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RESEARCH NOTES AND COMMENTARIES

NETWORK EFFECTS AND COMPETITION: AN EMPIRICAL ANALYSIS OF THE HOME VIDEO GAME INDUSTRY

VENKATESH SHANKAR[1] and BARRY L. BAYUS[2]*
[1] *Robert H. Smith School of Business, University of Maryland, College Park, Maryland, U.S.A.*
[2] *Kenan-Flagler Business School, University of North Carolina, Chapel Hill, North Carolina, U.S.A.*

Building on the resource-based view of the firm, we advance the idea that a firm's customer network can be a strategic asset. We suggest that network effects are a function of network size (i.e., installed customer base) and network strength (i.e., the marginal impact of a unit increase in network size on demand). We empirically study these network effects in the 16-bit home video game industry in which the dominant competitors were Nintendo and Sega. In the spirit of the new empirical IO framework, we estimate a structural econometric model assuming the data are equilibrium outcomes of the best fitting noncooperative game in price and advertising. After controlling for other effects, we find strong evidence that network effects are asymmetric between the competitors in the home video game industry. Specifically, we find that the firm with a smaller customer network (Nintendo) has higher network strength than the firm with the larger customer base (Sega). Thus, our results provide a possible explanation for this situation in which the firm with a smaller customer network (Nintendo) was able to overtake the sales of a firm with a larger network size (Sega). Copyright © 2002 John Wiley & Sons, Ltd.

INTRODUCTION

In many industries, the network of consumers using compatible products or services influences the benefits of consumption. Positive network effects arise when the consumer utility of using a product or service increases with the number of users of that product or service. The telephone system is a widely used example since it seems clear that the value of being part of the network rises as the network size increases. Consumption benefits can also arise in markets where a large customer network leads to increases in complementary products and services, which in turn leads to increased consumer utility (e.g., see Farrell and Saloner, 1985; Katz and Shapiro, 1985). Prominent examples of industries thought to exhibit network effects include automated bank teller machines, computer hardware and software, videocassette recorders, video games, and Internet web browsers. Not surprisingly, network externalities and the implications of having a large installed customer base are receiving increased

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*Correspondence to: Barry L. Bayus, Kenan-Flagler Business School, University of North Carolina, CB3490, Chapel Hill, NC 27599, U.S.A.

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attention by strategy researchers (e.g., Hill, 1997; Schilling, 2002).

As noted by Majumdar and Venkataraman (1998), the literature related to network effects broadly tackles three categories of research questions: (1) technology adoption decisions (e.g., what factors are related to whether and when a new technology is adopted); (2) technology compatibility decisions (e.g., what factors influence a firm's decision to seek compatibility); and (3) decisions among competing incompatible technologies (e.g., what factors are related to consumers' choices among rival incompatible products within a single product category). While theoretical research has addressed all three of these categories, empirical research has been limited to the first and second categories of questions (e.g., see the review by Economides, 2001).

With the exception of a few industry case studies (e.g., Gabel, 1991; Grindley, 1995), we are unaware of any published studies that empirically investigate the nature of network effects in an industry with multiple competing product technologies that are incompatible. Consequently, the purpose of this paper is to explore the third category of research questions that has received scant empirical attention; i.e., we investigate the possible network effects that might exist for a set of competing firms with incompatible product technologies. This general situation is important since many markets have more than one product standard in equilibrium. For example, currently in the PC market there are three major operating systems (Windows, Mac, and Linux) and in the cellular phone market there are three standards (CDMA, TDMA and GSM). Even the telephone system initially had multiple, competing networks that were incompatible (e.g., Mueller, 1997). Important questions in this context include the following. Do network effects exist within each competing product technology? What is the nature of these network effects? Are these network effects symmetric across firms? What are the implications of network effects on the outcome of competition among firms with incompatible technologies?

A more extensive version of this paper that includes a detailed discussion of the literature, video game industry, modeling approach, statistical estimation issues, and implications is in Shankar and Bayus (2002).

A THEORETICAL FRAMEWORK FOR NETWORK EFFECTS AND COMPETITION

The resource-based view suggests that firm capabilities and resources are related to long-term competitive advantage (e.g., Wernerfelt, 1984; Barney, 1991). Firms can achieve competitive advantage through heterogeneous, rare, and difficult-to-imitate assets or resources. The resource-based view goes on to suggest that how the firm uses its assets is a key determinant of a sustainable competitive advantage. In this paper, we propose that a firm's customer network is an important strategic asset that can be used to gain a competitive advantage. A customer network helps a firm gain an advantage by creating an isolating mechanism. An isolating mechanism is a phenomenon that protects a firm from imitation and preserves its rent streams (Rumelt, 1984). Particularly for incompatible product technologies, installed customer bases are heterogeneous across competitors, and are rare and difficult to imitate.

The effects associated with a customer network are not only a function of *network size*, but also *network strength*. A firm's network size is equivalent to its installed user base, whereas network strength can be viewed as the marginal impact of a unit increase in network size on demand. Drawing on the community focus theory of Feld (1981) and the social ties of belonging and sharing embedded within groups as described by Homans (1974), the source of a firm's network strength stems from the customers in its installed base. Importantly, network strength may be based on virtual or physical customer 'communities' and can vary across firms (e.g., Balasubramanian and Mahajan, 2000). Particularly strong customer networks share a common, underlying (actual or perceived) bond along some important dimension (e.g., personal interests, demographic characteristics, fanatical product loyalty). While some firms are pleasantly surprised with the existence of high network strength for their products (e.g., Apple, Harley-Davidson), others attempt to actively create, manage, and leverage their network strength (e.g., Saturn, Amazon.com). For a more complete discussion, see Rosen (2000). A firm's network strength is a strategic asset because the social ties among members in such a customer network constitute an imperfectly imitable socially complex resource (Barney, 1991). In addition, loyalty among members of a firm's customer base can make network strength a strategic asset (Wernerfelt, 1984).

As noted earlier, an installed customer base can positively affect demand when the utility of using a product increases with the number of users of that product, or when a large customer network leads to increases in complementary products and services. In addition, an existing customer network might influence the effectiveness of a firm's marketing mix decisions such as price and advertising. For example, customers are willing to pay a price premium for Microsoft's Excel, a spreadsheet product that boasts a large network of users (Brynjolfsson and Kemerer, 1996). Similarly, through its 'Friends and Family Long-Distance Calling Plan' (which increased the benefits to users when more users joined), MCI dramatically increased the effectiveness of its limited advertising budget (*Wall Street Journal*, 1995). In each of these cases, customer response to a given marketing mix decision (e.g., price and advertising elasticities) is a function of the firm's customer network.

Thus, network effects can be direct, that is, the direct effect of an installed customer base on demand, or interactive, that is, the effects operate through the interaction of an installed customer base with one or more marketing mix variables such as price and advertising. These interactive network effects are important to consider since they impact the firm's marketing mix decisions. The total network strength of a firm is reflected in its direct and interactive network effects.

THE HOME VIDEO GAME INDUSTRY

We empirically explore the nature of network effects in the 16-bit home video game industry. The network effects associated with a large customer base of hardware users are very important in this industry since they are typically associated with increased complementary products (e.g., software titles, licensed products, television cartoon shows, videos and movies), which in turn leads to greater utility and thus greater hardware demand. There are also benefits to a large user base from the word-of-mouth discussions of game strategies and experiences that take place between users of the same hardware system, as well as from the borrowing and swapping of games (e.g., Monopolies and Mergers Commission, 1995).

The two primary competitors in 16-bit hardware systems, Sega and Nintendo, offered incompatible product technologies. These product technologies were not backward (or forward) compatible with other systems offered in either firm's product line. Firms in this market did not compete by changing their 16-bit product, but instead competition primarily involved varying hardware price and advertising. The business strategies of Nintendo and Sega centered on their hardware systems, and these firms did not exhibit long-term strategic pricing or advertising behavior. By 1993, Nintendo had shifted its emphasis from the 8-bit NES to the 16-bit SNES, and had survived a government antitrust investigation due to its large installed base of 8-bit systems. These two firms had asymmetric installed customer bases (at the end of 1992, Sega had an installed base of 6.9 million units and Nintendo only had an installed base of 4.2 million units of 16-bit systems). Each firm made different hardware pricing and advertising decisions during this period, and obtained different outcomes; i.e., the firm with the smaller installed customer base of 16-bit systems (Nintendo) was able to eventually overtake the firm with the larger installed base (Sega) in monthly demand (see Table 1).

A MODEL OF NETWORK EFFECTS AND COMPETITION

Given the advances in game theory indicating that market outcomes (e.g., demand) and profitability are not only a function of broad structural variables but also significantly related to market- and firm-specific characteristics (e.g., the different demand and cost structures of competitors, the order of decisions by rivals) as well as rival firms' strategic decisions (e.g., Moorthy, 1993), to more fully understand the impact of a firm's strategic decisions on its performance we have to simultaneously understand its effects on demand, costs, and competitor reactions. To do this, researchers within the 'new empirical industrial organization' (NEIO) tradition develop and estimate structural econometric models where firm decisions are based on profit maximization and the decisions of competing firms are interdependent (i.e., the strategic decisions of one firm cause a reaction from its competitor). There are several advantages to the NEIO approach (e.g., Kadiyali, Sudhir, and Rao, 2001).

Table 1. Annual summary of data for the U.S. home video game industry

	1993	1994	Through August 1995
Nintendo 16-bit unit sales (in millions)	1.91	1.66	0.52
Sega 16-bit unit sales (in millions)	2.59	2.03	0.45
Nintendo 8-bit installed base (in millions)	25.7	26.0	26.2
Nintendo 16-bit installed base (in millions)	4.8	6.6	8.0
Sega 16-bit installed base (in millions)	7.6	10.1	11.7
Nintendo 16-bit top 10 software sales (in U.S. dollars, millions)	19.2	66.0	36.0
Sega 16-bit top 10 software sales (in U.S. dollars, millions)	56.4	50.4	34.8
Nintendo advertising expenditures (in U.S. dollars, millions)	46.4	47.2	22.5
Sega advertising expenditures (in U.S. dollars, millions)	46.9	40.7	11.6
Nintendo 16-bit average price (in U.S. dollars)	120	115	122
Sega 16-bit average price (in U.S. dollars)	112	118	114

Since structural models are based on a behavioral theory of firms (e.g., profit maximization), the estimated parameters have economic meanings that can be directly interpreted. The estimated parameters of structural models are invariant to policy changes (due to the simultaneous consideration of demand, costs, and competitive reactions), allowing for 'what if' analyses associated with changes in a firm's decision variables. The structural approach also provides an opportunity to empirically test alternative theories of strategic interaction since the best-fitting model can be considered to represent the particular market situation being studied. These advantages, however, come at a cost. Since NEIO studies consider greater details associated with the competition between firms in a particular situation, they are really only case studies that do not offer clear generalizations. Instead, generalizations come from the replication of NEIO results across similar competitive situations (e.g., Kadiyali *et al*., 2001).

Given our interest in studying the possible network effects for competing firms with incompatible product technologies, it is important to consider the different demand structures of the competitors (e.g., competitors can have different network sizes and network strengths) as well as the strategic interaction of the competing firms. Thus, we follow the NEIO research approach. Using data from the home video game industry, we will estimate a structural econometric model assuming the data are equilibrium outcomes of the best-fitting noncooperative game in price and advertising. We consider a situation with two firms, each offering its own proprietary and incompatible product technology. Each firm decides on the price and advertising expenditures for its product. We model the direct effects of each firm's customer network on its demand, as well as possible interactive network effects that may operate through price and advertising. Given the nature of the video game industry, we also consider the possible effects of Nintendo's (incompatible) installed base of 8-bit systems and the possible effects due to firm differences in software quality.

The demand model

We consider a situation of two competing firms, each having a demand function of the following form:

$$Q_{it} = e^{\alpha_{it}} P_{it}^{-\eta_{it}} A_{it}^{\beta_{it}} P_{jt}^{\varepsilon_i} A_{jt}^{-\gamma_i}$$
$$i = \text{N(intendo), S(ega)} \quad i \neq j \qquad (1)$$

Here, Q_{it} = firm i's demand at time t, P_{it} = firm i's price at time t, and A_{it} = firm i's advertising expenditures at time t. Further, α is the parameter for brand-specific effects, η and β are the own price and advertising elasticities, and ε and γ are the cross-price and cross-advertising elasticities. All the parameters are assumed to be nonnegative. Consistent with prior research that finds asymmetric price and advertising elasticities across firms, we do not impose any constraints that these parameters must be equal across competitors. In line with the published empirical literature, we also expect that there are diminishing marginal returns to advertising ($\beta_{it} < 1$, $\gamma_i < 1$) and the own price elasticity η_{it} is greater than one.

In line with other empirical studies of network effects (e.g., Majumdar and Venkataraman, 1998), we consider firm i's 16-bit network size at time t, $B16_{it}$, to be exogenously determined. This simplifying assumption seems reasonable for exploring the role of network effects in a competitive situation characterized by firms with short planning horizons (i.e., this analysis should at least provide a lower bound on possible network effects). Further, we also consider the effects of firm i's software quality at time t, K_{it}, since it is expected to influence firm i's demand, as well as the effectiveness of its price and advertising. Finally, we control for the possible effects of Nintendo's existing installed base of 8-bit systems at time t, $B8_{Nt}$.

Letting α_{1i} be firm i's direct network effect coefficient, we incorporate the direct effects of a firm's customer network through the exponential intercept term in the demand equation (1):

$$\begin{aligned} \alpha_{Nt} &= \alpha_{0N} + \alpha_{1N} B16_{Nt} + \alpha_{2N} K_{Nt} + \alpha_{3N} B8_{Nt} \\ \alpha_{St} &= \alpha_{0S} + \alpha_{1S} B16_{St} + \alpha_{2S} K_{St} \end{aligned} \tag{2}$$

Here, α_{0i} captures possible brand-specific effects that are constant over time and not explicitly accounted for by the other variables. We also include appropriate terms in (2) for K_{it} and $B8_{Nt}$. Following the established literature on network effects, we expect that α_{0i}, α_{1i}, α_{2i} and α_{3N} are non-negative. Our primary interest is in the parameters α_{1N} and α_{1S}, both of which we expect to be positive.

The possible influence of a customer network on the effectiveness of a firm's price decision is captured through its own elasticity:

$$\begin{aligned} \eta_{Nt} &= \eta_{0N} - \eta_{1N} B16_{Nt} - \eta_{2N} K_{Nt} - \eta_{3N} B8_{Nt} \\ \eta_{St} &= \eta_{0S} - \eta_{1S} B16_{St} - \eta_{2S} K_{St} \end{aligned} \tag{3}$$

Similarly, the possible influence of a customer network on the effectiveness of a firm's advertising decision is modeled as

$$\begin{aligned} \beta_{Nt} &= \beta_{0N} + \beta_{1N} B16_{Nt} + \beta_{2N} K_{Nt} + \beta_{3N} B8_{Nt} \\ \beta_{St} &= \beta_{0S} + \beta_{1S} B16_{St} + \beta_{2S} K_{St} \end{aligned} \tag{4}$$

Here, η_{0i} and β_{0i} are the own price and own advertising elasticities, respectively. Our primary interest, however, is in η_{1i} (firm i's price-network size coefficient) and β_{1i} (firm i's advertising-network size coefficient). These coefficients represent the interactive network effect of firm i's customer base on its price and advertising effectiveness. Following the theoretical and empirical literature dealing with network effects, price sensitivity is expected to decrease as the network size increases (i.e., $\eta_{1i} \geq 0$ or customers will be willing to pay more for a product technology supported by a large network of users due to an expected increase in complementary products; Brynjolfsson and Kemerer, 1996). Similarly, advertising is likely to be more effective as the network size increases (i.e., $\beta_{1i} \geq 0$ or firms with a large network can maintain their demand with less advertising expenditures due to scale efficiencies associated with a larger 'buzz factor' around the expected increase in complementary products; Rosen, 2000). As software quality increases, we also expect that price and advertising sensitivities will decrease and increase, respectively. Finally, a large installed base of prior product technology ($B8_{Nt}$) is expected to be associated with lower price and higher advertising sensitivities for Nintendo. It follows that $\eta_{0i} > 1$ (since $\eta_{it} > 1$ and η_{1i}, η_{2i}, η_{3N}, $B_{it} \geq 0$) and $\beta_{0i} < 1$ (since $\beta_{it} < 1$ and β_{1i}, β_{2i}, β_{3N}, $B_{it} \geq 0$).

The competitive situation

We view the duopolistic competition between firms as one of repeated games of strategic interaction. Repeated games enable firms to enhance their positions *vis-à-vis* a one-shot game and can reflect the long-term nature of strategic competition between firms. The unique equilibria in repeated games of finite duration are the same as those in a stage game played in every period (Fudenberg and Tirole, 1992).

The profit for firm i at time t is

$$\Pi_{it} = (P_{it} - c_i)Q_{it} - A_{it} - F_i \tag{5}$$

where c_i is the marginal cost and F_i is the fixed cost of production for firm i. Since technological products have relatively short life cycles, we assume marginal costs are constant for each firm; this is also consistent with the NEIO approach.

Firms simultaneously maximize their profits by choosing their own price and advertising expenditure levels. We do not discuss other noncooperative games that we considered in the course of our research, including several Stackelberg leader–follower structures, since our video game data do not exhibit any strong leader–follower patterns. Based on the demand model (1) and the profit function (5), the Nash equilibria in price and advertising can be derived from the first-order conditions. Details of the equations to be estimated, along with a discussion of the estimation approach, are in Shankar and Bayus (2002).

AN EMPIRICAL ANALYSIS

Data

The data available for estimation purposes include monthly time-series information between January 1993 and August 1995 for Nintendo and Sega 16-bit hardware sales (units), hardware price (dollars), advertising expenditures (millions of dollars), and installed customer base size (units) for the 16-bit systems (and Nintendo's 8-bit system). A summary of this information is in Table 1. Data on sales of the top 10 software titles (i.e., 'killer' games) for each system (millions of dollars) are used as our measure of software quality. Sales and price information come from the NPD Group, a leading organization that tracks this industry. The sales data are based on a sample of 17 leading U.S. retail chains that account for 65 percent of the video game systems sold. The average monthly price is computed by dividing the monthly dollar value of sales by the volume of units sold. Advertising information for the 16-bit systems comes from the *Broadcast Advertising/Leading National Advertisers (BAR/LNA)* reports published by Competitive Media Reporting. To obtain monthly advertising figures, we divided the original quarterly values using a uniform distribution of spending. Since the Sega Genesis and Nintendo SNES systems were introduced before the start of our data series, the January 1993 value of each firm's installed customer base was obtained from Brandenburger (1995). Given the wide range in values for the original data, natural logarithms of the network size variables ($B16_i$ and $B8_i$) and software sales were used in the empirical analysis to stabilize the variation within these variables. Also, dummy variables are included in the demand functions (via Equation 2) for November and December due to seasonal considerations. Finally, analysis of the correlations among the independent variables showed that multicollinearity was not a problem for these data.

Estimation results

We estimated the model using both 3SLS and GMM methods. Because a Glesjer (1969) test showed that heteroscedasticity is not a problem for our data, we only report the results for 3SLS in Table 2.

From Table 2, the signs of the coefficients are intuitive and reasonable. The network effects associated with each firm's 16-bit installed base are generally significant. Software 'quality' has significant main effects, as well as significant effects through price, for both Nintendo and Sega. With the exception of price, the effects of Nintendo's prior product technology are insignificant. Own price and advertising elasticities are significant for both firms, as are the cross-price elasticities. The significant results for the November and December dummy variables are consistent with the seasonal nature of demand in this industry.

Importantly, the parameters associated with the 16-bit network effects (α_{1i}, η_{1i}, β_{1i}) are significant for at least one of the firms. These results indicate that the home video game industry does indeed exhibit network effects as proposed in the theoretical economics literature. As indicated by the third column in Table 2, the coefficients relating to the direct effect of network size (α_{1i}) of Nintendo and Sega are not statistically different at the 0.05 level, consistent with the assumption in most theoretical studies. However, the difference between the firms' price-network size coefficients (η_{1i}) is significant at the 0.05 level, as is the difference between the firms' advertising-network size coefficients (β_{1i}). These results reflect asymmetry for the competitors in network strength through advertising and price; specifically, they are more favorable for Nintendo.

From Table 1, it is clear that between 1993 and 1995 Sega maintained a substantially larger installed base of 16-bit systems than Nintendo. In addition, both firms made different advertising and pricing decisions. This is particularly evident in 1995, when Nintendo spent almost twice as much in advertising than Sega, and had a higher price.

Table 2. 3SLS estimation results

	Nintendo coefficient estimates	Sega coefficient estimates	Test of coefficient difference
Network effects			
Direct effect (α_1)	1.71 (0.76)*	1.93 (0.78)**	Not significant
Price-network size interactive effect ($-\eta_1$)	0.10 (0.04)*	0.06 (0.02)*	Significant**
Ad–network size interactive effect (β_1)	0.08 (0.03)*	0.03 (0.10)	Significant**
Control variables			
Firm-specific effects (α_0)	6.34 (2.71)**	6.14 (4.13)	Significant*
Software quality (α_2)	1.65 (0.54)**	1.76 (0.51)**	Not significant
8-bit network size (α_{3N})	0.33 (0.61)	NA	Not significant
November seasonal effects (α_4)	0.70 (0.14)**	0.57 (0.24)**	Not significant
December seasonal effects (α_5)	1.42 (0.18)**	1.42 (0.18)**	Not significant
Own price elasticity ($-\eta_0$)	−3.23 (1.34)*	−3.46 (1.45)*	Not significant
Price–software quality ($-\eta_2$)	0.0025 (0.001)*	0.0031 (0.001)*	Not significant
Price–8-bit network size ($-\eta_{3N}$)	0.06 (0.03)*	NA	Significant*
Own advertising elasticity (β_0)	0.13 (0.04)*	0.21 (0.09)*	Not significant
Ad–software quality ($-\beta_2$)	0.003 (0.011)	0.0013 (0.0094)	Not significant
Ad–8-bit network size ($-\beta_{3N}$)	0.08 (0.12)	NA	Not significant
Cross-price elasticity (ε)	0.28 (0.11)*	0.20 (0.10)*	Significant*
Cross-advertising elasticity ($-\gamma$)	−0.03 (0.13)	−0.05 (0.11)	Not significant
Marginal cost (k in U.S. dollars)	54.67 (18.12)**	59.32 (21.27)**	Significant*

$n = 64$; standard errors in parentheses; system-wide $R^2 = 0.63$
* Significant at 0.05 level; **significant at 0.01 level

Despite Sega's initial lead in earned (estimated) gross profits, Nintendo was able to just surpass Sega's level of profits during the months leading to August 1995. At the same time, Nintendo was able to pass Sega in unit sales during 1995 (see Table 1). The parameter estimates in Table 2 provide a possible explanation for this observed behavior. The demand parameters of Nintendo are either comparable with, or more favorable than, Sega's parameters. In particular, Nintendo has stronger interactive network effects through price and advertising than Sega. These strong network effects may have contributed to a decision to have higher equilibrium advertising expenditures and prices, which in turn enabled Nintendo to eventually catch and surpass Sega in monthly demand.

An interesting result is that the cross-price elasticities are significant, but the cross-advertising elasticities are insignificant. Given that the home video game industry is characterized by incompatible hardware systems and unique game software (e.g., Nintendo's *Super Mario Brothers* and *Donkey Kong* vs. Sega's *Sonic the Hedgehog* and *Mortal Kombat*), the advertising of each system appeals to its own consumer segment and firms primarily compete for new customers to the market. Due to the inherent nature of incompatible systems, the home video game industry seems to represent a setting in which demand is elastic with respect to its own price and advertising as well as competitive pricing, but is unresponsive to advertising of the closest substitute product.

In summary, after controlling for various possible asymmetries between competitors, we find that each firm's 16-bit customer network has a direct effect on its own hardware demand and interactive effects through its own hardware price and advertising. More important, we find strong evidence of asymmetric interactive network effects between the competitors.

DISCUSSION

In several industries for which network effects are important, a common situation is one in which there are multiple competing product technologies that are incompatible (e.g., Voortman, 1993). Today, for example, there are several competing wireless communication standards, as well as several digital audio, video, and graphic formats.

When competing firms have incompatible and proprietary products, theory suggests that a competitive advantage accrues to the firm with largest customer network or installed base (e.g., Katz and Shapiro, 1985; Farrell and Saloner, 1985). Of particular interest is the *theoretical* result that in markets with strong and symmetric network effects across competitors, situations of technology 'lock-in' can be obtained. In other words, once a particular product technology gains any small lead over competing technologies in terms of its customer network size, there is a tendency for the technology with the larger network to become the industry standard (e.g., Arthur, 1996). This result implies that under some conditions an inferior product with a lead in establishing its own network will ultimately win out over a superior product (e.g., David, 1985). As noted by Hill (1997), network externalities and the possibility of lock-in also suggests that firms with competing technology standards should attempt to build their installed customer bases as quickly as possible.

Recall that we started out by asking three related research questions: Do network effects exist within each competing product technology? What is the nature of these network effects? Are these network effects symmetric across firms? Consistent with most theoretical models' assumption that the direct effect of a customer network on demand is symmetric across competitors, we find that the network size coefficients of Nintendo and Sega are significant but not statistically different (see α_{1i} estimates in Table 2). In agreement with the hedonic price models for computer spreadsheet software (e.g., Brynjolfsson and Kemerer, 1996), we find that price effectiveness of Nintendo and Sega is a function of network size (see η_{1i} estimates in Table 2). In addition, we find that each firm's advertising effectiveness is influenced by its relative network size (see β_{1N} estimate in Table 2). Our empirical results also show that Nintendo and Sega have asymmetric network effects since the interactive network strength values through price and advertising are statistically different for the two firms (see η_1 and β_1 estimates in Table 2). These asymmetric network strength values may help explain why Nintendo was able to pass Sega in monthly sales of 16-bit home video game systems despite Sega's larger installed base.

Our last research question concerned the implications of network effects on the outcome of competition among firms with incompatible technologies. Assuming that network effects are symmetric, the firm with the largest installed base of customers is generally thought to have an advantage over its competitors. However, our results indicate that network effects can depend on the size of the installed customer base *and* the network strength associated with its direct effect and with its interactive effects through price and advertising. Moreover, the strength of each firm's installed customer base can be different, leading to asymmetric network effects. As a result, a firm that has a relatively small installed base may compete successfully if it has adequately high network strength that can favorably impact the sales response to its price and advertising. Moreover, these results highlight the fact that the ultimate outcome in a competitive market with network effects is more complex than simply accepting that the firm with the largest installed customer base will always be the winner.

LIMITATIONS AND FUTURE RESEARCH

As is the case with all research, due caution should be exercised in generalizing our findings beyond the specific industry, time period, and data sample used in this study. In fact, an inherent limitation to our NEIO approach is the lack of clear strategic generalizations. Instead, we provide estimates of, and insights about, the underlying competitive structure, demand, and network effects for the two dominant firms in the 16-bit home video game industry. Our findings in this specific context suggest potential directions for future replications. For example, do firms with high network strength through advertising follow the more aggressive advertising and pricing strategy used by Nintendo? Do firms with a large customer network price higher than a competitor with a smaller network? Do firms with strong network effects enter later than their competitors and still emerge as an important market player?

Since the video game industry is characterized by heterogeneous consumer tastes (i.e., there is no 'winner-take-all' video game system), a stronger empirical test of a late entrant's ability to catch up to a competitor may come from studies in other industry settings (e.g., video cassette recorders, personal computer operating systems, spreadsheet software packages). For example, are network effects equal across competitors in other industries? Do competing firms in other markets exhibit asymmetric network effects? In what other ways, possibly involving other marketing mix variables such as distribution, do firms exhibit asymmetric network effects? Although a static model formulation is adequate for the video game data we study, dynamic models may be required for other industry settings. Further research along these lines will extend our understanding of network effects and competition.

To our knowledge, no analytical (or empirical) models have considered the potential implications of asymmetric network effects in a competitive situation. Thus, normative decisions dealing with technology adoption, entry timing, and pricing in markets with asymmetric network effects are unknown. For example, do competing firms desire product compatibility when one firm has stronger network effects than the other? Are there any first-mover advantages when a later entrant has stronger network effects? Addressing these questions would seem to be a promising direction for future analytical research. Empirical investigation of the sources of asymmetric network effects would also yield further insights. This effort, however, would require cross-sectional data on multiple markets with network effects. Although this would pose a considerable data challenge, it is a fruitful avenue for future research.

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