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Abstract

This paper investigates the scope of indirect network effects in the home video game industry. We argue that the increasing prevalence of non-exclusive software gives rise to indirect network effects that exist between users of competing and incompatible hardware platforms. This is because software non-exclusivity, like hardware compatibility, allows a software firm to sell to a market broader than a single platform's installed base, leading to a dependence of any particular platform's software on all firms' installed bases. We look for evidence of these market-wide network effects by estimating a model of hardware demand and software supply. Our software supply equation allows the supply of games for a particular platform to depend not only on the installed base of that platform, but also on the installed base of competing platforms. Our results indicate the presence of both a platform-specific network effect and – in recent years – a cross-platform (or generation-wide) network effect. Our finding that the scope of indirect network effects in this industry has widened suggests one reason that this market, which is often cited as a canonical example of one with strong indirect network effects, is no longer dominated by a single platform.

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I. Introduction

The home video game market has long been recognized as one in which network effects exist. As in many high-tech industries, these network effects are indirect. Home video games systems consist of a console (the hardware) and games that can be played on that console (the software). Because the value of a console is derived from the games that can be played on it, consumers prefer to buy a system with a greater variety of software. Because there are fixed costs to developing software, game publishers prefer to develop games for a console with a large base of users. Thus, consumers' value of a particular console depends positively – though indirectly – on the number of other users of that console.

This paper explores the scope of indirect network effects in the home video game industry. While previous work has assumed that network effects exist only between users of a given console (for example, Clements and Ohashi (2005)), we argue that in recent years network effects have also come to exist between users of competing platforms in the same technological generation. Interestingly, this change in the scope of indirect network effects has occurred without any change in the degree of hardware compatibility. Home video games systems have always been, and continue to be, incompatible with one another. As Katz and Shapiro (1985) explain, the scope of indirect network effects in an industry is typically determined by the degree of hardware compatibility. For example, if all hardware brands are incompatible network effects will operate at the brand level, while if all brands are compatible network effects will operate at the market level. Hardware compatibility is the relevant consideration in assessing the scope of indirect effects because it determines the size of the potential market that a software firm can appeal to when trying to recoup its fixed costs of software development. That is, the degree of hardware compatibility determines the set of technologies whose users are potential purchasers of a given piece of software.

While changes in the degree of compatibility between video game systems have not been responsible for the change in the scope of network effects in this industry, we believe that changes in the degree of software exclusivity have. Over the past 20 years, the fraction of games titles that are released on more than one console has increased from about 12% to almost 40%. Just as compatible hardware allows software providers to spread the fixed costs of software development over multiple brands, non-exclusive software allows providers to spread the fixed costs of development over multiple platforms. Software providers considering a multi-platform title will compare these fixed costs (plus the fixed costs of porting the game across platforms) to the revenue that can be earned by selling the game to users of *all* of the platforms on which the game will be released. Thus, once non-exclusive software is considered, the supply of games for any particular platform will clearly depend not only on the number of users of that platform, but also on the number of users of other platforms on which those games could be released. This gives rise to indirect network effects between users of incompatible video game consoles.[1]

Following existing work in this area, we will look for evidence of indirect network effects by estimating two relationships: (1) the relationship between hardware demand and software variety; and (2) the relationship between software availability and the installed base of hardware. Our analysis uses monthly data on U.S. hardware sales and software availability for all major home video game systems from 1995-2005.

We begin by specifying a standard discrete choice model of hardware demand. One important benefit of this demand model is that it allows us to account for both exclusive and non-exclusive software in a straightforward way. In particular, exclusive and non-exclusive titles need not be distinguished in the utility function because consumers' utility from having a particular game available on a console does not depend on whether that game is available on other consoles. Of course, whether a game is exclusive will affect the *relative* utilities of different consoles and, in turn, their market shares. The nested logit model that we use accounts directly for this, as each console's market share is a function of the characteristics of all products in the market. We can then use these market share expressions to illustrate the differential effects that exclusive and non-exclusive titles have on demand.

We then estimate a reduced-form software supply equation that accounts for the possibility of both console-specific and cross-console indirect network effects. We allow

[1] In fact, the theory literature (for example, Katz and Shapiro (1985) and Farrell and Saloner (1992)) has long recognized that this kind of indirect network effect can span incompatible platforms in the presence of technologies such as adapters and converters. The empirical literature has largely ignored this possibility, at least in part because the industries studied have typically been characterized by complete compatibility (e.g., CD players) or complete incompatibility (e.g., early home video games).

the supply of games for a particular console to depend on both the installed base of that console and the installed base of competing consoles in the same technological generation. By including this additional installed base measure in the supply equation, we allow for the possibility that the installed base of competing (and incompatible) hardware platforms can increase the supply of games for a console because the fixed costs of non-exclusive releases can be spread across users of multiple platforms. Furthermore, we will allow the coefficient on the competitors' installed base term to vary over time to capture the fact that software publishers' incentives to produce non-exclusive software have increased. As we explain in greater detail in the next section, we believe that a rise in the importance of licensed content and other content costs that are not platform-specific, a decrease in "porting" costs, and a rise in the size and sophistication of independent game publishers have increased the attractiveness of non-exclusive releases. As the attractiveness of multi-platform releases increases, the scope of indirect network effects at work in the industry broadens. Our software supply specification allows us to measure this effect.

Our empirical results support the existence of both a significant platform-level indirect network effect and an increasingly important generation-level network effect. The results of the demand estimation indicate that the demand for a particular console increases with the availability of software for that console. Furthermore, as expected, exclusive games have a larger impact on demand than non-exclusive games. The results from the software supply equation indicate that the supply of games for a console depends positively on the installed base on that console. The supply of games for a console also depends on the installed base of other consoles, with this relationship being negative early in our data and positive in later generations. This implies a positive indirect network effect operates at the generation level by the end of the period we study.

The video game market is often cited as the canonical example of a "tippy" market – one in which indirect network effects lead to dominance by a single firm. The complete dominance of the industry by Nintendo's NES system in the 1980s and early 1990s is often cited as evidence for this claim.[2] However, with successive technological generations, this market has become significantly less dominated by any single console.

[2] See, for example, Brandenburger and Nalebuff (1996), pp. 111-117, or Shapiro and Varian (1999), p. 178.

Indeed, in each of the two most recent technological generations, three competing platforms (those of Nintendo, Sony, and Microsoft) have retained sizable market shares (see Figure 1).[3] While we do not estimate a dynamic model and therefore cannot use our results to illustrate how changes in software exclusivity affect the evolution of market shares over time, we believe that our empirical results provide at least suggestive evidence as to why this market has become less prone to tipping. Our results indicate that non-exclusive software affects a market much in the same way that compatibility does – it changes the scope of indirect network effects. If network effects exist across users of different platforms, as our results indicate, then it should be no surprise that the tendency of this market to tip towards a single platform has fallen. At the end of Section V, we use our demand and supply estimates to carry out a simple exercise that illustrates how the presence of generation-wide network effects lowers the benefit that a console manufacturer gets from stimulating software provision.

This paper builds on a small but growing literature that seeks to estimate the role of indirect network effects in a variety of technology industries. It is most closely related to two recent papers that estimate network effects in the home video game industry. Clements and Ohashi (2005) estimate the effectiveness of console price and software variety as alternate ways of stimulating hardware demand. Their empirical analysis implicitly treats all software as exclusive to a platform. Thus, they do not distinguish between the introduction of exclusive and non-exclusive games in calculating demand elasticities nor do they allow for the possibility of cross-platform effects in their supply equation. Their data end several years earlier than ours, before the trend towards non-exclusive software had fully manifested itself (they state that, in their sample, 17% of titles are available on more than one platform), so the effect we focus on may not have been operative in their data in any case. Their focus is instead on the dynamics of indirect network effects and the evolution and price and software elasticities over a console's lifecycle.

[3] Figure 1 shows the long-run installed base (IB) market shares of the major platforms in each technological generation. We define a platform's "long-run" IB market share as its IB market share in the month in which the first major platform of the *next* generation is launched. We believe that the launch of the next generation acts as a good signal that the previous generation has reached a point of maturation.

Prieger and Hu (2006) also estimate indirect network effects in the video game industry. They acknowledge the presence of both exclusive and non-exclusive software and, in fact, are interested in testing whether indirect network effects are stronger for exclusive games. However, they approach this question by explicitly separating exclusive and non-exclusive games in the consumer utility function (which, as described above, we do not believe is the appropriate way to approach this question). Perhaps not surprisingly, they do not get sensible results from this specification. Other papers that explicitly estimate indirect network effects in technology industries by modeling the complementarities between hardware and software include Gandal, Kende, and Rob (2000) in the CD market and Nair, Chintagunta, and Dube (2004) in the personal digital assistant market.[4]

Our paper contributes to this literature by being the first to explicitly consider the role of software exclusivity and its impact on the scope of indirect network effects. Our analysis indicates that the scope of indirect network effects depends on more than just hardware compatibility. Rather, the scope of these effects is determined by software providers' ability to share fixed costs across platforms – which is possible if the platforms are compatible, but is also possible if the costs of porting software across incompatible platforms are relatively low. This research draws attention to the fact that features of the software market can also affect the scope of indirect network effects and, in turn, the likelihood that a market tips towards a single dominant platform. Moreover, it raises the possibility that hardware providers may have incentives either to sign contracts for exclusive software or to engineer their hardware to affect the costs of porting software across platforms.[5]

The remainder of this paper is organized as follows. In the next section, we provide relevant background information on the industry. Section III describes the

[4] There also exists a related empirical literature on "two-sided markets" (building on theoretical work by Rochet and Tirole (2003) and Armstrong (2005)). For example, Rysman (2004) estimates equations for readership and advertising demand in the "yellow pages" market, with multiple directories competing for readership and advertising dollars in many cities. Kaiser and Wright (2006) study the magazine industry using a similar approach.

[5] In fact, two recent theory papers (Hogendorn and Yuen (2007) and Mantena, Sankaranarayanan, and Viswanathan (2007)) focus on precisely this incentive for the console manufacturer to contract for the provision of exclusive complements and illuminate the tension between the software provider's desire to serve a large market and the console manufacturer's desire to differentiate its product through the provision of unique complements.

empirical approach. Section IV describes the data. Our results are presented in Section V. A final section concludes.

II. Industry Background

The home video game market is comprised of a small number of competing, incompatible video game systems (or "platforms"). A video game system consists of hardware (a console that is attached to a television set) and software (game titles on either cartridge or CD). Software produced for a given hardware platform cannot be played on an alternate platform; however, as described above, distinct versions of the same software title may be produced for multiple hardware platforms.

Platforms with similar technological characteristics are grouped into "generations" by industry observers. There have been seven generations of platforms in the "modern" home video game industry, spanning 1975 to the present. We focus our analysis on the years 1995 to 2005 inclusive. This time period covers the launch of most of the platforms in generations five and all of the platforms in generation six. It also includes several platforms from generations three and four which were still actively selling during this period.[6] Table 1 presents the platforms that are included in our sample, grouped into generations. The table also shows their date of introduction and basic technological characteristics. Three technical factors determine the quality of a home video game system: (1) instruction word length (in bits) of either the central processor (CPU) or graphics processor (GPU); (2) clock speed (in MHz); and (3) the amount of RAM (in MHz). As the table indicates, platforms within a generation are typically quite similar on these three characteristics.

Each video game platform is controlled by what we call a "console manufacturer" and, as is evident from Table 1, many of the same console manufacturers appear in each successive generation (after the firm's initial entry, of course).[7] In addition to developing the hardware and operating system, a console manufacturer typically also produces some

[6] We ignore handheld game devices and PC games.

[7] Note that while we use the term "console manufacturer", it is control of the operating system, rather than literal manufacturing of the hardware, that is relevant for our purposes. For example, Sony is the console manufacturer for the PlayStation2. This means that Sony owns the operating system for this platform and is responsible for the R&D that goes into the development and maintenance of PlayStation2 platform. Whether Sony outsources manufacturing of some or all of the components of the hardware is of no consequence for our purposes.

software that will run on this platform (so-call "in-house" or "first-party" titles). The console manufacturer will also enter into contracts with independent software publishers to provide games for the platform (known as "third-party" titles). Software publishers finance the development of the game (including obtaining and paying for any licensed content the game may use) and perform the marketing and distribution of the title. Game development (the actual programming) may be carried out by a development team internal to the publisher or may be contracted out to an independent game developer. Contracts between console manufacturers and software publishers generally stipulate that the console manufacturer is to provide software development tools to the publisher, while the publisher agrees to protect this intellectual property. The console manufacturer retains the right to approve games before they are developed and released for the console. The contract also specifies the per-unit royalties to be paid by the publisher to the console manufacturer. Finally, the contract may specify whether or not the game under development is exclusive to the console manufacturer.

As mentioned in the Introduction, over the past 20 years, this industry has seen a significant increase in the prevalence of non-exclusive software. In Tables 2A and 2B, we document this change in software exclusivity, first at the generation level and then at the platform level. Note that in Table 2A, the level of observation is the title rather than the platform-title. These trends would be even more pronounced if reported at the platform-title level since non-exclusive games would be double- or triple-counted depending on the number of platforms they were released for.[8] Table 2A indicates that there has been a significant decrease in software exclusivity. 88% of titles released in generation three were released for only a single platform. By generation six, only 61% were exclusive to a platform.[9] The trend in these averages has not been monotonic, however, as a greater fraction of generation five games than generation four games were exclusive. This is due at least in part to changes in the composition of console manufacturers from generation to generation. Specifically, Sony first entered the industry

[8] For example, suppose there are three titles with the first being exclusive to one platform, the second being exclusive to the other platform and the third being available on both platforms. Then the fraction of titles that are exclusive is two-thirds while the fraction of title-platforms that are exclusive is one-half.

[9] When we use platform-titles as the level of observation, we calculate that while 81% of platform-titles in generation three were exclusive, only 37% of platform-titles in generation six were.

in generation 5 and accounted for the majority of games in that generation. As Table 2B shows, Sony has also generally had a higher proportion of exclusive games than other console manufacturers.

Since exclusive titles are often games that the console manufacturer publishes itself (i.e. in-house games), one might wonder whether the observed decrease in the extent of exclusive software is simply reflecting a decrease in the prevalence of in-house games. To investigate this, the next row of Table 2A calculates the fraction of titles that are exclusive to a single platform, looking only at titles developed by third-party publishers. These numbers indicate that the fall in exclusive titles is not due to a reduction in in-house publishing. The fraction of third-party titles that are exclusive to a single console is also decreasing over this period.

In Table 2B, we show the fraction of each console's games that are exclusive. This table is useful for highlighting differences in exclusivity across consoles as well as differences in exclusivity across successive consoles produced by the same parent (i.e., differences across Nintendo's various systems). For example, the table indicates that both Nintendo's and Sony's generations five consoles had a substantially higher fraction of exclusive titles than their generation six consoles.

The patterns apparent in Table 2A and 2B clearly beg the question of why non-exclusive software has become more prevalent in this industry. While not the focus of this research in the sense that we are interested in estimating the effects of changes in exclusivity on the scope of network effects (and not explaining the change in exclusivity), it is important to briefly discuss what may be causing this trend. To motivate this discussion, we consider the incentive of a software publisher to release a game for one or more platforms.

Suppose that there are two consoles in the market. If a software publisher releases a game that is exclusive to one of these consoles, he earns revenues from the sale of that game to users of that console, incurs the fixed costs of developing the game and pays royalties to the console manufacturer for each unit of the game produced. If the publisher instead releases the game on both consoles, he earns revenues from the sale of the game to users of both consoles, incurs the fixed costs of the developing the game as well as the fixed costs of porting the game to the second console, and pays royalties to both console manufacturers (which may be higher than the royalties paid on the exclusive game if the console manufacturer offers a lower royalty rate in exchange for exclusivity). The publisher will prefer to develop the game for both consoles if the additional revenue from selling to users of the second platform exceeds the additional fixed costs (i.e., the "porting" costs) and the additional licensing fees. Note that as the fixed costs of developing a game increase and/or the fixed costs of a porting a game decrease, games may increasingly be profitable as multi-platform releases but not as exclusive releases.

Based on our reading of the trade press and other industry sources, we believe that changes in the cost structure and technology of game development, an increase in the use of licensed content in games, and changes in the structure of the software industry all influence software publishers' incentives to develop non-exclusive games. Figure 2 shows one industry analyst's estimate of game development costs over the past 25 years. This figure is roughly consistent with data we have seen elsewhere that estimates the average cost of game development in generation five was around $1 million, while the average cost of game development in generation six was $5-7 million (Loftus, 2006). As illustrated by the discussion above, when the fixed costs of game development increase, more projects become viable only when they reach a very large audience—larger perhaps than any one platform can provide. In order to recoup these massive development costs, publishers have an incentive to release a title on multiple platforms.

The composition of development costs has also changed in important ways. With the rise to dominance of the CD-based console in generation five, games have become relatively more "content"-intensive. CDs make it cheaper to store vast quantity of graphical and musical data in a game, compared to the prior technology that used semiconductor chip-based cartridges. As a consequence, a larger fraction of the development costs has become attributable to tasks like music licensing or composition and performance, motion-capture studies, background art and design (see Loftus (2006) and Reimer (2005)). Since these costs are not specific to a platform (for example, music is not operating system-specific), the fraction of initial development costs that must be duplicated in order to port a game to a second platform have shrunk. In addition, porting costs have fallen because of the rise of sophisticated cross-platform development tools called "middleware" that can dramatically reduce the costs of writing a game for multiple platforms compared to the traditional complete rewrite (Reimer, 2005).[10] Middleware allows specific technical aspects of the game—for example, 3-D animation—to be developed within a programming tool that can provide output usable by the operating systems of more than one platform. In sum, the technology of game development has changed so that more of the initial costs incurred when writing a game for its first platform are avoidable in porting the game for a second. This reduction in the relative cost of porting clearly increases the attractiveness of nonexclusive releases.[11]

Furthermore, as shown in Table 2A, software publishers are increasingly relying on licensed content and sequels. Industry observers attribute this to an attempt to mitigate risk of failure in an environment with skyrocketing development costs (Reimer, 2005). This move to a "blockbuster" model mimics an often cited development in Hollywood filmmaking, which experienced a similar simultaneous run-up in production budgets and increased reliance on sequels. Not only may ballooning budgets make the relative predictability of a licensed game seem attractive, but it also introduces another player into the game development process. If the owner of the relevant intellectual property (e.g., the Batman franchise) is pursuing a broad, multi-product or multi-channel strategy for disseminating its content and building/exploiting its brand, and if there are spillovers across markets (e.g., video game sales stimulate action-figure sales), it may provide publishers with incentives (perhaps with lower licensing fees) to develop a non-exclusive game based on its content (even if, in the narrow context of video games sales alone, it might be more profitable to license its content for development exclusively on one platform).

One final change that might have facilitated the rise in nonexclusive games is the growth and maturation of the software publishing industry, which could contribute to the decline in the proportion of (almost always exclusive) in-house games evident in the third row of Table 2A. The final row of Table 2A shows that the average number of titles released by an independent publisher has grown more than three-fold over this period. As game development has increasingly become financed by publishers rather than by developers, and as development costs have soared, publishers have grown larger and

[10] Also see the "Porting in gaming" entry in Wikipedia.
[11] Mantena, Sankaranarayanan and Viswanathan (2007) state that industry figures indicate that porting costs are now typically in the range of 15% to 25% of the initial development costs.

better capitalized, with a number of the largest becoming publicly traded. This should correct some capital market imperfections likely present in the industry's earlier days and make in-house publishing less necessary as a means of stimulating software development due to lack of financing. Of course, there may be other reasons that console manufacturers wish to be involved in in-house publishing, but the relative increase in the independent provision of games may be in part due to this development. And, since in-house games are almost always exclusive (apparently because console manufacturers are reluctant to share their IP and development tools with rival platforms, in addition to the fact that it may in their interest to stimulate platform-specific demand), a rise in independent publishing may increase the prevalence of non-exclusive games.

III. Empirical Approach

Indirect network effects can be estimated in two ways. One can treat them as direct network effects and estimate a direct relationship between the demand for a given hardware platform and its installed base (see Ohashi (2003) for an example). Or, one can explicitly account for the feedback between hardware and software by estimating both a hardware demand equation (in which hardware demand depends on software availability) and a software supply equation (in which software supply depends on the installed base of hardware). Finding a positive effect of software availability on hardware demand and a positive effect of hardware installed base on software supply establishes the (indirect) positive relationship between the demand for a hardware platform and the existing number of users of that hardware. This is the basic approach followed in the existing literature cited above, and we employ it as well. However, as we describe in the next two subsections, we modify it to account for the changing scope of indirect network effects in this industry.

III.A. Hardware demand

We model a consumer's choice of which (if any) hardware platform to buy in a given month as a discrete choice problem in which the consumer evaluates the utility that he would receive from each potential platform and chooses the one platform that maximizes his utility. We include an explicit outside good so that consumers also have the option of buying none of the platforms. Following Berry (1994), consumer *i*'s utility from purchasing console *j*, in month *t* is written as,

(1) $$u_{ij}^t = x_j^t \beta + \alpha p_j^t + \gamma SW_j^t + \xi_j^t + v_{ij}^t$$

where x_j^t is a vector of observed characteristics for console *j* in month *t*, p_j^t is the price of console *j* in month *t*, SW_j^t is a measure of software availability for console *j* in month *t*, ξ_j^t is a vector of unobserved (to the econometrician) characteristics for console *j* in month *t* (such as marketing or brand image), and v_{ij}^t is an idiosyncratic error term. Each consumer is assumed to choose the product that maximizes his utility.

The coefficient γ measures the relationship between hardware demand and software availability. We expect $\gamma > 0$, meaning that greater software availability on platform *j* increases a consumer's utility from console *j*. Because of data limitations, in most of our specifications we have to assume that consumers care only about the number of titles available for the console and not about the quality of those titles. But, because we know that there is, in fact, significant heterogeneity in the quality of games (and, indeed, only a small number of titles actually become "hits"), we also employ some quality-adjusted software measures as robustness checks.

Continuing to follow Berry (1994), we let $\delta_j^t = x_j^t \beta + \alpha p_j^t + \gamma SW_j^t + \xi_j^t$ denote the mean valuation of console *j* across all consumers, meaning we can interpret v_{ij}^t as the difference between consumer *i*'s valuation of console *j* in month *t* and the mean valuation. The distribution assumed for v_{ij}^t determines the choice probabilities and substitution patterns. We adopt a nested logit framework and group all inside goods (i.e.: all consoles) into one nest and the outside good into another. This allows for correlation in v_{ij}^t across the inside goods, allowing them to be closer substitutes with each other than they are with the outside good. As Berry (1994) shows, with these assumptions on v_{ij}^t and by setting the mean utility of the outside good to zero, the following linear estimating equation for one-level nested logit can be derived,

(2) $$\ln(s_j^t) - \ln(s_0^t) = x_j^t \beta - \alpha p_j^t + \gamma SW_j^t + \sigma \ln(s_{j/g}^t) + \xi_j^t$$

where, $s_{j/g}$ is console *j*'s within-group share (this is console *j*'s share of all consumers who purchase any console in month *t*) and ξ_j^t is the econometric error term. In our empirical specifications, we divide ξ_j^t into a time invariant component, which we will estimate as a platform fixed effect, and a time-varying component.[12] We also include dummy variables to control for the month of the year. These capture the fact that the perceived quality of all consoles may be higher in some months such as November and December, when parents are purchasing gifts for children. Furthermore, we control for the age of the console (with either polynomials or dummy variables) to capture how perceived and actual quality changes with a console' age.[13] Finally, in some specifications we replace the separate platform and age effects with platform-age fixed effects. This is our most flexible specification in the sense that these fixed effects control for the unobserved quality of each platform in each year of its "life".

It is worthwhile to highlight the way in which non-exclusive software (i.e.: game titles available on multiple competing platforms) affects the demand analysis. Exclusive and nonexclusive software titles do *not* need to be distinguished from one another in the data or in equation (2). This is because the right-hand side of equation (2) is literally the mean utility that a consumer receives from purchasing product *j*. As is evident from the utility function in (1), whether or not a particular game is exclusive to console *j* has no impact on the *utility* that a consumer derives from console *j*. That is, when evaluating his utility from a given console, a consumer will consider the games that can be played on that console, but not whether or not those same titles are also available on other consoles. However, whether or not software is exclusive to a console will affect the *relative* utilities of the different alternatives and therefore which console a consumer ultimately chooses. Games that are available on multiple platforms will increase the utility the consumer gets from *each* of those platforms and will, in turn, have little effect on the probability that the consumer chooses one of those platforms over another. On the other

[12] Because we include platform fixed effects, the marginal utility of platforms characteristics which do not change over time (for example, whether the platform is cartridge or CD based) will not be separately identified.

[13] For example, consumers may use console age as a signal for how much longer they expect software writers to produce software for that console. Alternatively, other types of complementary products may emerge for a console (such as, gaming websites or magazines that offer "tips") as it ages. The age variables will pick up both of these things.

hand, an exclusive title will increase the likelihood that a consumer chooses a particular platform.

Given this, one way to illustrate the different effects that exclusive and non-exclusive software have is to calculate separate derivatives of demand with respect to exclusive and non-exclusive software.[14] When calculating the change in demand in response to a change in exclusive software, the change in software will affect only the attributes and utility of platform *j*. In contrast, when calculating the change in demand with respect to non-exclusive software, the change in software will affect both the attributes of platform *j* as well as the attributes of all other platform on which this game is available. In a logit model, the demand for any product depends on the characteristics of all products in the market; therefore, an increase in exclusive software will clearly have a larger effect on demand than an increase in non-exclusive software.

III.B. Software supply

Our supply equation generally follows the previous literature, with modifications that allow us to estimate whether and how the scope of indirect network effects in this industry has changed. In particular, we modify the software supply equation so that we can explicitly estimate whether, in successive generations, the installed base of competing platforms generates a positive spillover in the production of software for platform *j*. This would provide evidence that the increase in non-exclusive software acts like an increase in compatibility in that it changes the scope of indirect network effects from being platform-specific to being generation-specific.

We estimate a reduced-form relationship between the variety of software available on a platform and that platform's installed base of hardware.[15] Specifically, we estimate the following equation,

(3) $$\ln(SW_j^t) = \alpha_j + Z_j^t \beta + \gamma_1 IB_j^t + \gamma_2 IB_{-j}^t + \eta_j^t$$

[14] Prieger and Hu (2006) try to estimate whether indirect network effects in the video game industry are stronger for exclusive than non-exclusive games. They explicitly distinguish the two types of software in the consumer utility function find no difference (if anything, they find that non-unique games have a larger effect). However, given the discussion here, it is clear that there is no reason to expect the utility of the two types of games to differ. Rather, it is their effects on demand that should differ.

[15] This is basically the same reduced form model employed by Clements and Ohashi (2005) and Prieger and Hu (2006) in estimating the supply of software. The primary difference is that we allow dependence of one platform's software supply on all platforms' installed base of hardware.

where, α_j is a platform fixed effect, Z_j^t is a vector of characteristics of console *j* in month *t* that may affect firms' incentive to supply software for that console (such as the age of the console), IB_j^t is the installed base of console *j* in month *t*, IB_{-j}^t is the installed base of all other consoles in the same technological generation as platform *j*, and η_j^t is an error term. Because we believe that there have been several important technological changes in the software side of this industry over the period we study, we control for time effects with either year or month dummies.[16] We control platform age because the diffusion of knowledge and expertise related to programming for a specific console may increase the supply of developers over time. The inclusion of platform and year (or month) dummies prevents us from also including platform age dummies (this is the common cohort/age/year problem) so we instead include higher order polynomials of platform age.[17]

γ_1 captures the relationship between the supply of software for platform *j* and its installed base, while γ_2 captures the relationship between the supply of software for platform *j* and its competitors' (combined) installed base. We expect $\gamma_1 > 0$, meaning that increases in a platform's installed base stimulate the provision of software for that platform. This is the source of the traditional platform-level indirect network effect.

The sign of γ_2 depends on the nature of the technology of software provision. At one extreme, imagine that all development costs were completely specific to a platform, so that writing a version of the same game to run on a second platform required replication of all the same steps and the same costs. If the supply of inputs to this process was perfectly elastic, then the decision about whether to write a game for each potential platform would be a completely independent decision. A software firm would simply calculate the required potential market size and then develop the game for all platforms whose installed base (or projected installed base) exceeded that threshold. This would imply γ_2=0. Alternatively, if some inputs to the software development process were scarce, or less than perfectly elastically supplied, then such a model could imply a

[16] These are actual month dummies as opposed to the calendar month dummies we include in the demand equation. Obviously, these month dummies subsume the calendar month dummies; however, we do include the calendar month dummies when we include only year effects.

[17] See Hall, Mairesse and Turner (2005) for example.

γ_2 <0—that is, some crowding out of software development based on the growth of rival platforms. In this case, the growth of a rival platform is bad news for the focal platform because the consequent increase in software development for that platform diverts resources away from software development for the focal platform. Under another interpretation, software providers might use the installed base of competitors as a signal about the likely evolution of platform *j*; for example, if platform *j*'s competitors have large installed bases, software providers may infer that the market is likely to tip away from platform *j* and avoid writing software for the platform. This would again generate a negative spillover on software development from the growth of the installed base of rival platforms.

Now imagine instead that the portion of the fixed development costs that must be replicated to "port" the game to another platform falls. This increases the attractiveness of multi-platform releases and introduces the potential for a positive relationship between the supply of games for platform *j* and the installed base of platform *k*—that is, γ_2 >0. Specifically, for a software provider who is contemplating writing a game for platform *j*, the installed base of platform *k* represents an additional set of customers over which the fixed costs of this game can be spread. As the costs of porting games to additional platforms fall and/or as the development costs of games increase, games that may not be profitable if developed only for platform *j* might become profitable if developed for platforms *j* and *k*. If so, the supply of games for platform *j* will be directly affected by the installed base of platform *k*. This would give rise to generation-wide indirect network effect, and it is this relationship that we seek to test. Given the evolution of the gaming industry described in section II, we specifically expect γ_2 to become more positive (or less negative) over time. We test this hypothesis by allowing the coefficient γ_2 to vary by generation so that we estimate how the relationship between competitors' installed base and the supply of games for platform *j* changes over our sample period.

We can then combine the parameters of the demand and supply equations to establish the existence and scope of indirect network effects in this industry. In particular, a finding of $\lambda > 0$ in the demand equation and $\gamma_1 > 0$ in the supply equation establishes the presence of a *platform-level* indirect network effect. A finding of $\lambda > 0$ in the demand equation and $\gamma_2 > 0$ in the supply equation establishes the presence of a *generation-level* indirect network effect. Moreover, a finding that γ_2 increases over successive generations in our sample would indicate that the scope of indirect network effects has changed from users of the same platform to users of different platforms in the same generation. Note that this change in the scope of indirect network effects can take place even in the absence of physical compatibility between the products.

III.C. Endogeneity

i. Hardware Demand

Price, ***Within Group Share*** and ***# of Titles*** are all potentially endogenous in the demand equation. With the inclusion of platform fixed effects, the error term in the demand equation can be interpreted as the deviation of the unobserved quality of platform *j* in month *t* from its average unobserved quality. This error term may capture several sources of variation in unobserved quality. First, it may capture changes in perceived quality that result from advertising campaigns (since these would occur at different points in a platform's life cycle, they would not be controlled for by the platform fixed effects). Second, it may capture changes in quality that result from the release of new information about the platform–for example through positive or negative product reviews. Finally, it may capture changes in quality that result from the emergence of complementary products (other than software) that enhance the value of the platform – for example, a website that provides "tips" on how to solve games. Because these types of changes in unobserved quality will be considered by firms when setting prices and by consumers when making choices, they will likely be correlated with both ***Price*** and ***Within Group Share***.

In addition, if changes in unobserved quality are persistent over time (i.e.: if there is serial correlation in the error term in the demand equation), then ***# of Titles*** may be endogenous as well. This logic is perhaps best illustrated with an example. Suppose that in month *t*, platform *j* has a "high" level of unobserved quality because the platform received positive reviews from gaming websites. This increase in quality will lead to higher demand from platform *j* that month. This, in turn, will increase the installed base of platform *j* in month *t+1* and, through the software supply relationship, increase the supply of games for platform *j* in month *t+1*. If the increase in the unobserved quality of platform *j* persists (i.e., the positive reviews in month *t* increase the perceived quality of platform *j* in month *t+1* as well), then there will be correlations between ***# of Titles*** in month *t+1* and the error term in the demand equation in month *t+1*. Because we expect that at least some of the time-varying components of unobserved quality may persist for more than one month, we treat ***# of Titles*** as endogenous.

Following Berry, Levinsohn and Pakes (1995), we construct instruments that measure the extent of competition faced by a platform as well as the extent to which that competition comes from other platforms owned by the same "parent". Specifically, our instruments include the sum of each hardware characteristic (processor speed, memory, and processor word length in bits) over the competing products in the market, the total number of competing platforms in the market, the number of competing platforms from the same generation, and the number of competing platforms from the same manufacturer (i.e., the number of other Nintendo consoles actively selling in the market). We expect that these variables will be correlated with platform *j*'s price (because they affect platform *j*'s ability to raise prices), platform *j*'s within group share (because they affect the relative utilities of the different options), and platform *j*'s software (because, as we show in our modified supply equation, they affect software providers' incentives to supply games to platform *j*). However, these instruments should be uncorrelated with the error in the demand equation because that error term is literally the unobserved utility of platform *j* in a given month which is independent of the characteristics of other offerings. Note that all of these instruments vary over time for a given platform (and are therefore not subsumed in the platform fixed effects) because the mix of platforms in the market changes with entry and exit. Note as well that the endogeneity concerns discussed here are likely to be considerably less severe in specifications that include platform-age fixed effects since these allow the unobserved quality of a platform to change in each year of its "life".

ii. Software Supply

The installed base variables may be endogenous in the software supply equation. As above, this endogeneity problem will result if there is serial correlation in the error term. Specifically, a high value of η_j^t will stimulate additional games for platform *j* in month *t*. This will increase the utility and sales of platform *j* that month which will increase the installed base of platform *j* in month *t+1*. If η_j^{t+1} is correlated with η_j^t, then ***Platform IB*** will be endogenous. Because the software available on platform *j* also affects the demand for competing platforms (and hence their installed base), the ***Generation IB*** terms can be endogenous as well. To instrument for a platform's installed base, we construct a measure of that platform's price history by taking the average of its price in each month since its launch. To instrument for the installed base of other platforms in a generation, we use the average price history of all competing platforms in the generation. In both cases, we expect that the price histories will be correlated with the installed base variables because they influenced sales in prior periods. However, they should be unrelated to the error term in the software supply equation since software providers care only about current and future installed base (and thus the only avenue by which past prices should affect current software availability is through their affect on past sales).

IV. Data

IV. A. Sources of Data

Our empirical analysis combines several sources of data. Our data on hardware prices and quantities were obtained from the NPD Group, a market research firm. The NPD Group collects data from approximately two dozen of the largest game retailers in the United States. These retailers account for about 65% of the U.S. market. From this data, NPD formulates estimates of figures for the entire U.S. market. The NPD data provides monthly unit and dollar sales of each console with positive sales. Dollar sales are divided by unit sales to obtain an average monthly price for each console. Our hardware data covers the period 1995-2005, inclusive. We supplement these data with information on the technological characteristics and release dates of each console, which we collected from a variety of sources including analyst reports, company websites, and trade publications. Technological characteristics include processor speed, processor word length (8-bit, 16-bit, etc—the basis of most groupings of video game systems), console memory capacity, and whether the system was CD-ROM based. While these characteristics are not separately identified from the platform fixed effects that we include in our specifications, they are important because we use them as instruments for price.

Our main source of data on software is www.mobygames.com. www.mobygames.com is a website that seeks to "catalog all relevant information about electronic games (computer, console, and arcade) on a game-by-game basis."[18] MobyGames provides a database of software titles that includes the release date of each title, for each platform on which it appears and for each country in which it is released. The data also contain the name of the publisher, the genre of the game, and an indication of whether it uses content licensed from another party (like a movie studio). This database in principle goes back indefinitely in time, and is intended to capture all releases from the beginning of each platform's life.[19]

IV. B. Variables[20]

i. Market Shares and Installed Base Measures

Estimation of the hardware demand equation requires that we construct measures of each platform's share of the total potential market for video game consoles as well as its share of the share of the market captured by all of the "inside goods" combined. Following Clements and Ohashi (2005), we define the potential market for video games consoles in any month to be the number of households with a television (taken from the U.S. Census website) less the combined installed base of all active platforms (i.e.: we want to subtract a measure of the number of consumer who are not in the market because they already own platforms). The simplest such measure would be the sum of each console's past sales. We start by constructing this type of platform-level installed base measure (***Platform IB***). Since six of the ten platforms that we study launch within the period of our data, we can construct their past sales simply using the sales figures from

[18] See http://www.mobygames.com/info/faq1#a. The information contained in MobyGames' database is provided by the website's creators as well as from voluntary contributions. All information submitted to MobyGames is checked by the website's creators.
[19] Its earliest entries are in 1972, for which there are six releases for the Odyssey game system.
[20] Variable names and definitions appear in Table 3a. Table 3b presents summary statistics.

our data.[21] For the other four platforms, we obtained data on their year-end 1994 installed base from other sources. The year-end installed base figures for the platforms in generations three and four come from Shankar and Bayus (2003) while the figure for 3DO comes from an analyst report. For these four platforms, we construct ***Platform IB*** by combining these figures with the NPD sales data. Note that for each platform, we truncate the time series in the month that its sales first fall under 1000, defining this as a platform's "exit" from the market.

While we could use this ***Platform IB*** measure in our construction of the total potential market, it presents a problem. In particular, this approach does not allow users of an old platform to gradually re-enter the market; rather, when an old platform "exits" the market by having its sales fall below 1000 in a month, it yields a discrete (and potentially huge) influx of new customers into the "potential market." We solve this problem by modifying the installed base variable based on a depreciation rate. Specifically, we calculate each month's installed base as a fraction of the previous month's installed base plus the previous month's hardware sales, where the depreciation rate varies with the age of the platform.[22] We call this variable ***Depreciated IB***. We focus on this particular formulation of the depreciation rate because, practically speaking, it yields declines in installed base that roughly coincides for most platforms with their exit from the market defined by current sales. We also run robustness checks using alternate ways of measuring installed base.

Having calculated each platform's depreciated installed base, we then calculate the total potential market for video game systems in a month as the number of U.S. households with a television minus the sum of ***Depreciated IB*** over all active platforms. We construct a platform's market share in a month as its hardware sales divided by the total potential market and call this ***Market Share***. We construct a platform's within-group share (***Within Group Share)*** as its hardware sales that month divided by the total hardware sales of all active platforms that month. The share of the outside good (which

[21] While Table 2 gives a launch date for Jaguar that predates our sample, its national launch was not until the end of 1994, so we ignore sales prior to our data, which begins in January 1995.

[22] The monthly depreciation rate (or rate of reentry into the potential market) is 0.00065 times the age of the platform in years. This yields about a 1% re-entry over the course of the first year and about a 7.5% re-entry rate over the course of a platform's tenth year.

is needed to construct the dependent variable for the demand equation) is calculated as one minus the combined market shares of all of the active consoles in a month.

Our software supply equation includes measures of both a platform's own installed base and the installed base of the other platforms in its generation. We use ***Platform IB*** in the software supply equation and calculate ***Generation IB*** as the sum of ***Platform IB*** over the competing platform's in a generation.

ii. Console Characteristics

Because our hardware demand equation includes console fixed effects, non-time varying console characteristics (such as technical specifications) are not separately identified. The three time-varying characteristics that we include in the demand model are price, age and, of course, software availability. We construct the average price of each console in each month (***Price***) by dividing the console's dollar sales by its unit sales. We measure the age of a platform as the number of months that have past since the platform's U.S. launch month. We call this variable ***Platform Age***. In some specifications, we measure a platform's age in years since its U.S. launch. While the age of a console may not directly affect consumers' utility, we expect that it matters indirectly. For example, consumers may use console age to predict how many more new games may be released for that console, or they may use it to predict when the next generation of machines may be launched. As mentioned above, age may also capture the availability of complementary products other than software, such gaming magazines or websites.

We use the MobyGames data to measure the cumulative amount of software available on a console in a month. Our primary measure of software availability is simply the sum - from the platform's release date up through the present month - of all titles released on that platform in the US. We call this variable ***# of Titles***. This variable appears on the right-hand side of the demand equation and as the dependent variable in the supply equation. More detailed information on what software titles were actually selling at any point in time would likely yield a more accurate portrayal of the software available to consumers at the time they made their hardware choice. While we do not have this information for the entire time period covered by our hardware data, we do have monthly sales for each game title 1995-2001.[23] As we explain in Section VI, we try to exploit this software sales data in two ways.

V. Results

This section presents our empirical results. It proceeds in several steps. First, we present the results of the hardware demand equation and use the logit market share equations to illustrate the differential impact of exclusive and non-exclusive software titles on hardware demand. We then present the results of the software supply equation and show that, over time, positive cross-platform (within-generation) network effects arise. That is, we find that, controlling for a platform's own installed base, in Generation 6 the installed base of competing platforms stimulates the supply of games for that platform. Together, the results of the hardware demand and software supply equations indicate that while platform-specific indirect network effects still exist, generation-wide indirect network effects exist as well. Finally, we conclude this section with an empirical exercise that illustrates the effects of having network effects between users of competing consoles.

V.A. Hardware Demand Results

Tables 4 and 5 present the results of the hardware demand estimation. All of our models include platform fixed effects (except for the final column of Table 4 which includes platform-age fixed effects) and calendar month fixed effects. All specifications treat ***Price***, ***# of Titles*** and ***Within Group Share*** as endogenous. Recall that the right-hand side of our model is literally the mean utility of product *j* in month *t* and therefore the coefficients that we estimate on ***Price*** and ***# of Titles*** are marginal utilities of these attributes. Thus, the magnitudes of these coefficients are not, on their own, informative; however, the ratio of the coefficients can be used as a way to illustrate the relative effects of different attributes.

The first three columns of Table 4 estimate the hardware demand model using alternate ways of controlling for platform age. Because both price and software

[23] This data is also from the NPD Group. Software sales are by platform. Thus, if a given title is available on multiple hardware platforms, we know the sales on each platform.

availability will change with age, it is important to carefully control for any other ways in which platform age may affect the demand for a particular platform. In (4-1), we include the linear age variable and its square, in (4-2) we include fixed effects for age in years and in (4-3) we include fixed effects for age in months. Each of these specifications yields quite similar results. In particular, we find that higher prices lower consumers' utility from a platform while greater software availability increase their utility. The relative magnitudes of the coefficients in (4-3) indicate that decreasing the hardware price by $10 has roughly the same effect on utility as introducing 20 new exclusive games. As expected, the coefficient on ***log(Within Group Share)*** lies between zero and one and ranges from 0.54 to 0.65. This suggests that the "inside products" are indeed closer substitutes for each other than for the outside good.

As described in Section III, if there are unobserved shocks to the quality of a platform that persist for more than one month, then the software variable may be endogenous. Of course, a second implication of unobserved changes in quality that persist over time is that error terms in the hardware demand equation will be serially correlated. To account for this, we do two things. First, in the fourth column of Table 4, we re-estimate (4-3) using standard errors that are robust to arbitrary autocorrelation. The point estimates do not change, but the standard errors increase and the significance of the coefficients on ***Price*** and ***# of Titles*** is reduced. Second, in (4-5) we replace the platform and age fixed effects with platform-age effects. Intuitively, these estimate the unobserved quality of each platform in each year of its life (i.e., rather than estimate one level of unobserved quality for, say, the Sony PlayStation, we now estimate ten different levels). These fixed effects will clearly do a better job of capturing unobserved and potentially persistent changes in quality that occur at different points in a platform's life; moreover, the error term in the hardware demand equation is much less likely to exhibit serial correlation with their inclusion. The disadvantage of these fixed effects, however, is that they are more demanding of the data in the sense that we can only identify the effects of the price and software variables from variation in these variables within a year for a given platform (and there are many platform-ages in which there is very little variation in one or both of these variables). When we include these fixed effects, we again find a positive and significant effect of software availability on hardware demand though the effect of price is not significant.

Having obtained estimates of the marginal utility of software, we can now illustrate the differential impact of exclusive and nonexclusive titles on hardware demand. As described in Section III, there is no need to distinguish exclusive and nonexclusive software in the mean utility expressions. Rather, the logit demand system accounts for the fact that a non-exclusive game affects the utility of each platform for which it is available. Using the nested logit market share equations and the estimates from specification (4-3), we compare the effects on demand of ten additional exclusive games and ten additional non-exclusive games. We do this in the following way. First, we back out the mean utility implied by our estimates for each observation. We then use this to calculate the implied shares of the total market. Then, we recalculate the implied share for each platform-month under the assumption that that platform's mean utility has increased through the addition of 10 software titles (i.e., its mean utility is increased by 10 times the coefficient on ***# of Titles*** in specification (4-3)). We then calculate the resulting change in share and average these changes over all observations.

The average share of the total market for all platform-month observations is 0.00217; given the roughly 100 million households in the total potential market, this amounts to about 217,000 units. The calculation described above implies that, on average, the introduction of ten exclusive games increases a platform's share of the potential market by 0.000305, or about 30,500 units per month. We can compare this with the estimated effect of adding ten games that are compatible with all available hardware platforms. Such an addition increases each firm's predicted share of the potential market by only 0.000142, or about 14,200 units. That is, the relationship between hardware demand and exclusive titles is on average a little over two times stronger than the relationship between hardware demand and titles available on all platforms.

In Table 5, we estimate specification (4-2) of our demand model using two alternate software measures that attempt to capture differences in the quality of games.[24]

[24] One could also check for robustness to different assumptions on the inter-generational compatibility between platforms from the same provider. In particular, the PlayStation 2 can play PlayStation 1 games,

First, we construct a weighted software measure that exploits the software sales data that we have for the years 1995-2001. Specifically, we estimate a software sales equation for each title for which we have the sales data. The right-hand side variables of this equation include a series of dummy variables capturing the size of the publisher, a dummy variable for whether the title is part of a series (i.e., a sequel to a previously released game), a dummy variable for whether the title includes licensed content, and dummy variables indicating whether the game is part of one of four major franchise games (Zelda, Mario Brothers, Donkey Kong, and Sonic the Hedgehog).[25] We use the coefficient estimates from the sales equation to calculate the predicted sales of all titles in our MobyGames database. We then scale these sales projections by the number of consoles sold for each platform (this has a similar effect to including platform fixed effects, but has the benefit that it allows projections to platforms not yet introduced during this period). Thus, our projected sales variable is measured as dollars per console.[26] These projected sales are summed up for each platform to create a weighted software availability measure that can be used in place of the simple count of titles described above. We call this variable ***Weighted # of Titles***. (5-1) replaces the simple ***# of Titles*** variable with ***Weighted # of Titles***. When we include this quality-adjusted measure of software, we again find a positive and statistically significant effect of software on utility.

In (5-2), we try to capture software quality in a more direct way. We restrict our sample to the period for which we have the software sales data (1995-2001) and construct a software variable that measures the number of titles on a platform in a month that experience positive sales.[27] We again find a positive and statistically significant effect of software on utility.

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though these are not counted in the ***# of Titles*** variable for PlayStation 2. However, this is irrelevant since all our specifications contain platform fixed effects, which absorb this fixed increase in titles available on PlayStation 2.

[25] We also tried including genre dummies but these proved insignificant. We have replicated the results using publisher dummies in this regression and obtained similar results. We present results that use the publisher size dummy variables because this specification allows us to project sales for a larger set of titles (i.e., we can still project sales for games that are published by firms that do not exist during the period for which we have software sales data).

[26] For example, a value of one would represent a game that was projected to sell to 2% of the market (at its size at maturity) at $50, yielding $1 average revenue per console sold.

[27]We estimate this regression using only the platforms in generations 5 and 6 because these are the platforms launched during or just before the period for which we have this data. Software launches for extremely mature platforms are likely to exhibit different patterns.

V.B. Software Supply Results

This section presents the estimates from our software supply equation. In all specifications, the dependent variable is ***# of Titles***. All models include platform fixed effects and either year or month fixed effects (to control for general trends on the software side of the market). Since we cannot include platform, year, and age fixed effects, we control for the age of platform using the square and cube of ***Age in Months***. The installed base variables are treated as endogenous in all specifications.

In the first column of Table 6, we estimate the relationship between the supply of software for a video game platform and that platform's installed base of hardware. As expected, we find that a positive relationship. Together with the positive effect of software on hardware demand, the positive coefficient on ***Platform IB*** establishes the presence of platform-specific indirect network effects.

The most interesting and novel of our software supply results is the relationship between the supply of games for a platform and the installed base of its competitors. In the second column of Table 6, we add ***Generation IB*** - recall that this variable measures the combined installed base of competing platforms in a generation. When we do not allow the coefficient on this variable to change by generation, we find that ***Generation IB*** has a negative and significant effect on the ***# of Titles***. That is, increasing the installed base of a platform's competitors lowers the supply of games for that platform. As discussed in Section III, the finding of a negative coefficient on ***Generation IB*** in a reduced-form model should not be surprising.

In specifications (6-3) – (6-5) in Table 6, we allow the relationship between ***Generation IB*** and ***# of Titles*** to change over successive generations. We implement this by interacting ***Generation IB*** with dummies for Generations four through six. Since we have data on only one platform in Generation three (the NES), we cannot estimate a coefficient on ***Generation IB*** for that generation.[28]

We incorporate these additional interactions into the model of (6-2) and present the results as specification (6-3). The coefficients on all three of the ***Generation IB*** terms

[28] To instrument for these interactions with ***Generation IB***, we interact our instruments (described in Section III.C) with Generation dummies.

are significantly different from zero. Moreover, they are monotonically increasing over successive generations. The coefficients imply that, in Generation four, increases in the installed base of its competitors lower the supply of games to a platform. In Generation five, the effect is still negative but an order of magnitude smaller. Finally, in Generation six, increases in its competitors' installed base stimulate the supply of software for a platform. The magnitude of this effect is reasonably large with the point estimates in (6-3) implying that an increase in rivals' combined installed base is worth, strictly in terms of software availability for a platform, about one quarter of what an increase in one's own installed base is worth.

The positive coefficient on ***Generation IB*Generation-6*** establishes the existence of indirect network effect that are operating at the generation level, rather than platform level. The hardware demand estimates establish that the demand for a platform is increasing in the availability of software for that platform, and the software supply estimates establish that in Generation six the availability of software for a platform is increasing in the hardware sales of the entire generation. Thus, users of competing video game platforms create positive externalities for each other within a generation. These results suggest that a consumer's utility of purchasing a Microsoft Xbox is not only increasing in the number of other users of the Xbox but also in the number of users of the PlayStation2 because, with high costs of developing common content and low enough porting costs, their combined size will induce software providers to write games that are released on both platforms. Thus, the scope of indirect network effects in this industry has changed.

The remaining columns of Table 6 estimate slight variations on (6-3). Column four replaces the year fixed effects with month fixed effects and column five adjusts the standard errors for arbitrary autocorrelation. The supply results are quite robust to both of these specification changes.

V.C. Implications of the Estimates

We can illustrate the implications of the change in the scope of indirect network effects in this industry by tracing out the effect on hardware sales of an exogenous change in software availability. In markets with indirect network effects, an exogenous increase in software for a platform has both a direct effect on hardware demand (increasing utility and sales) and an indirect effect (since this direct effect stimulates the provision of additional software, which further increases utility and sales). This latter effect—which is sometimes called the "virtuous cycle"—illustrates how, in markets with network effects, the "strong get stronger" and the "weak get weaker" (Shapiro and Varian (1999)). However, once network effects exist across users of competing platforms, this cycle is weakened. In particular, an increase in (exclusive or non-exclusive) software for a platform still increases the installed base of that platform, which still increases the supply of games for that platform, but now it also increases the supply of games for competing platforms. Thus, in this scenario, one could say that the strong may get stronger but the weak may not get as weak as they would have absent this cross-platform positive spillover.

Although we do not estimate a dynamic model, we can use the results of our demand and supply equations to illustrate one iteration of this cycle under the assumption that network effects do not exist across platforms (i.e., using our Generation four estimate of the coefficient on ***Generation IB***) and under the assumption that network effects do exist across platforms (i.e., using our Generation six coefficient on ***Generation IB***). We do this by calculating the effects of a hypothetical addition of 10 exclusive titles for PlayStation 2. We do this separately (not cumulatively) for each month from January 2004 onward, which is the period in which PS2, GameCube, and Xbox are the three competing platforms in generation 6, and then present the average effects over these months.

We calculate these effects as follows. We begin with the same calculation employed in the illustration of the demand estimates, in which we back out implied mean utilities and calculate predicted shares of the total market. We then increase PlayStation2's mean utility to reflect the addition of ten new games. We make no changes to software measures of the other platforms, consistent with the interpretation that these software titles are exclusive to PlayStation2. We then recalculate the firms' predicted market shares based on these new mean utilities, calculate the difference from the original implied share, and multiply this by the size of the potential market. We refer to this increase in market share as the *direct effect* of the increase in software for the

PlayStaion2, and we report it in the first row of Table 7. This row demonstrates two consequences of an increase in software for PS2. First, the increase in software diverts sales from both of the other platforms to PS2. Second, total sales grow since the sum of the numbers in this row is positive; that is, PS2 gains more sales than XBox and GameCube lose.

We then use the estimates from our software equation to predict how the number of titles provided on each platform changes as a result of the installed base changes that result from the sales changes reported in the first row. This takes into account both the change in each platform's own installed base and the change in other platforms' installed base. Thus, the implied effect on software provision will vary depending on whether we use the Generation 4 or Generation 6 estimates. Finally, we use this implied change in software availability to calculate the *indirect effect* on hardware sales of the initial hypothetical increase in exclusive titles for PS2. The second and third row of Table 7 follow this exercise through using the Generation 4 estimates—that is, the estimates that show a negative cross-platform spillover. The fourth and fifth rows of Table 7 follow the exercise through with the Generation 6 estimates, which show a positive cross-platform spillover.

The contrast in these calculations using Generation 4 and Generation 6 estimates helps make concrete the implications of the change in the scope of indirect network effects that we find. Note that in both scenarios (rows two and four) the effect of the diversion of hardware sales to PS2 is to stimulate additional software provision for PS2 and to reduce software availability for the other two platforms. This is one sense in which the indirect network effects lead the strong to get stronger and the weak to get weaker—an exogenous increase in software for one platform leads to both additional software for that platform and a decrease in software for other platforms. However, the magnitudes of the effects are quite different between the two scenarios. The broadening of the network effect in moving from Generation 4 estimates to Generation 6 estimates cuts the implied follow-on increase in software for PS2 in half, from 0.35 titles to 0.18 titles. However, the negative effect on the other platforms is cut in both cases by more than a factor of 15 (-0.32 to -0.02 and -0.28 to -0.005). In this sense, the broadening of the network effects leads to a scenario in which the strong still get stronger, but the weak do not suffer nearly the same penalty from further increases in the leader's sales. This is, of course, precisely because of the positive spillover that the leader's increased sales creates in the way of software provision for the smaller platforms.

The third and fifth rows of Table 7 show how this effect on follow-on software provision translates into an indirect effect on hardware sales. The numbers there exhibit a similar pattern: the broadening of network effects in Generation 6 somewhat weakens the indirect benefit to the leader but dramatically reduces the penalty to the weaker firms.

VI. Conclusion

In this paper we investigate the scope of indirect network effects in the home video game industry and argue that, despite the fact that all home video game systems are incompatible, indirect network effects increasingly exist between users of rival systems. This is because multi-platform releases (or non-exclusive software titles) allow software publishers to spread the fixed costs of game development over users of competing platforms. Over time, software publishers' incentives for multi-platform releases have increased as the fixed development costs of common content have soared, while the fixed costs of porting a game to additional platforms have fallen. Both of these increase the relative profitability of non-exclusive software releases, which in turn lead to the presence of cross-platform indirect network effects.

Our empirical results support this interpretation. We estimate a model of hardware demand and software supply that indicates that while platform-specific indirect network effects exist, in recent years generation-wide indirect network effects have also come to exist. Thus, the scope of indirect network effects has changed. We also carry out a simple illustrative exercise that shows why the presence of positive cross-platform spillovers weakens the benefit that a platform gets from a strategy aimed at stimulating demand, such as the introduction of new software. While we do not estimate a dynamic model, we believe that our findings are suggestive of why, in recent generations, this industry has not been dominated by any single console. Furthermore, our results indicate that hardware compatibility is not the only factor affecting the scope of network effects in an industry. Rather, non-exclusive software creates another avenue by which cross-platform spillovers can arise, as changes in software development and porting technology increase the attractiveness of expanding the potential market through multi-platform releases.

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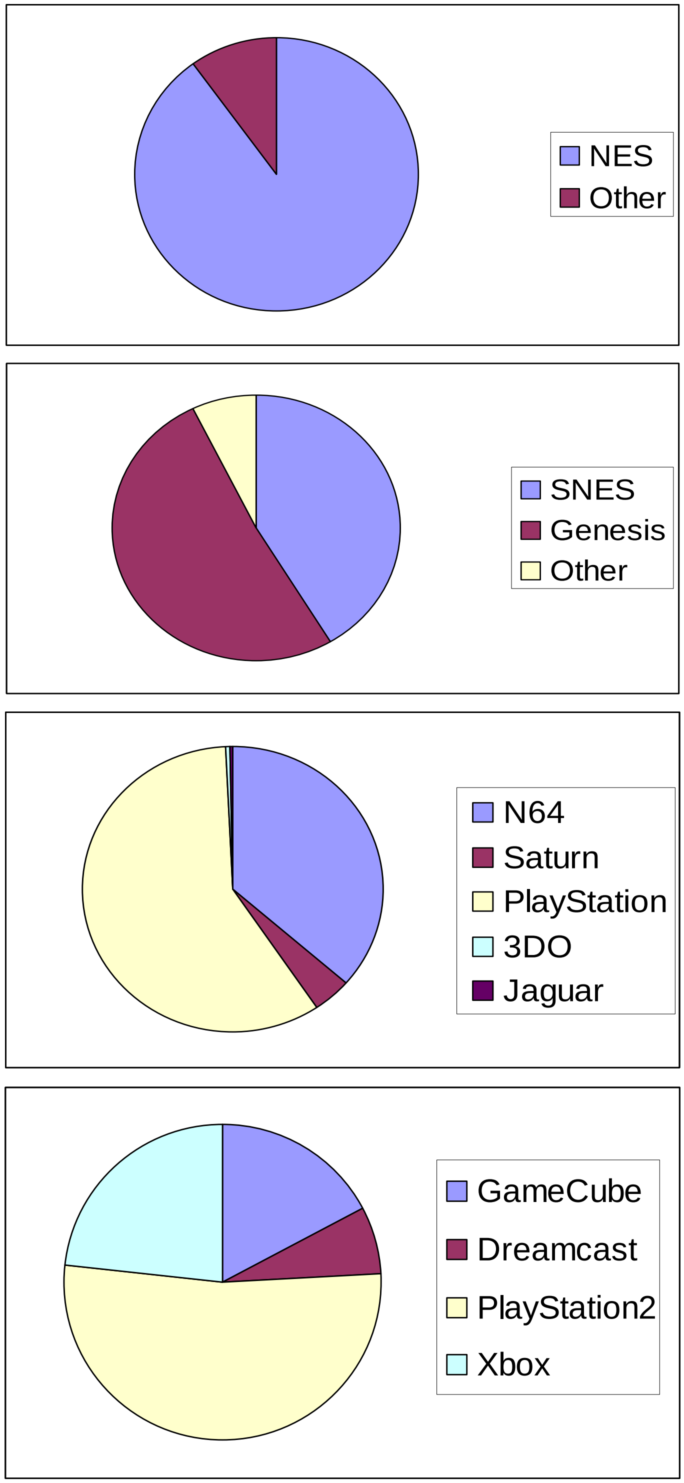
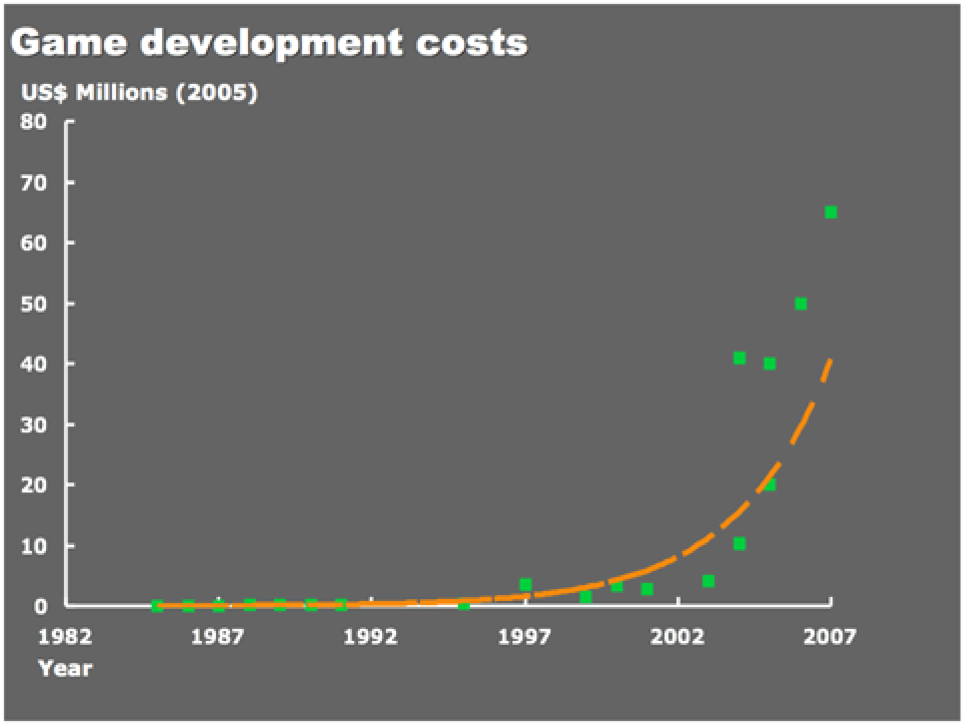
Figure 1
Long-Run Installed Base Market Share, by Generation



Source: Generation 3, Power Play (A); Generation 4, Power Play (B); Generations 5 and 6, NPD data.

Figure 2
Game Development Costs



Source: http://arstechnica.com/articles/paedia/hardware/crossplatform.ars/2

Table 1
Generations of the U.S. Modern Home Video Game Industry

	U.S. Launch Date	Platform Parent	Hardware Technological Characteristics		
			CPU bits	MHZ	RAM (M bytes)
Generation 3					
NES	October 1985	Nintendo	8	1.8	0.002
Generation 4					
Super NES	August 1991	Nintendo	16	3.6	0.128
Genesis	August 1989	Sega	16	7.6	0.064
Generation 5					
N64	September 1996	Nintendo	64	93.75	36
Saturn	May 1995	Sega	32	28	4
PlayStation	September 1995	Sony	32	33.87	2
3DO	October 1993	3DO	32	12.5	2
Jaguar	November 1993	Atari	32	26.59	2
Generation 6					
GameCube	November 2001	Nintendo	128	485	24
Dreamcast	September 1999	Sega	128	200	16
PlayStation2	October 2000	Sony	128	300	32
Xbox	November 2001	Microsoft	Intel Pentium II	733	64

Table 2A
Changes in Software Characteristics, by Generation

	Generation[1]				
	All	**3**	**4**	**5**	**6**
# of Titles	3544	585	622	1124	1225
Game Characteristics					
% Exclusive[2]	73%	88%	71%	80%	61%
% Exclusive, Third-Party Titles Only	68%	88%	65%	77%	54%
% In-House	21%	25%	21%	23%	16%
% Utilizing Licensed Content	25%	18%	24%	26%	27%
Size of Publisher, Measured by # of Titles per Publisher (independent publishers only)	30	10	18	33	39

[1]Data are at the title level. Title's generation is determined by the first platform on which it is released. 273 of the titles in our sample (7.7%) are, at some point, released on platforms in different generations. For the purpose of this table, these titles are counted in the generation of the first platform on which they are released.
[2]Exclusive is defined as *never* being released on any other platform

Table 2B
Software Characteristics, by Platform

	# Titles[1]	% Exclusive	% Exclusive, Third-Party Titles Only	% Licensed
Generation 3				
NES	531	84%	82%	21%
Sega Master System[2]	100	66%	40%	13%
Generation 4				
Super NES	428	51%	47%	28%
Genesis	441	50%	41%	27%
Generation 5				
N64	246	61%	52%	37%
Saturn	152	37%	20%	24%
PlayStation	871	69%	65%	28%
3DO	85	59%	59%	11%
Jaguar	67	64%	38%	15%
Generation 6				
GameCube	378	26%	17%	40%
Dreamcast	211	57%	49%	25%
PlayStation2	832	43%	38%	32%
Xbox	569	29%	23%	35%

[1]Data is at the title-platform level (i.e.: titles that are released on multiple platforms will count for each of those platforms).
[2]The Sega Master System is included in this table for the purpose of illustrating software trends. It is not included in our estimation sample since it does not have new sales during our sample period, 1995-2005.

Table 3A
Variable Definitions

Variable	Definition	Source
Price	Monthly retail price of platform. 2005 dollars	NPD data
# of Titles	Cumulative number of software titles that have been released for a particular platform	Moby data
Platform Age	Platform's age in months (0 for month of launch)	Authors' construction
Platform IB	The installed base of a given platform, calculated as its cumulative sales of hardware, in thousands	NPD data and authors' construction
Generation IB	The sum of the installed bases of all other platforms in a given generation, in thousands	NPD data and authors' construction

Table 3B
Summary Statistics

Variable	N	Mean	Std Dev	Min	Max
log(market share$_j$/market share$_0$)	716	-7.40	2.11	-14.71	-3.25
log(within_group_share$_j$)	716	-2.58	1.92	-9.04	-.39
Price	716	162.95	112.64	22.18	942.67
# of Titles	716	322.80	242.98	2	871
Platform Age (months)	716	49.54	36.41	0	138
Platform IB (thousands)	716	11115.08	9734.29	0	32174.05
Generation IB (thousands)	716	13111.8	11422.48	0	48161

Table 4
Hardware Demand

Dependent Variable	$log(s_j/s_o)$				
Age Control	Age (months) & Age (months)^2	Age (years) Fixed Effects	Age (months) Fixed Effects		Platform-Age Fixed Effects
	(4-1)	(4-2)	(4-3)	(4-4)	(4-5)
Price	-0.0006	-0.0016	-0.0015	-0.0015	-0.0046
	(0.0006)	(0.0007)*	(0.0006)**	(0.0010)	(0.0049)
# of Titles	0.0008	0.0009	0.0007	0.0007	0.0216
	(0.0004)*	(0.0004)*	(0.0004)+	(0.0006)	(0.0129)+
log(within_group_share$_j$)	0.5428	0.6017	0.6509	0.6509	0.9287
	(0.0715)**	(0.0697)**	(0.0648)**	(0.1030)**	(0.3737)*
Observations	716	716	716	716	716

+ significant at 10%; * significant at 5%; ** significant at 1%. All specifications report 2SLS estimates. All specifications include platform and calendar month fixed effects (coefficients not reported). Coefficients on age variables also not reported. All standard errors are robust to arbitrary heteroskedasticity. Standard errors in (4-4) are also robust to arbitrary autocorrelation.

Table 5
Hardware Demand – Alternate Software Measures

Dependent Variable	$\boldsymbol{log(s_j/s_o)}$	
Age Control	Age (years) Fixed Effects	
	(5-1)	(5-2)
Price	-0.0040 (0.0013)**	-0.0005 (0.0013)
Weighted # of Titles	0.0036 (0.0018)*	
# of Titles with Positive Sales		0.0023 (0.0006)**
log(within_group_share$_j$)	0.6910 (0.0465)**	0.5979 (0.1262)**
Observations	716	236

+ significant at 10%; * significant at 5%; ** significant at 1%. All specifications report 2SLS estimates. All specifications include platform and calendar month fixed effects (coefficients not reported). All standard errors are robust to arbitrary heteroskedasticity and arbitrary autocorrelation. Sample in (5-2) excludes years before 1994 or after 2000 and excludes the following platforms: NES, SNES, Genesis, Xbox and Genesis.

Table 6
Software Supply

Dependent Variable			***# of Titles***		
Estimation Method	IV	IV	IV	IV	IV
Time Control	Year Fixed Effects	Year Fixed Effects	Year Fixed Effects	Month Fixed Effects	Month Fixed Effects
	(6-1)	(6-2)	(6-3)	(6-4)	(6-5)
Platform IB (000s)	0.0103	0.0320	0.0234	0.0241	0.0241
	(0.0039)**	(0.0070)**	(0.0007)**	(0.0007)**	(0.0013)**
Generation IB (000s)		-0.0130			
		(0.0043)**			
Generation IB*Generation=4			-0.0482	-0.0388	-0.0388
			(0.0064)**	(0.0053)**	(0.0094)**
Generation IB*Generation=5			-0.0047	-0.0039	-0.0039
			(0.0015)**	(0.0014)**	(0.0025)
Generation IB*Generation=6			0.0056	0.0049	0.0049
			(0.0010)**	(0.0010)**	(0.0019)*
Observations	652	652	652	652	652

+ significant at 10%; * significant at 5%; ** significant at 1%. All specifications include platform fixed effects and platform age (in months) squared and cubed (coefficients on not reported). (6-1) – (6-3) also include calendar month fixed effects. All standard errors are robust to arbitrary heteroskedasticity. Standard errors in (6-5) are also robust to arbitrary autocorrelation.

Table 7
Direct and Indirect Effects of 10 Additional Exclusive Titles for PlayStation2

	PS2	Xbox	GameCube
Direct increase in hardware sales	8399	-2216	-1459
Generation 4 estimates			
Resulting increase in software titles	0.35	-0.32	-0.28
Indirect increase in hardware sales	719	-415	-235
Generation 6 estimates			
Resulting increase in software titles	0.18	-0.02	-0.005
Indirect increase in hardware sales	285	-92	-49