HONGJU LIU*

Nintendo lost its dominant position in the video game industry during the console war between its Nintendo 64 and Sony's PlayStation. However, Nintendo could have made several different strategic decisions to change the outcome. This article develops a structural model and investigates these alternative strategies through policy simulations. In particular, the author provides a framework to study firms' optimal pricing strategies under network effects, consumer heterogeneity, and oligopolistic competition. Consumer heterogeneity provides an incentive for a durable goods manufacturer to price skim, while network effects lead to an opposite motive for penetration pricing. The proposed framework incorporates these two competing motives under oligopolistic competition. The author estimates a demand system that allows for indirect network effects and consumer heterogeneity and then numerically solves for the Markov perfect equilibrium in firms' dynamic pricing game. Policy simulations indicate that Nintendo could have won the console war either with 10% more games or with a "head start" of one million units in installed base at the time of the PlayStation introduction.

Keywords: price skimming, penetration pricing, policy simulation, indirect network effect, dynamic programming

Dynamics of Pricing in the Video Game Console Market: Skimming or Penetration?

In September 1996, Nintendo launched its new video game console, Nintendo 64 (N64), in the U.S. market, while its main competitor, Sony, released PlayStation (PS) one year before in September 1995. As Table 1 indicates, the console war between N64 and PS marked a turning point in the history of the video game industry; Nintendo had dominated the console market for the two previous generations with its Nintendo Entertainment System and Super Nintendo Entertainment System, but Sony became the market leader with PS and continued to dominate the next generation with its PS2.

Nintendo made several far-reaching decisions before the launch of N64, some of which may have contributed to the loss of its dominant position. First, Nintendo allowed Sony to gain a significant first-mover advantage. If Nintendo had released N64 earlier, would the outcome have been different? Second, PS had far more games available than N64 because Sony and Nintendo employed distinct strategies with respect to games. Sony was determined to attract as many game publishers as possible, while Nintendo charged a much higher royalty fee to game publishers and enforced strict content and quality restrictions. Would it have helped if Nintendo had managed to support N64 with more games? Third, Nintendo chose cartridges over CD-ROM as the storage media for games. A cartridge format could lower the production cost of a console, but a CD-ROM format would increase the number of games. Would Nintendo have been better off with a CD-ROM format instead?

It is difficult to answer these questions because the market outcome under such counterfactual situations can never be observed. In particular, firms could have set different

*Hongju Liu is Assistant Professor of Marketing, School of Business, University of Connecticut (e-mail: hliu@business.uconn.edu). This article is based on the author's dissertation. He thanks his thesis advisors—Pradeep Chintagunta, Jean-Pierre Dubé, Günter Hitsch, Jeremy Fox, and Ting Zhu—for their guidance and support. He also benefited from helpful comments and discussions from Junhong Chu; Maria Ana Vitorino; and seminar participants at the University of Chicago, the University of Texas at Dallas, Texas A&M University, the University of Connecticut, Southern Methodist University, the University of Georgia, Cornell University, Hong Kong Polytechnic University, and Hong Kong University of Science and Technology. The article has also improved substantially from the suggestions of the anonymous *JMR* reviewers. All errors remain the author's own. Michel Wedel served as associate editor for this article.

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Table 1
HISTORY OF MODERN GAME CONSOLES

Start Year	*Generation*	*Market Leader*	*Other Major Players*
1985	8-bit	Nintendo Entertainment System	
1989	16-bit	Super Nintendo Entertainment System	Sega Genesis
1995	32-/64-bit	PS	N64, Sega Saturn
2000	128-bit	PS2	Nintendo GameCube, Xbox
2005	Current	Nintendo Wii (up to 2008)	PS3, Xbox 360

prices from the observed ones under a counterfactual situation, which in turn would have led to different unit sales and profits. However, as Franses (2005) and Bronnenberg, Rossi, and Vilcassim (2005) suggest, policy simulations can be used to study the economic consequences of alternative strategic options. Following this approach, this article develops a structural model that allows Nintendo to examine market outcomes of alternative strategies through policy simulations.

Specifically, this article provides a framework to study firms' optimal pricing strategies under the following characteristics of the console market: network effects, consumer heterogeneity, and oligopolistic competition. Such characteristics require a model of dynamic oligopolistic competition. An important feature of this model is that consumer heterogeneity and network effects provide competing incentives for price skimming and penetration pricing, respectively.

Price skimming involves charging a relatively high price at first and lowering it over time. The objective is to "skim" off consumers who are willing to pay more. In contrast, penetration pricing is a strategy in which the initial price is set relatively low in hopes to "penetrate" the market quickly and secure a significant market share.

Historical data show that the price of PS declined over time. This seems consistent with price skimming. Sony priced high initially for hardcore gamers and cut the price later to attract casual gamers. Such a view was echoed in a *Wall Street Journal* article (Guth 2004, p. B1) that commented on a price cut for the Microsoft Xbox: "By many estimates, the latest cycle has peaked because hard-core gamers already have bought their consoles and their favorite games. Now the industry has to focus on casual gamers and other price-conscious consumers, and it is betting that price cuts will lure them."

Conversely, it is widely believed that console makers often incur substantial losses in early stages of a product launch. For example, as another *Wall Street Journal* article (see Wingfield 2006) mentioned, "Hardware makers like Sony often lose money on the sale of consoles in their early days on the market." As Sony went from incurring losses early to breaking even or making profits later, its markup must have increased over time, which implies that, though its price declined, its marginal cost may have dropped even faster.

Why would the markup rise over time? The reason has to do with the video game industry exhibiting indirect network effects, under which the value of a console critically depends on the availability of its complementary goods—namely, video games. The more games available for a particular console, the more attractive this console is to consumers. In turn, as the installed base of a console becomes larger, software vendors are more likely to develop games for it. This mutually enhancing feedback loop between hardware and software provides an incentive for penetration pricing. Hardware firms may be willing to cut prices early to build up the network and attract more game writers to supply games.

Therefore, PS's increasing markup reveals Sony's incentive to engage in penetration pricing despite the falling price, which is consistent with price skimming. Indeed, the existence of heterogeneous consumer segments provides an incentive to skim the market. However, this incentive must be reconciled with the competing incentive to penetrate the market quickly and take advantage of the indirect network effects that exist between consoles and games.

To study firms' optimal pricing strategies in the console market, I first estimate a demand system that allows for indirect network effects and consumer heterogeneity and then proceed to solve for firms' equilibrium pricing policies under falling marginal costs and oligopolistic competition. Because current prices affect future network sizes and future distributions of heterogeneous consumers, firms' pricing decisions are inherently dynamic. Such dynamics are captured by a dynamic oligopoly pricing game. Given the difficulty in obtaining an analytical solution, I use numerical dynamic programming techniques to solve for the equilibrium pricing policies. The equilibrium concept used is Markov perfect equilibrium (MPE) in pure strategies.

After obtaining firms' equilibrium pricing policies, I simulate the price competition between Sony and Nintendo over a life cycle of five years. The predicted prices follow similar patterns to the actual ones—that is, prices fall, but Sony's markup increases over time. Using the mean absolute percentage deviation (MAPD) as a criterion, I find that indirect network effects and consumer heterogeneity are equally important in determining price patterns in the console market.

Network effects, consumer heterogeneity, and falling marginal costs are common features of many high-technology markets. This article develops an empirical model to study firms' dynamic pricing decisions in an oligopoly market characterized by such features. When firms set prices for a new product launch, there are important trade-offs to be made. Price skimming may help recover the product development costs earlier, but this strategy may slow down the growth of the network. Conversely, penetration pricing may lead to a faster diffusion, but at the likely cost of initial profitability. The proposed model clearly illustrates such trade-offs.

Previous empirical studies on network effects have not attempted to solve for firms' optimal pricing policies. In the absence of a pricing model, it is difficult for these studies to evaluate firms' potential policy changes because any perturbation in the market environment might induce firms to price differently. In contrast, this article directly solves the dynamic pricing game, making it possible to perform policy experiments while taking into account adjustments in prices under alternative policy regimes.

In markets with network effects, the importance of first-mover advantages is frequently emphasized (e.g., Shapiro and Varian 1999). Using the proposed model, I am able to quantify the impact of a first-mover advantage in the console market. As observed in the data, by the time N64 arrived in the market, Sony had already sold one million units of its PS. Policy simulations indicate that given a similar "head start," Nintendo could have won the console war. This quantifies the importance of being first to market in an industry in which anecdotal evidence has indeed suggested the importance of being on market first (see Gapper 2006).

Another aspect of PS's success has been attributed to its advantage in having far more games available than N64. If Nintendo had attracted more game publishers, it would have been in a better competitive position. Indeed, policy simulations show that a 10% increment in the number of N64 games would have helped Nintendo surpass Sony and take the lead. Again, the proposed model helps quantify the importance of having a large number of games in this market.

A major decision Nintendo faced was the choice between cartridges and CD-ROM as the storage media for games. A cartridge format would lower the production cost of a console, while a CD-ROM format would increase the number of game titles. I show that unless switching to a CD-ROM format could increase its number of game titles by more than 40%, Nintendo was better off with a cartridge format.

RELATIONSHIP TO THE LITERATURE

Since the work of Robinson and Lakhani (1975), there has been an extensive theoretical literature that has developed dynamic pricing models to incorporate the evolution of costs and demand. More closely related to the current article, Xie and Sirbu (1995) study the dynamic pricing behaviors of an incumbent and a later entrant by incorporating network effects into a diffusion model. They find an increasing price to be optimal under strong network effects. As is typical in this literature, they establish the optimal price trajectories as open-loop controls, whereas I apply numerical dynamic programming techniques to obtain a closed-loop solution. Such a solution is potentially more relevant to managerial decision making in an empirical context. Another feature of previous theoretical studies is that they keep demand specifications simple to derive tractable analytical solutions. Because I use numerical methods to obtain the equilibrium pricing strategies, I am able to use a demand function that has been widely employed in the empirical literature and that may be more appropriate for the market I analyze.

This article also extends the empirical literature on measuring network effects using actual market data. Koski and Kretschmer (2004) review the relevant studies on various network industries. However, the focus of these empirical studies has been on showing the existence of network effects, and none explicitly model a firm's dynamic pricing decisions.

Notably, Nair (2007) numerically solves the dynamic pricing problem of PS game (not console) providers facing declining consumer valuations over time. He finds price skimming to be optimal. The current article differs from Nair's research along several important dimensions. First, I am interested in markets characterized by indirect network effects. As noted previously, this provides a competing incentive to skimming and results in firms possibly adopting penetration pricing. Such an incentive does not exist in Nair's research. Second, Nair assumes that each game is in a monopoly market with consumers choosing between the game and the option of not purchasing it. In contrast, I study an oligopoly market in which a firm must account for the strategic behavior of its rivals. This adds significantly to the complexity of obtaining the equilibrium price paths.

Dubé, Hitsch, and Chintagunta (2010) develop a model to study tipping and concentration in markets with indirect network effects and calibrate the model using data from the game console market. Because their focus is on the role of consumer expectations on tipping, they abstract from certain aspects of the market, including persistent consumer heterogeneity and declining production costs. However, such aspects are crucial to the purpose of the current work, and thus I do not model consumer expectations, focusing instead on indirect network effects, consumer heterogeneity, and declining production costs.

THE 32-/64-BIT VIDEO GAME CONSOLE MARKET

There has been substantial growth in the video game industry over the past two decades. In 2008, revenues for video game hardware, software, and accessories totaled \$21.33 billion in the United States according to the NPD Group (Ortutay 2009), while in comparison movie box office receipts came in at \$9.79 billion, according to the Motion Picture Association of America (2008).

Since the rise and fall of Atari, there have been five generations of game consoles (Coughlan 2000, 2001). The focus of this article is on the 32-/64-bit generation, whose life cycle extended roughly from 1995 to 2001. There were three players in this generation—namely, PS, N64, and Sega Saturn. Sega encountered a series of production and distribution problems with its Saturn product (Coughlan 2001). As a result, it captured only a small market share and exited from the market early. Thus, I restrict attention to the duopolistic competition between PS and N64. The period of this study starts in September 1996 when Nintendo launched N64 in the U.S. market. By this time, PS had been on the market for a year and had accumulated an installed base of one million units.

Figure 1 displays the prices of the two consoles over time. Similar to many other high-technology products, game consoles exhibit declining prices over time. Prima facie, this appears to be price skimming. The rationale is that firms target game enthusiasts first and then move to the mass market through price cuts.

However, although prices dropped over time, Sony's markup may have increased. Indeed, a deep initial loss on each console has been repeatedly mentioned for PS, PS2, PS3, Xbox, and Xbox 360, whereas such losses were reported to shrink or disappear later (eWeek.com 2007; Gomes 2006; Hamm and Greene 2001; Hesseldahl 2008; Reuters 2005; Shim 2001). Because the unit markups on these consoles improved over time, their marginal costs must have dropped even faster than prices.

Although Sony and Nintendo do not disclose their exact cost information, industry analysts have tried to estimate the production costs of various consoles by adding up the bill of materials for parts and factory assembly costs. When Sony launched PS in September 1995, the production cost was estimated to be \$260 (see Alexander & Associates 2002). When N64 was launched in September 1996, Nintendo was said to be able to manufacture a cartridge-based console at \$160 per unit, while PS was believed to cost \$210 each, for a drop of \$50 since it was launched (CIBC Oppenheimer 1998; Morgan Stanley Dean Witter 1998).

Because the cost information is available only twice for PS and once for N64, I make additional assumptions on the function form to determine the cost curves. In each period, the cost function is specified as follows:

$$C_{jt}(Q_{jt}) = c_{jt}Q_{jt} + F_{jt}.$$

Here, c_{jt} is the constant marginal cost, and F_{jt} is the fixed cost. To describe how marginal costs declined over time, I assume the rate of decline to be proportional to the current cost level:

$$\frac{dc_{jt}}{dt} = -b_j c_{jt}.$$

This differential equation gives rise to a marginal cost curve that decreases exponentially over time:

$$c_{jt} = a_j \exp(-b_j t). \tag{1}$$

Note that this specification is consistent with the Moore's law in the semiconductor industry.[1]

Equation 1 implies exogenously falling marginal costs over time. Is this a reasonable assumption? In principle, multiple reasons may contribute to cost declines, including drops in input prices, supply-side economies of scale, and learning-by-doing. However, game consoles are similar in design and build to computers. Most of the components in a game console, such as chips, memory, data storage devices, and so forth, are widely used in other high-technology industries. I believe that economies of scale and learning-by-doing in console production are not as important as dropping component prices in explaining falling marginal costs of game consoles. Therefore, I focus on exogenously falling marginal costs induced by decreases in input prices.

For PS, cost estimates are available at two points in time, which can determine the two parameters a and b in Equation 1, but for N64, only the initial cost of \$160 is available. I obtain the rate of decline by assuming that the marginal costs of N64 and computers declined at a similar rate. Using the Producer Price Index for computers, I estimate the rate at which the price of computers declined. I further assume that the average margin remained stable in the personal computer market during the period of this study.[2] This implies that the marginal cost of computers declined at the same rate as the price. Therefore, the same rate of decline is used for N64.

I have made several assumptions to augment the limited cost information. It is important to ensure that the results are not driven by these assumptions. In Web Appendix A (http://www.marketingpower.com/jmrjune10), I discuss the impact of varying the production costs of both consoles in various ways and show that the results are insensitive to such variations.

After obtaining retail prices and marginal costs, I still need an estimate of the retail margin to calculate wholesale markups. According to the estimates of industry experts, I use a constant retail margin of 20%.[3] Again in Web Appendix A (http://www.marketingpower.com/jmrjune10), I verify the robustness of the results to this assumption by varying the retail margin between 15% and 25%.

In Figure 2, I plot the marginal costs and wholesale markups of both consoles. The marginal cost of PS decreased at a faster pace than that of N64. This seems reasonable because Nintendo decided to stay with the old cartridge format so that it could keep using its existing production facilities, while Sony chose to adopt the relatively new CD-ROM format, which raised the production cost initially but, later on, became much cheaper.

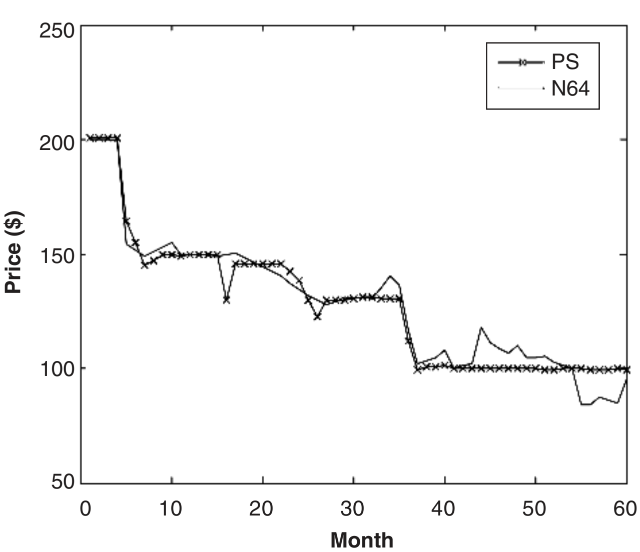
Although the prices of PS and N64 declined, Sony's markup increased over time. This pattern is consistent with the comments from popular press and industry analysts (see Shim 2001; Wingfield 2006). The declining prices seem to indicate price skimming, but the increasing markup indicates that Sony may have tried to cut initial prices and penetrate the market quickly.

There are incentives for both price skimming and penetration pricing in the console market. Consumer heterogeneity provides an incentive for price skimming, while indirect network effects provide a competing incentive for penetration pricing. In the next section, I develop a structural model to study firms' price competition under both factors.

MODEL

Consider an oligopoly market with J competing hardware firms. Each firm offers a single hardware product, indexed

Figure 1
RETAIL PRICES OF PS AND N64

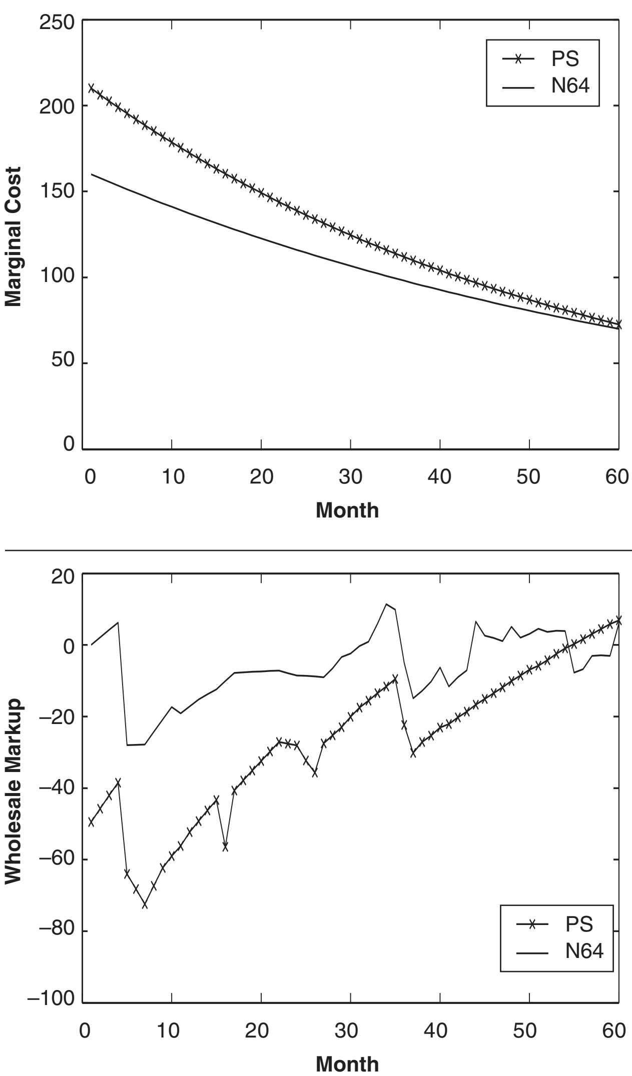


[1]Although an exponential specification is plausible, the results in this article are robust to a linear specification as well.

[2]By reviewing the financial reports of major personal computer manufacturers, I find small variations in their gross margins over time. However, their impact on the rate of cost decline for N64 is small, and the results are robust to such an impact.

[3]According to BBC News (see Scott-Joynt 2004), an average console gives a retail margin of 20%–25%. In a separate report by Merrill Lynch analyst Henry Blodget in March 2001 (see Becker and Wilcox 2001), a 17% retail margin was used to analyze the profitability of the Microsoft Xbox.

Figure 2
MARGINAL COSTS AND WHOLESALE MARKUPS



by j. These hardware products are mutually incompatible, meaning that the software developed for one hardware product cannot be used on another.

Time t is discrete. At each time t, a consumer decides whether to adopt one of the hardware products. Because the product is durable, a consumer exits the market after making a purchase. The timing of the game is as follows: At the beginning of each period, hardware firms make pricing decisions, and software firms make entry decisions based on existing installed bases of hardware products. Given hardware prices and software varieties, consumers then make their purchase decisions.

Demand for Hardware

Consumer i's conditional indirect utility from choosing hardware product j in period t is specified as follows:

$$U_{ijt} = \alpha_{ij} - \beta_i p_{jt} + \gamma_i N_{jt}^{\lambda} + \xi_{jt} + \varepsilon_{ijt}. \tag{2}$$

This specification is similar to the one Nair, Chintagunta, and Dubé (2004) and Clements and Ohashi (2005) derive using a constant elasticity of substitution (CES) utility framework. Here, α_{ij} captures consumer i's intrinsic preference toward product j, p_{jt} is the price of hardware product j in period t, and N_{jt} is the number of software titles that are compatible with hardware product j in period t.

According to Equation 2, a consumer's utility from a hardware product depends on the number of compatible software titles. Therefore, indirect network effects are summarized into a function of the software variety. Although the number of compatible software titles is the single most important summary statistic, as Clements and Ohashi (2005) point out, a limitation of this specification is that it may not be able to incorporate heterogeneity in software quality.

The ξ_{jt} term represents unobserved demand shocks specific to product j and period t. For example, advertising is not captured explicitly by the model and thus contributes to this term. The other error term, ε_{ijt}, represents an individual consumer's taste toward product j.

Following Besanko, Dubé, and Gupta (2003), I use a latent-class approach to capture consumer heterogeneity. Every consumer belongs to one of R segments, and each segment r is characterized by a distinct set of parameters $\{\alpha_{rj}, \beta_r, \gamma_r\}$.

In each period t, a consumer chooses among the J competing hardware products and an outside option (j = 0). The indirect utility from the outside option is normalized to be $U_{i0t} = \varepsilon_{i0t}$.

Consumers' heterogeneous tastes, ε_{ijt} and ε_{i0t}, are assumed to follow an independent Type I extreme-value distribution. So, the market share of hardware product j within segment r is as follows:

$$s_{rjt} = \frac{\exp\left(\alpha_{rj} - \beta_r p_{jt} + \gamma_r N_{jt}^{\lambda} + \xi_{jt}\right)}{1 + \sum_{k=1}^{J} \exp\left(\alpha_{rk} - \beta_r p_{kt} + \gamma_r N_{kt}^{\lambda} + \xi_{kt}\right)}. \tag{3}$$

Let M_{rt} be the size of segment r at time t. The demand for hardware product j is as follows:

$$Q_{jt} = \sum_{r=1}^{R} M_{rt} s_{rjt}. \tag{4}$$

Software Provision

Let Y_{jt} be the installed base or, equivalently, the cumulative sales of hardware product j up to period t – 1. An installed base gives the total number of consumers who might be interested in purchasing a software title that is compatible with a hardware product. The larger an installed base, the more software titles can be accommodated. This relationship is captured by the following software provision equation:

$$\ln N_{jt} = \kappa_j + \varphi_j \ln Y_{jt} + \upsilon_{jt}. \tag{5}$$

With $\varphi_j > 0$, Equation 5 indicates that a larger hardware installed base will induce the development of more software titles. Conversely, with $\gamma > 0$, the indirect utility function (Equation 2) indicates that more software titles will lead to higher demand for the corresponding hardware product.

This interplay between hardware adoption and software provision generates a mutually enhancing feedback loop—the indirect network effect.

As in Nair, Chintagunta, and Dubé (2004) and Clements and Ohashi (2005), Equation 5 can be derived from free-entry equilibrium in the software market. The underlying assumption is that consumer preferences for software follow a CES utility function. In effect, a consumer values all software titles equally. When applying this framework to the video game market, as a limitation I am not able to capture the heterogeneity in the quality of different games. However, for the purpose of studying hardware firms' pricing strategies, Equation 5 captures the indirect network effect between consoles and games in a parsimonious way.

Pricing of Hardware

Hardware firms collect revenues from two sources—hardware sales and software royalties. A royalty fee is levied by a hardware firm for each sale of a software title compatible with its hardware product. To quantify the amount of software royalties that a hardware firm receives, I assume that, on average, hardware firm j will receive f_j dollars of software royalties after selling each unit of hardware product j. Therefore, assuming a constant retail margin of $1 - \tau$ on the hardware product, the profit function of the hardware firm is as follows:

(6) $$\pi_{jt} = (\tau p_{jt} - c_{jt} + f_j)Q_{jt}.$$

Note that the fixed-cost term F_{jt} has been omitted because it does not affect firms' pricing decisions.

In a static framework, firms set prices to maximize single-period profits. However, in a durable goods market with heterogeneous consumer segments and indirect network effects, firms' pricing decisions not only determine current profits but also affect future market conditions and, thus, future profits. With heterogeneous consumer segments, different prices in the current period result in different segment sizes in future periods. With indirect network effects, a lower current price leads to higher hardware sales and more software titles, which in turn makes the product more attractive in later periods. Therefore, firms' pricing decisions are inherently dynamic. Firms set prices to maximize the expected present value of total profits $E[\Sigma_{k=t}^{T}\delta^{k-t}\pi_{jk}]$ over a planning horizon T. Note that a finite horizon is chosen for the empirical context in this article, and δ is a discount factor.

The state vector is $S_t = \{Y_{rjt}\}$, which consists of the installed base of each hardware product in each segment. It summarizes all the payoff-relevant information in period t, and N_{jt} is related to Y_{jt} according to the software provision equation (Equation 5). Let M_{r0} be the initial size of segment r; M_{rt} is also a function of Y_{rjt} according to

$$M_{rt} = M_{r0} - \sum_{j=1}^{J} Y_{rjt}.$$

The marginal cost, c_{jt}, declines exogenously over time. In any period t, marginal costs are determined according to Equation 1. Therefore, c_{jt} does not enter the state space in a finite-horizon game.

The state transition rule is straightforward. Given the current state, actions, and realizations of error terms, the state variable Y_{rjt} evolves according to

$$Y_{rj,t+1} = Y_{rjt} + M_{rt}s_{rjt}.$$

Therefore, the state transition density $P(S_{t+1}|S_t, p_t)$, which is the probability of having a new state S_{t+1} given the current state and prices, is determined by the joint distribution of ξ_t and υ_t.

Equilibrium

Given the current state S_t and hardware prices p_t, the profit function can be written as follows:

$$\pi_{jt}(S_t, p_t, \xi_t, \upsilon_t).$$

Here ξ_t is the vector of hardware demand shocks in Equation 2, and υ_t includes the error terms in the software provision Equation 5. Firms are assumed to set prices before the error terms are realized. Therefore, firms' pricing decisions are based on the expected profit function:

$$\bar{\pi}_{jt}(S_t, p_t) = E[\pi_{jt}] = \int \pi_{jt}(S_t, p_t, \xi, \upsilon)dP(\xi, \upsilon).$$

Let $\sigma_{jt}: S_t \to p_{jt}$ denote firm j's pricing strategy in period t, and let σ_j be the vector of σ_{jt} for all periods. Under a strategy profile $\sigma = \{\sigma_1, \ldots, \sigma_J\}$, which lists the pricing strategies of all firms, the expected present value of firm j's total profits starting from period t is given by the following:

(7) $$V_{jt}(S_t|\sigma) = E\left\{\sum_{k=t}^{T}\delta^{k-t}\bar{\pi}_{jk}[S_k, \sigma_k(S_k)]|S_t, \sigma\right\}.$$

Given some guess about competitors' strategy profile $\sigma_{-j} = \{\sigma_1, \ldots, \sigma_{j-1}, \sigma_{j+1}, \ldots, \sigma_J\}$, firm j will choose a pricing strategy σ_j that maximizes $V_{jt}(S_t|\sigma)$ for any t. In equilibrium, the following Bellman equation must be satisfied:

(8) $$V_{jt}(S_t|\sigma) = \sup_{p_{jt}}\Big\{\bar{\pi}_{jt}[S_t, p_{jt}, \sigma_{-jt}(S_t)] + \delta\int V_{j,t+1}(S_{t+1}|\sigma)dP[S_{t+1}|S_t, p_{jt}, \sigma_{-jt}(St)]\Big\}.$$

Intuitively, firm j just looks for the best response to σ_{-j}.

The equilibrium concept used here is MPE. An MPE is a strategy profile σ such that no firm j would deviate from $\sigma_{jt}(S_t)$ in any subgame starting from state S_t. Formally, for any state S_t, any firm j, and any alternative price p_{jt},

$$V_{jt}(S_t|\sigma) \geq \bar{\pi}_{jt}[S_t, p_{jt}, \sigma_{-jt}(S_t)] + \delta\int V_{j,t+1}(S_{t+1}|\sigma)dP[S_{t+1}|S_t, p_{jt}, \sigma_{-jt}(S_t)].$$

For simplicity, I focus on pure strategy equilibria only. Note that the existence or uniqueness of an MPE in pure strategies is not guaranteed. This is different from the contraction-mapping results in the single-agent dynamic-programming models. However, what is relevant in this case is the existence of an equilibrium at the estimated parameter values, which can be verified by the convergence of the numerical solution algorithm. To address the uniqueness issue, I compute the equilibrium starting from various initial values to check for any evidence of multiple equilibria.

EMPIRICAL STRATEGY AND ESTIMATION

In this section, I estimate the proposed model using data from the 32-/64-bit video game console market. On the basis of the parameter estimates, I proceed to solve for firms' equilibrium pricing strategies in the subsequent section. Because the demand parameters are estimated without imposing supply-side restrictions, it is possible to compare different supply-side models according to their ability to explain the observed price patterns. Benkard (2004), Dubé, Hitsch, and Manchanda (2005), and Nair (2007) take a similar approach.

I have monthly data on price, unit sales, and number of games for PS and N64. Summary statistics of these variables appear in Table 2. A feature of the data is the jump in sales for both consoles during the Thanksgiving and Christmas holiday. Therefore, holiday dummies are used to control for such effects.

The aggregate nature of the data puts a limit on the amount of heterogeneity that can be identified. I assume that consumers are heterogeneous in their preferences toward game consoles but homogeneous in other parameters. In this market, people have different levels of interest in playing games. Hardcore gamers place much higher value on new game consoles than casual gamers. Thus, I believe that it is of foremost importance to account for the heterogeneity in consumer preferences, which can translate into difference in price elasticities, as I discuss subsequently in this section.

Empirically, the demand estimation is based on the following utility specification for consumer i who belongs to segment r:

$$U_{ijt} = \alpha_{rj} + \theta_1 I_{Nov} + \theta_2 I_{Dec} - \beta p_{jt} + \gamma N_{jt} + \xi_{jt} + \varepsilon_{ijt}. \quad (9)$$

Note that N_{jt} appears in linear form. I try to estimate the model with a power function N_{jt}^{λ}, but the exponent λ cannot be precisely estimated, and the hypothesis $\lambda = 1$ is not rejected. Therefore, following Clements and Ohashi (2005), I use a linear specification.

Parameters are estimated in a generalized method-of-moments framework. The moment conditions are constructed by assuming that demand shocks are orthogonal to a vector of instrumental variables. Because the components of a game console are similar to those of a computer, it is reasonable to expect the prices of computers to be correlated with console prices but uncorrelated with the demand shocks in the console market. For similar reasons, I use the Producer Price Index for computers, computer storage devices, and audio/ video devices as instrumental variables. These variables are interacted with console dummies to make the effects brand specific.

Demand shocks ξ_{jt} are not directly observed, but following Berry, Levinsohn, and Pakes (1995), I am able to recover ξ_{jt} from the demand equation (Equation 4) given a set of parameter values. The contraction-mapping property makes this inversion computationally efficient. In Web Appendix B (http://www.marketingpower.com/jmrjune10), I show a simulation study on the recoverability of the demand parameters using this estimation procedure.

To determine the number of different segments in the market, I proceed by adding segments to the model until one of the segment sizes is not statistically different from zero. Besanko, Dubé, and Gupta (2003) and Nair (2007) have taken a similar approach. The data reveal two distinct segments. The demand estimates appear in Table 3. Standard errors are obtained using a bootstrap procedure. A Hansen's J-statistic of .87 ($p = .35$) indicates that the orthogonality conditions cannot be rejected, which provides more confidence on the validity of the instruments.

Although in console preferences are not significantly different from zero in Segment 1, a Wald test ($p < .01$) indicates that N64 enjoys a significantly higher preference than PS. This may be due to a couple of reasons. Nintendo had been extremely popular in the console market ever since the 1980s, while Sony was a new entrant to the console market despite being a strong player in other markets. Furthermore, N64 is a 64-bit console, which renders faster and better graphics than the 32-bit PS.

Consumers in Segment 1 have much higher preferences toward game consoles than those in Segment 2. This suggests that Segment 1 comprises game enthusiasts, and Segment 2 includes mass-market consumers. Table 4 gives the average price elasticities and game elasticities of demand for each segment. Similar to price elasticity, game elasticity measures the change in demand in response to a change in the number of games. Demand is clearly more elastic in Segment 2.

In Figure 3, I plot the quarterly adoption pattern of game consoles by segment. In the first three years, a majority of game consoles are sold to game enthusiasts in Segment 1. Sales to mass-market consumers in Segment 2 began to pick up in the fourth quarter of 1999, right after a price cut from \$129 to \$99 for both consoles. This pattern is consistent with the comments made by a Nintendo executive regarding a similar price cut, from \$149 to \$99, for the next-generation GameCube: "Every time a generation of technology has moved into the true mass market, Nintendo has prospered" (see *Business Wire* 2003).

Parameter estimates for the software provision equation (Equation 5) appear in Table 3. Although PS has a smaller value for parameter φ, its value for parameter κ is much larger. Within reasonable ranges for the hardware installed base Y_{jt}, the effect of a much larger κ dominates that of a smaller φ—at the same installed base, PS would induce the

Table 2
DATA DESCRIPTION

Variable	PS				N64			
	Minimum	*M*	*Maximum*	*SD*	*Minimum*	*M*	*Maximum*	*SD*
Unit sales (in thousands)	33	293	1609	295	6	212	1005	201
Price (\$)	99	126	201	28	69	125	200	30
Number of games	134	654	1158	315	2	145	277	103
Number of observations		66				66		

Table 3

PARAMETER ESTIMATES

Variable	*Estimate*	*SE*
Hardware Demand		
Segment 1: PS (α_{11})	–1.8298	1.6236
Segment 1: N64 (α_{12})	–1.1048	1.5616
Segment 2: PS (α_{21})	–5.8409	1.9511
Segment 2: N64 (α_{22})	–4.4834	1.0237
November dummy (θ_1)	.6620	.1876
December dummy (θ_2)	1.6472	.1679
Price (β)	.0216	.0093
Game variety (γ)	.0026	.0015
Size of Segment 1 (in millions)	23.91	1.47
Software Provision		
PS: κ_1	–4.1429	.2943
PS: φ_1	.6553	.0183
N64: κ_2	–16.6255	.6405
N64: φ_2	1.3471	.0407

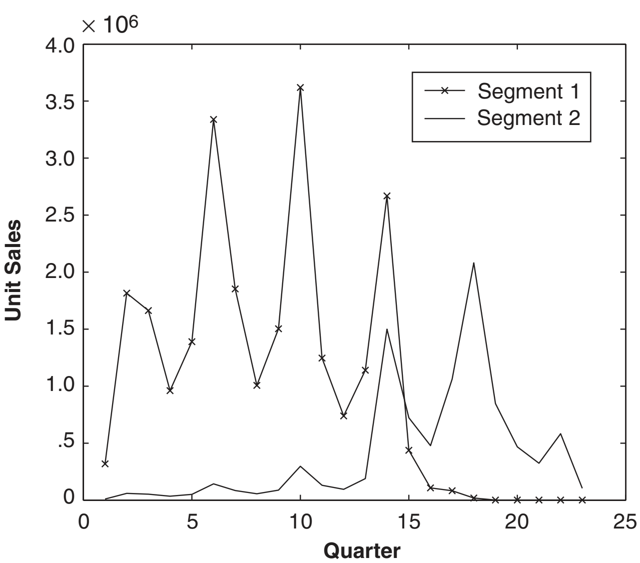
Table 4

ELASTICITY OF DEMAND

	Segment 1		*Segment 2*	
Elasticity	*Own*	*Cross*	*Own*	*Cross*
Price Elasticity				
PS	–2.1655	.5561	–2.7070	.0146
N64	–2.3901	.3099	–2.6847	.0153
Game Elasticity				
PS	1.3530	–.3474	1.6913	–.0091
N64	.3337	–.0433	.3749	–.0021

Figure 3

UNIT SALES BY SEGMENT



development of more games than N64. This is also evident in the observed data. At the end of the period under study, the installed base for PS was approximately 45% larger than that of N64, but there were over three times more games available for PS—1158 games for PS versus only 277 games for N64.

Indeed, the two companies had very different strategies regarding software. Sony strove to support PS with as many games as possible, partly because of the lesson learned from the loss of its Betamax to the opposing VHS standard in the videocassette industry. Meanwhile, Nintendo enforced strict content and quality restrictions, which limited the support from game publishers. In addition, Sony chose CD-ROM as the storage media for PS games, while Nintendo kept using cartridges, which made it much more expensive for game publishers to produce games. A higher production cost, plus a higher royalty fee, left third-party game publishers with much lower gross margins on Nintendo's platform, even though N64 games were priced approximately \$20 higher than PS games (see *BusinessWeek* 1997). Therefore, Sony had a clear advantage over Nintendo with respect to games.

Following the literature on network effects (Clements and Ohashi 2005; Nair, Chintagunta, and Dubé 2004; Ohashi 2003; Park 2004), I use the demand estimates to study the relative importance of network effects in relation to price–quality effects in the console market. Within a consumer segment r, the following relationship can be derived from the utility specification:

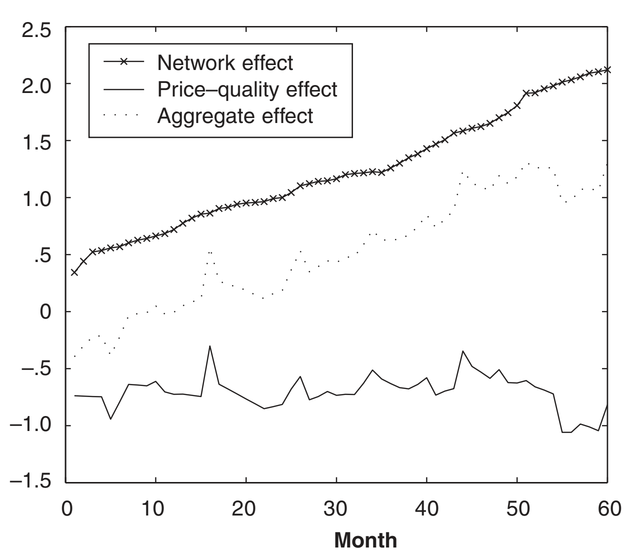
$$\ln\frac{s_{r1t}}{s_{r2t}} = \left[\left(\alpha_{r1} - \beta p_{1t}\right) - \left(\alpha_{r2} - \beta p_{2t}\right)\right] + \gamma\left(N_{1t} - N_{2t}\right) + \left(\xi_{1t} - \xi_{2t}\right).$$

Here, a subscript of 1 indicates PS, and a subscript of 2 indicates N64. The first term on the right-hand side measures the price–quality difference between the two consoles. The second term measures the relative strength of their corresponding networks. I focus on the first two terms because the residual effect represented by the third term is relatively small, with a zero mean. Note that a positive term indicates Sony's lead and a negative term indicates Nintendo's advantage.

Using the observed prices and game varieties, I calculate these two terms for Segment 1 and plot them in Figure 4. I omit the plot for Segment 2 because it follows the same pat-

Figure 4

NETWORK EFFECT AND PRICE–QUALITY EFFECT



tern. The curve on the top corresponds to the relative strength of the networks, and the curve on the bottom represents the price–quality difference. Here, PS clearly enjoys a stronger network effect, while N64 holds the price–quality advantage. The curve in the middle, labeled "aggregate effect," is the sum of the network effect and the price–quality effect. Although Nintendo began with a slight edge over Sony, the ever-growing number of PS games eventually helped Sony overtake its rival.

DYNAMICS OF PRICING

Using the parameter estimates from the previous section, I solve for firms' equilibrium pricing policies and study the resultant price patterns in the console market. Because a product life cycle of approximately five years is expected in this market, I chose a finite horizon of 60 months for the dynamic pricing game between Sony and Nintendo. I assume the discount factor to be .995, which corresponds to an annual interest rate of 6%.

In the profit function equation, τ is assumed to be .8, consistent with the 20% retail margin used previously. To determine f_j, the average amount of royalties that console maker j expects to receive from each unit of hardware sold, I multiply the average game royalty by the software-to-hardware tie ratio, which is the ratio between the cumulative number of games sold and the hardware installed base. In practice, I use $(f_1, f_2) = (72, 56)$ corresponding to average game royalties of ($9, $14) and tie ratios of (8, 4) (Banc of America Securities 2001; CIBC Oppenheimer 1998; Coughlan 2001; Morgan Stanley Dean Witter 1998).

The tie ratios of (8, 4) indicate that an average PS owner bought twice as many games as a typical N64 owner. This is not surprising given that PS had many more games at a much cheaper price. Royalty rates vary depending on the relative bargaining power of the parties involved, but virtually all contracts contain confidentiality provisions that prohibit the disclosure of the specific terms of the agreements. Various sources have reported the PS royalty to be approximately $9 but put the N64 royalty anywhere between $10 and $18. I use the average amount of $14. The robustness of the results to the assumptions made on (f_1, f_2) is verified in Web Appendix A (http://www.marketingpower.com/jmrjune10).

Next, I solve for the MPE in firms' dynamic pricing game. Because of the complexity of this game, an analytical solution cannot be obtained. Therefore, I numerically compute the equilibrium by applying numerical dynamic programming techniques.

Because it is a finite horizon game, I start from the last period and work backward in time. In the last period T, there is no future period, and thus the pricing game is static. Thus, solving for the Bertrand equilibrium, I obtain firms' value functions, $V_{jT}(S_T)$. For any other period $t < T$, I iterate on the Bellman equation (Equation 8) to compute firms' value functions $V_{jt}(S_t)$, given their value functions in the next period, $V_{j,t+1}(S_{t+1})$.

To alleviate the concern for multiple equilibria, I compute the equilibrium using different initial values. The same equilibrium is reached regardless of the initial values. As Doraszelski and Satterthwaite (2005) point out, different iteration schemes on the Bellman equation (Equation 8) can also lead to different equilibria. I tried both Gauss–Seidel and Gauss–Jacobi iterative schemes and found no evidence of multiple equilibria.

At convergence, the equilibrium pricing policies of both firms are obtained. I can then simulate the market evolution for five years. Because one million units of PS had been sold before N64 entered the market, in the simulation, PS is endowed with an initial installed base of one million units. In Figure 5, I plot the predicted retail prices and wholesale markups and compare them with the actual ones. The predicted and actual ones follow similar patterns; that is, the prices of both consoles fall over time, but Sony's markup rises more than Nintendo's.

In the first few months, the observed prices are significantly higher than the predicted ones. A couple of factors might have contributed to this discrepancy. First, firms often have limited production capacity initially, which limits the expected gains from early price cuts. Second, in the beginning, firms may choose to target a small group of consumers with exceptionally high willingness to pay for game consoles. Unfortunately, such a consumer segment cannot be identified with the monthly data available, and only two segments were uncovered (see Table 3).

Price Patterns Without Network Effects

To better understand the impact of indirect network effects on pricing, consider a market situation in which consumers derive no benefit from software—that is, $\gamma = 0$ in the utility specification (Equation 9). Without network effects, firms' pricing decisions are still dynamic because of the existence of heterogeneous consumer segments, which provides an incentive for price skimming. Therefore, in such a scenario, I would no longer expect markups to be increasing over time.

I re-solve the dynamic pricing game with $\gamma = 0$. Figure 6 plots the predicted prices and markups along with the actual ones. When I artificially remove the incentive for penetration pricing, predicted markups for both PS and N64 decrease over time. As such, the PS price would drop by $189 without network effects, but with network effects, it would drop by only $106.

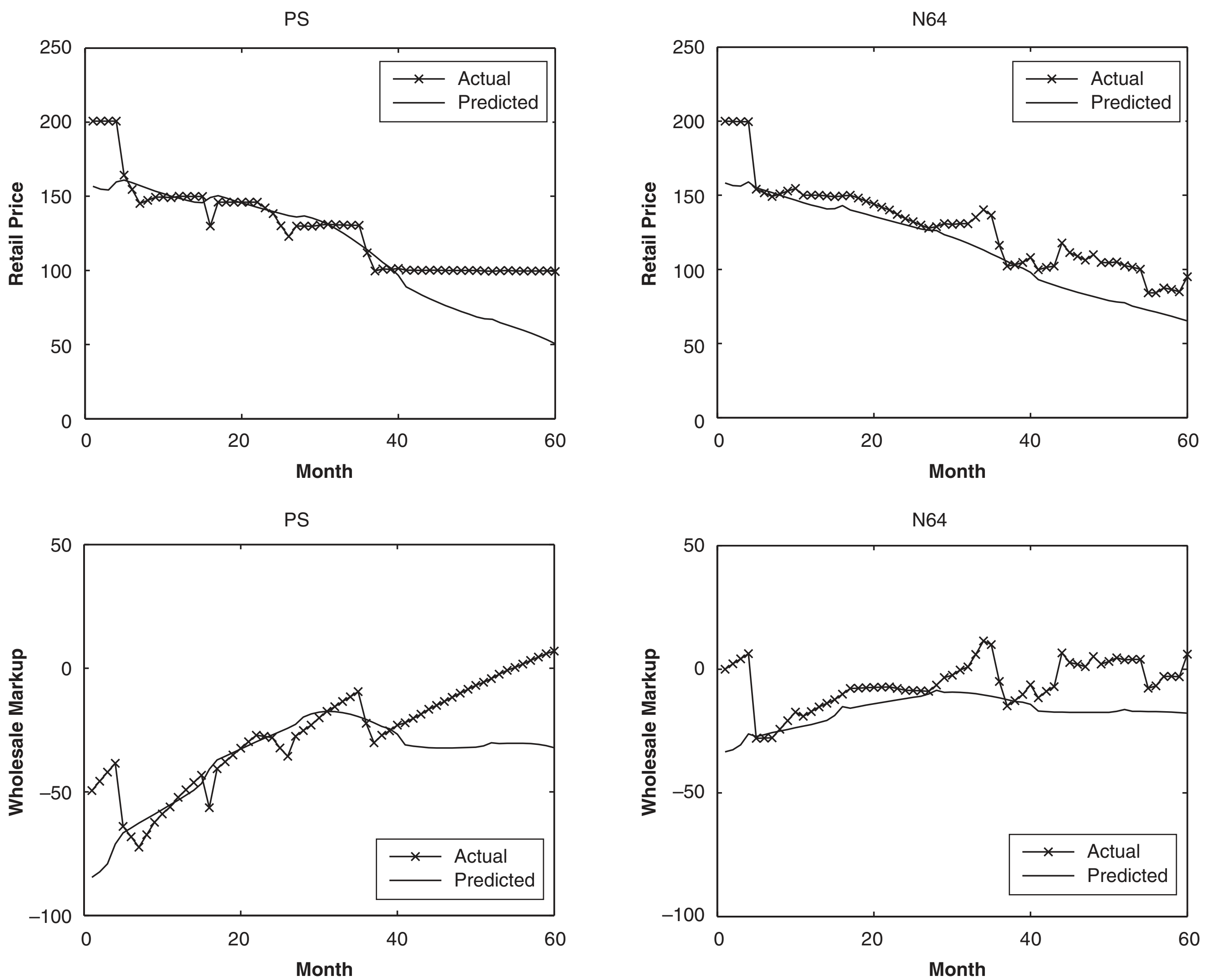
On average, the predicted prices without network effects deviate from the actual ones by 17.5%. I use this MAPD of 17.5% to measure the impact of removing network effects from the market and compare it with the impact of removing consumer heterogeneity in the following subsection.

Price Patterns Without Consumer Heterogeneity

Similarly, I can examine the price patterns without consumer heterogeneity but with indirect network effects. I assume that there is only one segment in the market and that everyone has the same preference levels, which are set to be the weighted average of the preference levels previously estimated (in Table 3). In this case, firms can no longer exploit the heterogeneous consumer segments through intertemporal price discrimination. Therefore, the incentive for penetration pricing under network effects would clearly dominate.

Using the new parameter values, I re-solve the dynamic pricing game. I plot the predicted prices and markups in Figure 7. Although marginal costs declined over time, without consumer heterogeneity, the predicted price for PS would increase by $37. The implied $167 increment in markup is more than three times the originally predicted increment of $52.

Figure 5
PREDICTED PRICES AND MARKUPS



Notes: MAPD in retail price = 11.6%.

In reality, such a strong incentive for penetration pricing in case of homogeneity may be dampened by other factors. For example, if firms set prices too low, the demand can exceed the production capacity. Nevertheless, such dampening factors are beyond the scope of this model, given its focus on the trade-offs between consumer heterogeneity and indirect network effects.

The predicted prices without consumer heterogeneity deviate from the actual ones by 18.9% on average. Compared with the 17.5% deviation in the case of no network effect, this suggests that consumer heterogeneity and indirect network effects are equally important in determining the price pattern in the console market.

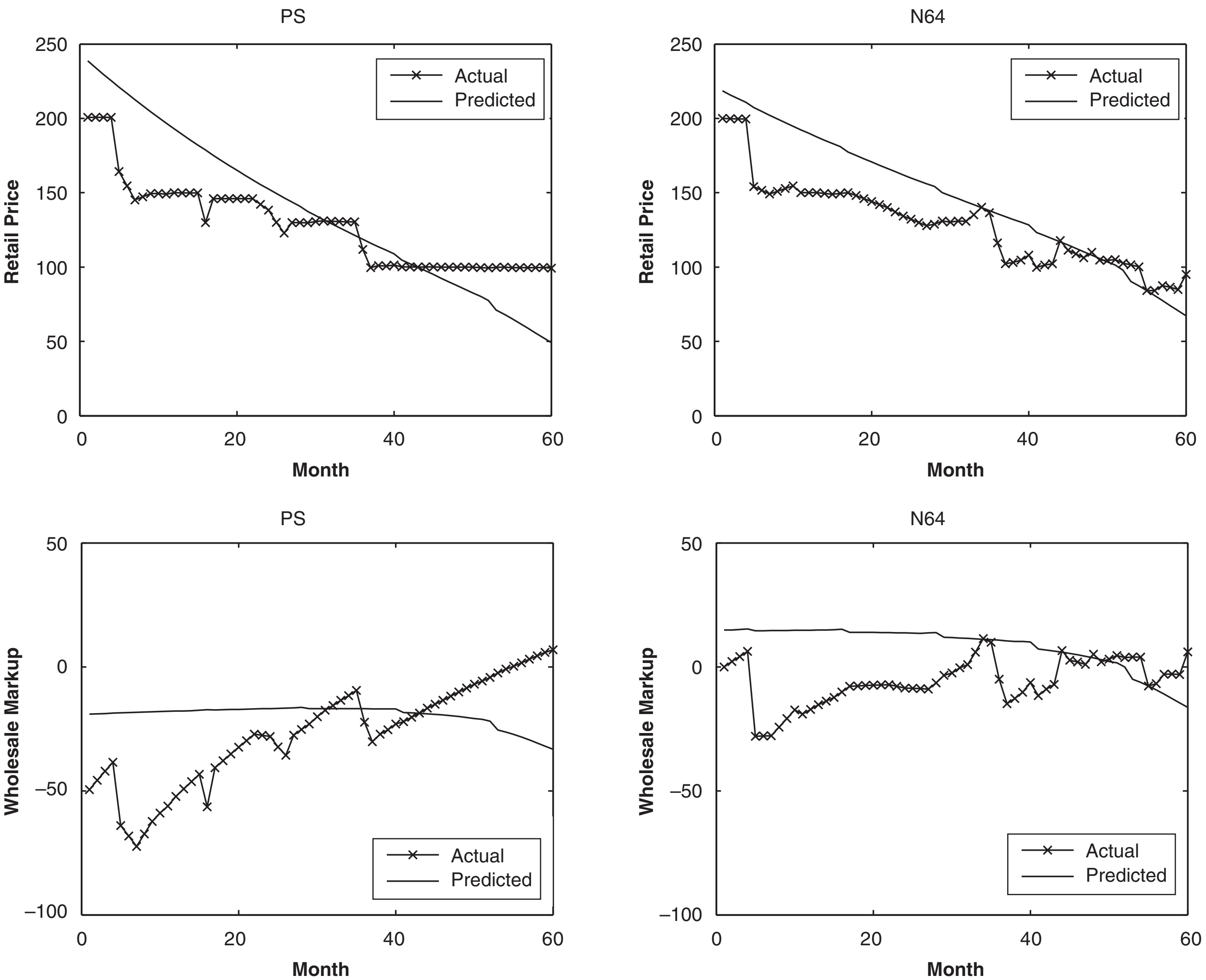
Price Patterns Under Static Pricing

I also examine the implications of a static pricing game in which firms are assumed to be myopic and consider the current period profits only when setting prices. I compute the Bertrand equilibrium in each period and simulate the market evolution. Figure 8 plots the resultant prices and markups. Static pricing predicts stable markups and thus cannot explain the actual patterns in the market.

POLICY SIMULATIONS

Prior empirical studies on indirect network effects have not formally modeled hardware firms' pricing decisions. Consequently, in these studies, it is difficult to evaluate firms' potential policy options. One approach is to hold prices constant when perturbing other variables at firms' disposal. However, such an approach may lead to biased results because any changes in the market environment can induce firms to price differently. Therefore, the adjustment in prices should be taken into account for policy experiments. In this article, by explicitly modeling firms' dynamic price competition, I can perform various policy experiments to study Nintendo's strategic options while taking into account their implications on prices.

Figure 6
PREDICTED PRICES AND MARKUPS: NO NETWORK EFFECT



Notes: MAPD in retail price = 17.5%.

First-Mover Advantages

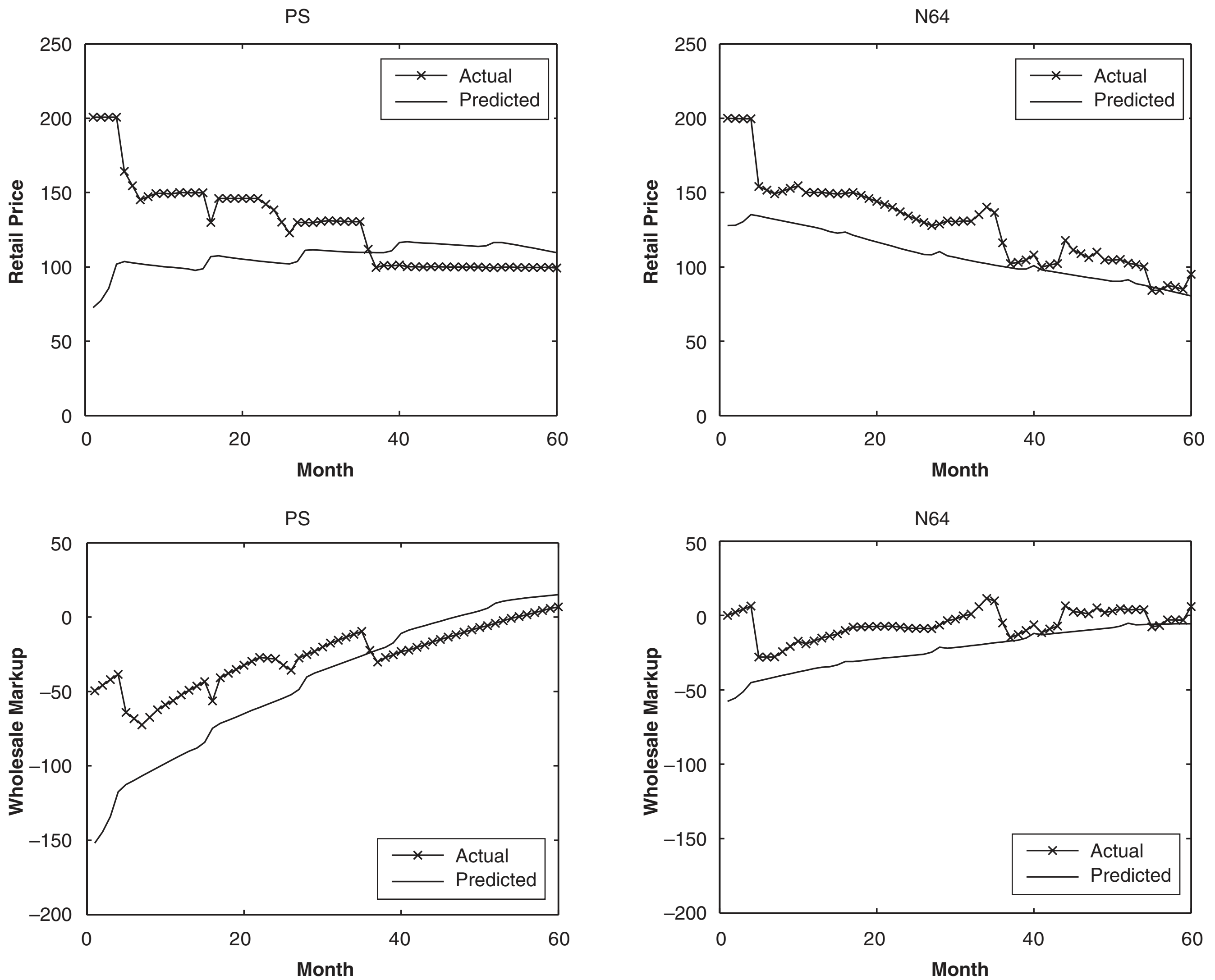
A first-mover advantage may have contributed to PS's success. Because N64 came to the market one year after PS, Sony was able to build up its installed base and game selections before facing the competition from N64. In the end, Sony won the 32-/64-bit console war and went on to dominate the 128-bit generation of game consoles with its PS2. Note that, again, Sony launched PS2 one year before its opponents Xbox and GameCube.

To evaluate the consequences of first-mover advantages, I use firms' equilibrium pricing policies obtained previously to simulate the market evolution starting from different initial states. Specifically, I let Sony's head start, measured by its installed base at the time of Nintendo entry, vary from negative five million (i.e., Nintendo has an installed base of five million units at the time of Sony's entry) to positive five million (i.e., Sony has an installed base of five million units at the time of Nintendo's entry).

Figure 9 plots the installed base at the end of the five-year period and the present value of total profits against the head start for Sony. The pivotal role of having a first-mover advantage in this market is evident. Given a head start of one million units, Sony became the market leader, but given a similar head start, Nintendo could have won the console war.

In particular, with a head start of 1 million units, after five years, Sony is predicted to have an installed base of 18 million units and profits of $489 million, while Nintendo is predicted to have a 15 million installed base and profits of $512 million. However, if Nintendo had a similar head start, Sony would have ended up with a 14 million installed base and profits of $387 million, while Nintendo would have had an 18 million installed base and profits of $566 million. Thus, Sony's profits would change by $102 million, while Nintendo's profits would change by only $54 million. This suggests that a first-mover advantage is especially important to Sony, which may be caused by a higher intrinsic preference for N64.

Figure 7
PREDICTED PRICES AND MARKUPS: NO HETEROGENEITY



Notes: MAPD in retail price = 18.9%.

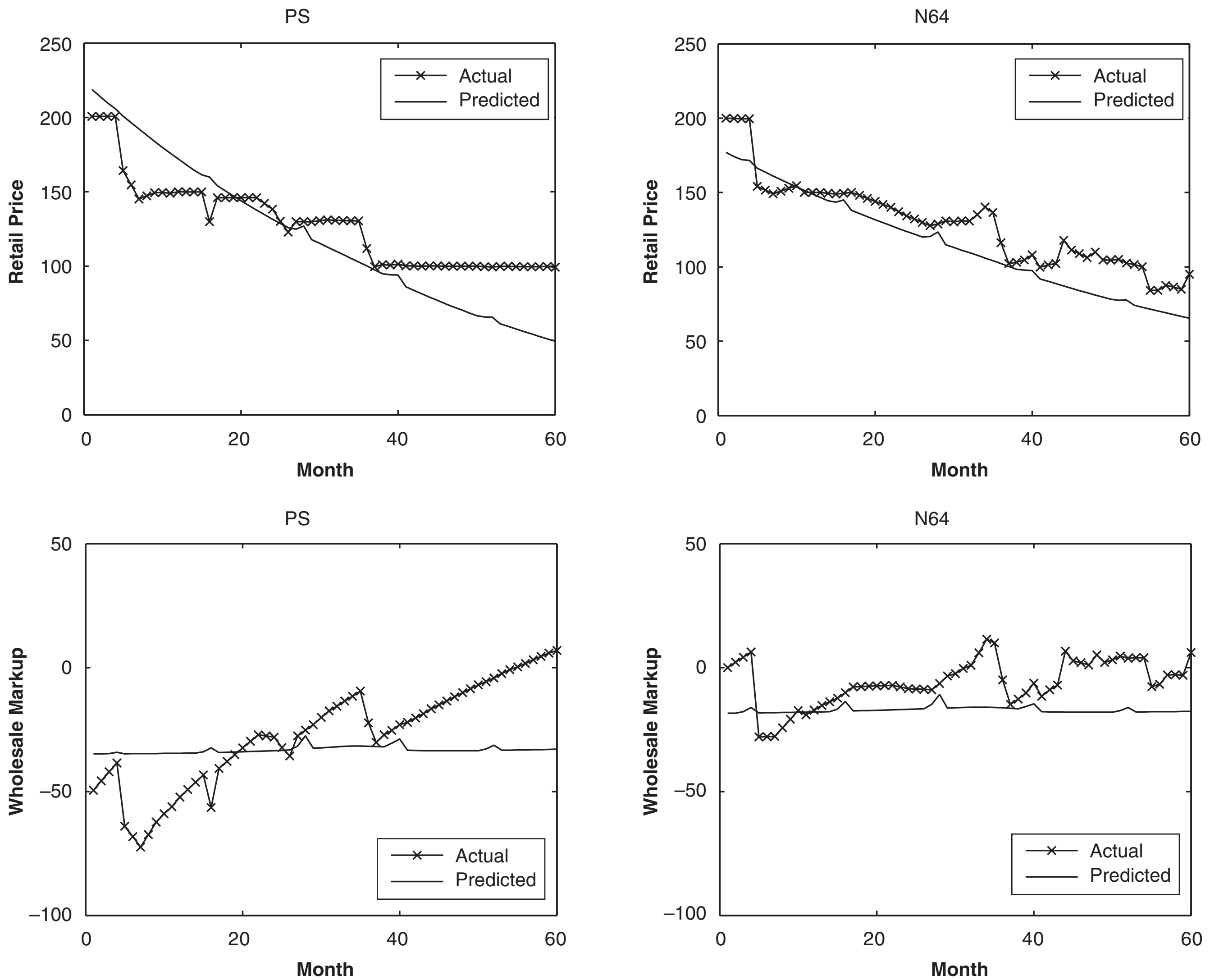
There might have been some other reasons behind Nintendo's decision to delay the launch of N64. For example, Nintendo might have hoped to collect more revenues from its previous console, while Sony did not have a similar concern. Admittedly, the preceding analysis focuses on the 32-/64-bit generation only. In addition, an implicit assumption in this experiment is that parameter values are independent of the product launch schedule. In Web Appendix C (http://www.marketingpower.com/jmrjune10), I discuss the potential impact of relaxing this assumption.

It Is All About Games

A major reason behind PS's success is its advantage in game variety (i.e., having more games at the time of launch and thereafter). If Nintendo had been able to attract more game publishers, it would have been in a better competitive position. To evaluate the effect of an improvement in N64's game variety, I assume that certain shocks in the cost structure of the software market had increased the parameter κ_2 in the software provision equation (Equation 5). In turn, this would result in a corresponding increase in the number of games titles for N64 at any given hardware installed base. With more games, Nintendo would have received more royalties, and thus parameter f_2 in the profit function equation (Equation 6) would have increased by the same percentage as the number of game titles.

For each different value of the percentage increase, I re-solve the dynamic pricing game and simulate the market evolution beginning from the observed head start of one million consoles for PS. Figure 10 describes the market outcomes for different percentage increments in the number of N64 games, highlighting the importance of having many compatible games; a 10% increment in the number of N64 games would have helped Nintendo surpass Sony and become the market leader. In addition, with a 10% increment in its number of games, Nintendo would have addi-

Figure 8
PREDICTED PRICES AND MARKUPS: STATIC PRICING



Notes: MAPD in retail price = 15.8%.

tional profits of $71 million. Therefore, it might have been profitable for Nintendo to provide monetary incentives to encourage software firms to develop more games for it.

The Choice Between Cartridges and CD-ROM

Before the 32-/64-bit generation, previous consoles used cartridges as the storage media for video games. As CD-ROM technology gained widespread adoption, console makers needed to decide whether to switch away from cartridges. Eventually Sony chose to adopt the CD-ROM format, but Nintendo kept using cartridges.

The CD-ROM format significantly reduces the manufacturing cost of games, which leads to lower game prices and more game sales. Thus, it is more appealing to game publishers. Nonetheless, because Nintendo had extensive experience with the cartridge format, it was much cheaper for Nintendo to produce a cartridge-based console (CIBC Oppenheimer 1998; Morgan Stanley Dean Witter 1998). To examine more carefully the trade-offs involved in this decision, I perform a counterfactual experiment to find out what would have happened if N64 had adopted the CD-ROM format.

I assume that as a result of the format switch, N64's marginal cost increases to the same level as PS's, but in exchange, N64's number of games and amount of royalties increase by a certain percentage. For hypothetical values of this percentage increase, I re-solve the dynamic pricing game and rerun the simulation. Figure 11 shows the results. To facilitate the comparison with the original case, the final installed bases and profits under the original parameter values are also included and represented by horizontal lines. The figure shows that Nintendo would have been strictly worse off by choosing the CD-ROM format unless the number of N64 games increased by more than 40% (as a result of switching to CD-ROM).

Figure 9
FIRST-MOVER ADVANTAGES (ALL NUMBERS IN MILLIONS)

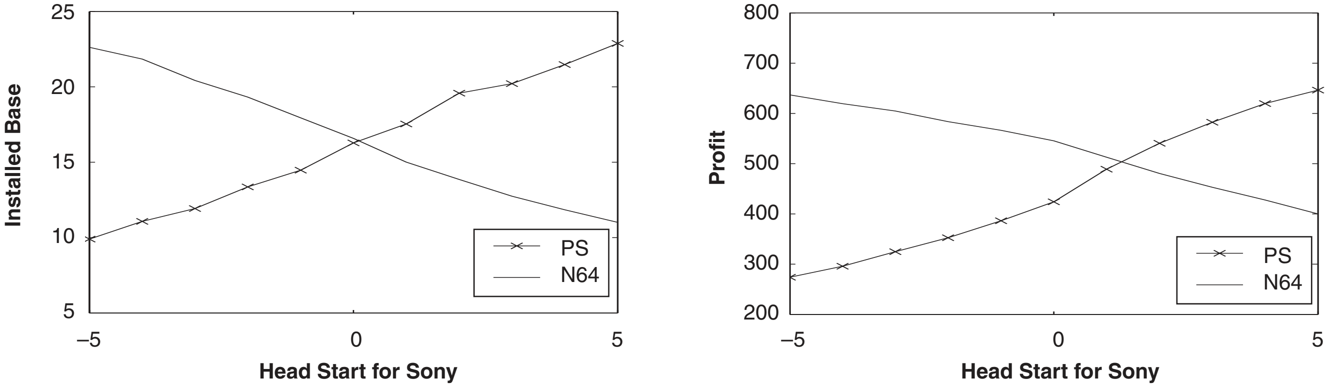
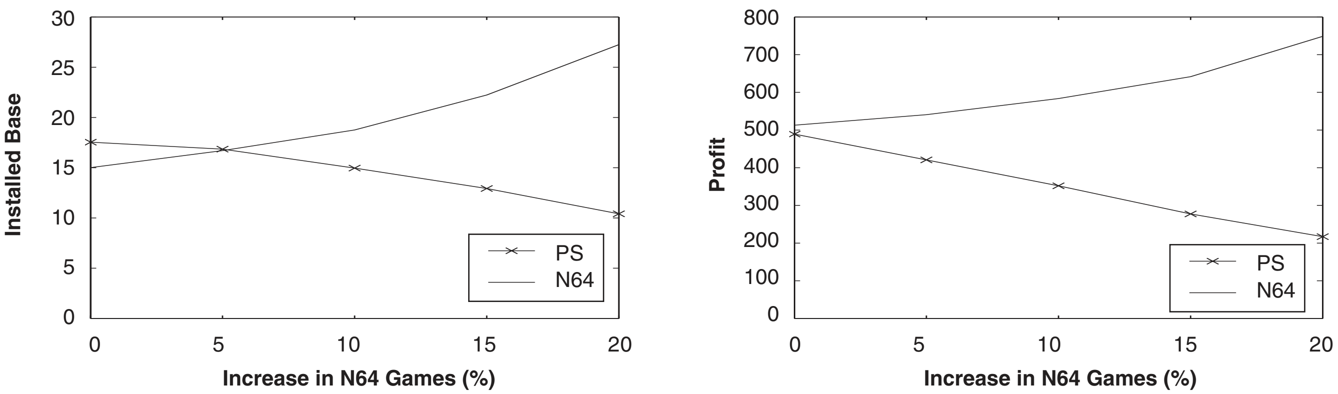


Figure 10
MORE GAMES FOR N64



CONCLUSIONS

Using a structural model and policy simulations, this article examines Nintendo's alternative strategic options in the console war between its N64 and Sony's PS. The results show that Nintendo could have won the console war either with 10% more games or with a head start of one million units in installed base at the time of the PS introduction. Switching from cartridges to CD-ROM would not have helped unless it could increase the number of games for N64 by more than 40%.

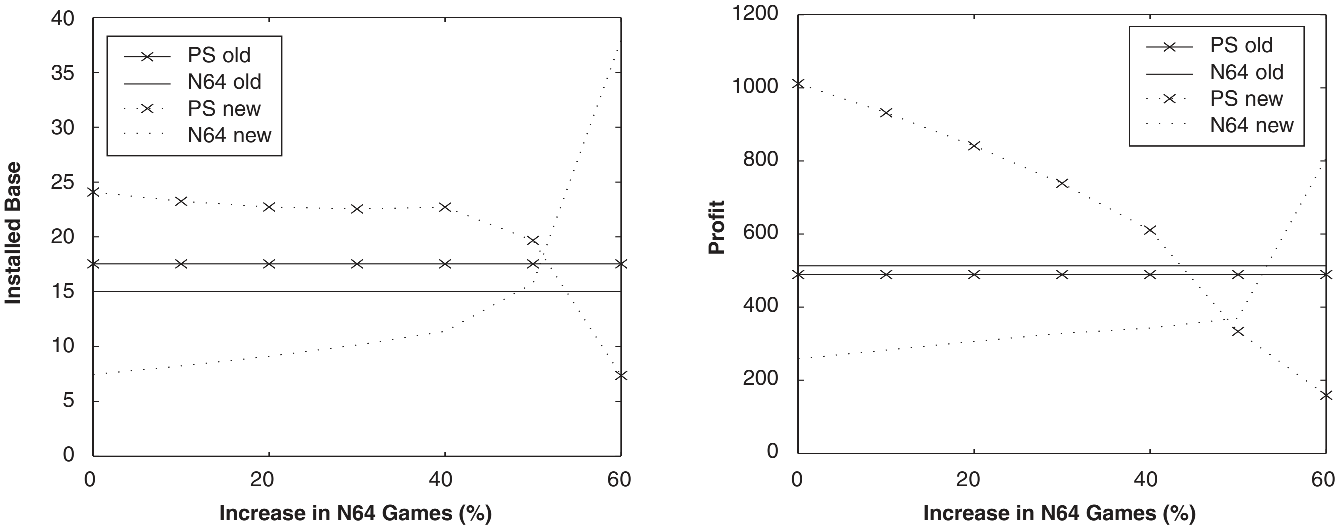
The characteristics in the console market, including indirect network effects, consumer heterogeneity, declining costs, and oligopoly competition, are common to many other high-technology markets. With these characteristics, the choice between price skimming and penetration pricing can be difficult to make. Marketers can use the model proposed in this article to evaluate the trade-offs between the two pricing strategies.

Several limitations of this model leave opportunities for further research. First, consumers' expectations on future prices and software varieties may play a role in their adoption decisions. Nair (2007) and Dubé, Hitsch, and Chintagunta (2010) assume that consumers' expectations are "rational" in the sense that consumers' and firms' expectations are mutually consistent in equilibrium. However, incorporating rational expectations from consumers would dramatically increase the computational burden. Thus, I do not model consumer expectations and instead focus on the more important factors for the purpose of this article, namely, indirect network effects, consumer heterogeneity, and declining costs. As I show, the proposed model is able to explain the actual price and markup patterns reasonably well.

Some simplifying assumptions have also been made regarding the software market. For example, indirect network effects are summarized into a function of software variety, which makes it possible to abstract from modeling the heterogeneity in game quality. Although it is desirable to relax such assumptions and develop a more elaborate model for the software market, I leave this for further research, given that the focus of the article is on the pricing decisions of hardware firms.

There have been several generations of video game consoles. This study focuses on the price competition between the two major hardware firms within a particular generation and takes the market structure as given. In addition to pricing decisions, firms may strategically decide on the timing

Figure 11
MORE GAMES FOR A CD-ROM-BASED N64



of entry, exit, and product replacement. Future work might model these decisions jointly.

In summary, this article provides a framework to study firms' optimal pricing strategies under network effects, consumer heterogeneity, and oligopolistic competition. I show how these factors have played a role in the pricing of 32-/64-bit video game consoles and examine several issues of interest in this industry, such as first-mover advantage, the role of games, and format choice. At the same time, I consider this a first step in studying the pricing decisions of a complex industry and hope that further research will shed more light on these and related issues.

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