titles also declines, but only after a lag. Looking at the trajectories for different consoles, we see different rates at which the deviation in software titles declines relative to the deviation in installed base; but different consoles tend to follow the same pattern described above.

The elasticity results from the previous section further illustrate the U.S. video game market during our study period. As discussed in Section II, platform providers profit primarily through software royalties. They can only do this if they establish both sides of the software market: i.e., establish an installed base of customers, which then induces software entry and provides the ultimate source from which royalties will be drawn. Once the feedback process is under way, the consumer base and software variety build upon each other. To get the process started, however, it is particularly effective for a hardware producer to attract consumers through price. The price elasticity of demand for hardware by vintage points to the effectiveness of penetration pricing. In fact, as we describe in Section II, console providers priced aggressively in the first few years of console introduction: Table I illustrates that the price cut was on average 28% annually in the first three years of a consoles introduction, while the price drop became more modest at 7.45% when the console is in the market for four years or longer. The price elasticity declines throughout the product cycle, indicating that price cutting is less effective as a console ages. (Although we observe hardware prices declining over time, costs are certainly declining. Penetration pricing is thus most reasonably interpreted as an increasing price-cost margin. Holding the degree of competition fixed in the hardware market, a decrease in price elasticity implies an increasing price-cost margin.[24] It is likely that console producers have followed a strategy of penetration pricing in this sense.)

On the other hand, the elasticity of demand for hardware with respect to software variety is relatively low at the beginning of the product cycle, increases to a peak in the middle of the cycle, and then declines. This suggests that, while a low price is necessary to start the adoption process, software variety is necessary to continue adoption of the console. It is not obvious why the elasticity with respect to software variety is low at the beginning of the product cycle. The industry wisdom seems to be that software provision is crucial for the establishment of a console. This is a primary reason why hardware firms develop their own game titles: they want to ensure the supply of enough high-quality games to start the adoption process. However, our elasticity results indicate that an additional software title has little effect on software adoption early in the cycle. We could speculate that it is necessary to have a set of games to draw early adopters, but that there is little marginal impact beyond this critical level.[25] Later in the product cycle, as the console becomes more mainstream, the variety of software expands greatly, and the impact of each additional title is greater than before. Considering the incentives of a hardware producer, the best strategy in the middle of the product cycle is to encourage software entry directly, perhaps by lowering royalties or relaxing other restrictions on the acceptance of new titles.[26]

Near the end of the cycle, when a platform is in decline, additional software has less effect on demand. This could be due to the fact that by then there is already a large set of software associated with the platform, so each additional title is not worth as much to consumers. At this point, the network effect becomes less important: increases in software variety have less of an effect on hardware demand. Because of competition from newer consoles,

[24] The degree of competition, measured by the annual Herfindahl index from 1994 to 2002, is calculated as 0.47, 0.34, 0.22, 0.40, 0.48, 0.29, 0.28, and 0.38 (the values are divided by 10,000). The magnitude of changes in the index is swamped by the magnitude of those in the price elasticity. Although this inference is based on static homogeneous Cournot competition, it is hard to believe, from our reading of the trade press, that the hardware market became concentrated by a magnitude similar to the elasticity changes during the study period.

[25] To get an idea of what this critical level is, we would need to compare adoption patterns of successful and unsuccessful consoles; i.e., consoles that never quite caught on can give us an indication of how much software provision is necessary to launch a console.

[26] This point perhaps explains why 3DO did not succeed in the market: 3DO expended much of their attention to providing game titles in the early stage of product cycle, rather than to penetrating the console market.

there are not many new adopters. It is in the interest of the platform provider to capture as much surplus as possible from the established installed base.

We have examined a market in which indirect network effects are crucial to the persistence of a technology: without game software, video game hardware is useless. Other notable markets have this same characteristic: PCs and software, CD players and CDs, DVD players and DVDs, and probably more to come in the future. It would be reasonable to guess that the product cycle is similar in all of these markets, and thus that the diffusion strategies discussed here would be useful in these markets also.

VII. CONCLUSION

Network effects and positive feedback loops have received a great deal of attention, academically and otherwise. In a market with network effects, competition among multiple incompatible systems is intense, because a small, initial advantage confers a larger advantage in the future. Many theoretical papers suggest various competitive strategies in a market with strong indirect network effects, but little work has been done on what strategies are most effective in each phase of the product cycle. To tackle this problem, this paper analyzes two sides of the U.S. video game market, hardware adoption by consumers and software provision by game makers, and estimates the elasticities of adoption with respect to console price and software variety. We find that the relative size of the elasticities of hardware demand differs over the product cycle: when a console is introduced, hardware demand is quite elastic with respect to price, but much less elastic with respect to software variety. As the console becomes mature, the price elasticity declines substantially, but the elasticity with respect to software variety increases substantially. The estimation results suggest that, while a sufficiently large set of software may be necessary to launch a system, a platform provider should use penetration pricing to encourage adoption at the outset (i.e., a lower price-cost margin). Once the platform provider succeeds in establishing an installed base, it can expand the installed base, and thus the profitability of the platform, by encouraging software entry. A wider variety of software is crucial for attracting later adopters to the platform.

An important direction for future research is to characterize the dynamics of the market more precisely. By explicitly incorporating dynamic incentives of consumers and game providers into our framework, we can expand upon the inferences drawn in this paper.

APPENDIX: COMMENT ON MULTIPLE EQUILIBRIA

A common implication of models of network effects is the existence of multiple equilibria. Generally, there is an equilibrium in which no consumers buy hardware and no software firms enter. This degenerate equilibrium is eliminated from our model because of the use of logarithm specifications in (2) and (4). With the assumption of linearity in N in (2) (see footnote 10), the model has at most two equilibria; it always has one stable equilibrium, and the other equilibrium, if it exists, is unstable. Substituting N_{gt} in (4) with the right-hand side of (2) yields

$$\ln\left[s_{jt}/\left(1-\sum_{i} s_{it}\right)\right] = \delta_{jt} + B\omega\left(\sum_{q=1\ldots t-1} M_q s_{jq}\right)^{\gamma}, \tag{7}$$

where $B \equiv \exp(\alpha_j + \eta_{jt})$ and M_q is the potential market size for video game consoles at time q. In a steady state, the left-hand side of (7) is monotonically increasing in s_j, and the right-hand side is either a U shape (if $\gamma > 1$), or an inverse U shape (if $\gamma < 1$) with respect to s_j. The stable steady-state equilibrium is where the left-hand side of (7) intersects with the right-hand side from the above. We assume that the data and estimation results correspond to the stable equilibrium.

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