Vertical Integration and Exclusivity in Platform and Two-Sided Markets

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Abstract

This paper empirically measures the impact of vertical integration and exclusive contracting in the sixth-generation of the U.S. videogame industry (2000-2005) through modeling the software supply-side responses to a counterfactual regime change. Using results from a structural model of dynamic consumer demand for hardware and software developed in Lee (2010), this paper (i) estimates the underlying "porting costs" faced by software providers to develop for multiple consoles, (ii) specifies a dynamic network formation game to model the hardware adoption decisions of software providers, and (iii) computes a new equilibrium industry structure if exclusive vertical arrangements were prohibited. Counterfactual experiments indicate banning exclusivity would primarily benefit the incumbent and not the smaller entrant platforms, which stands contrary to the interpretation of exclusivity as primarily a means of foreclosure and entry deterrence.

Keywords: platform competition, two-sided markets, vertical integration, exclusive contracting, network formation, videogame industry

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1 Introduction

In most networked industries, consumers adopt, join, or visit a platform in order to access goods or services provided by firms who are also affiliated with the same platform. Also known as *platform* or *two-sided markets*, these industries include hardware-software markets, content and media markets, retail marketplaces, payment systems, and buyer-seller networks.[1] Often certain firms and their products have significant market power over consumers, inducing consumers to adopt the platform(s) that they have joined. Via exclusive contracts or vertical integration, platforms compete fiercely with one another to get such firms and products exclusively "onboard" in order to dominate the market. This paper studies these exclusive vertical arrangements between platforms and firms and measures their impact on industry structure and competition.

Whether or not such arrangements are primarily pro- or anti-competitive or harmful to consumers is still a source of active debate and an open empirical question. On the one hand, exclusive contracts raise anti-competitive issues since they may deter entry or foreclose rivals (Mathewson and Winter (1987), Rasmusen, Ramseyer, and Wiley (1991), Bernheim and Whinston (1998).); these concerns may be exacerbated by the presence of network externalities (Shapiro (1999)). From a consumer welfare perspective, these vertical arrangements can limit consumer choice by preventing consumers on competing platforms from accessing exclusive content, products, or services. On the other hand, theory has argued that exclusive arrangements may also have pro-competitive benefits, such as encouraging investment and effort provision by contracting partners (Marvel (1982), Klein (1988), Besanko and Perry (1993), Segal and Whinston (2000)). In networked industries, integration by a platform provider may be effective in solving the "chicken-and-egg" coordination problem, one of the fundamental barriers to entry discussed in the two-sided market literature. Furthermore, exclusivity may be an integral tool used by entrant platforms to break into established markets: by preventing contracting partners from supporting the incumbent, an entrant can gain a competitive advantage, spur adoption of its own platform, and thereby spark greater platform competition.

Given the growing prevalence of networked and platform industries, resolving this theoretical ambiguity is of central importance for policy and regulation. The competitive implications of integration and exclusive contracting were at the heart of several recent prominent antitrust cases – e.g., *U.S. v. Microsoft* [253 F.3d 34 (2001)], *European Union v. Microsoft* [COMP/C-3/37.792 (2004)], and *U.S. v. Visa* [344 F.3d 229 (2003)] – and also are the main issues to consider whenever evaluating exclusive carriage deals in the media industry, or opening up closed hardware-software systems to competitors.

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[1] C.f. Rochet and Tirole (2006).

This paper has two primary objectives. The first is to contribute to the literature on exclusivity by studying a canonical hardware-software market – the sixth-generation of the U.S. videogame industry (2000-2005) – and measuring empirically the impact of exclusive vertical arrangements between hardware platforms and software firms. By comprising multiple differentiated hardware platforms each with its own distinct base of software, the videogame industry exhibits features easily generalizable to a variety of networked environments; additionally, given the poor substitutability of videogame software, focusing on this industry abstracts away from potential anti-competitive effects in software development and instead focuses on foreclosure and entry-deterrence in hardware provision alone.

The second objective of the paper is to provide a framework for analyzing the adoption decisions of consumers and firms for competing platform intermediaries. Understanding how parties on each side of the market choose which platform(s) to join is required not only for analyzing the impact of exclusive arrangements, but also for evaluating any change in the competitive structure of a networked industry. I use the structural discrete choice model of consumer demand developed in Lee (2010) to understand how consumers choose which platforms and software products to purchase; this model allows me to recover the individual impact of each software title on hardware demand, and hence quantify how many platforms (and subsequent software titles) would sell if the allocation of software on each platform changed. I then combine this model with a model of software "demand" for platforms developed in this paper, which involves both (i) estimating the underlying "porting costs" faced by software providers to develop for multiple consoles, and (ii) specifying a dynamic network formation game to model the hardware adoption decisions of software providers. This network formation game importantly allows both consumers and software firms to act in a way that anticipates and is consistent with the future actions of all other consumers and firms, thereby explicitly capturing the *dynamic indirect network effects* prevalent in this industry. Finally, I use this combined model to compute a new equilibrium industry structure if exclusive vertical arrangements were prohibited.

Via a counterfactual experiment, the paper simulates forward the industry structure had hardware providers been unable to develop their own exclusive software or write exclusive contracts with software providers. The counterfactual explicitly focuses on the adoption decisions of software firms and consumers in the absence of exclusivity, and abstracts away from many potential issues: platform providers are assumed to offer the same non-discriminatory contracts to all firms, investment and product qualities do not change, and prices, entry, and exit of all products are held fixed. The main finding of this paper, focusing on re-contracting decisions alone, is that banning exclusive arrangements between hardware platforms and software publishers benefits the incumbent and harms the smaller entrant platforms: the incumbent would have sold 220M more software titles and realized nearly an additional $1.5B in profits if platforms could not integrate or contract exclusively with software providers.

The intuition is as follows: without exclusive arrangements, the developers of high quality software would have primarily developed titles for the incumbent due to its larger installed base, and only later, if at all, developed a version for either entrant platform; as a result, neither entrant platform would have been able to offer consumers any significant benefit over the incumbent. Exclusive access to certain software titles, however, could create a competitive advantage, and was leveraged by the entrants to gain traction in this networked industry. However, if exclusive vertical arrangements were prohibited, consumers may have benefitted from access to a greater selection of software titles onboard any given platform: consumer welfare would have increased by approximately $1B during the five-year period without exclusivity.

Importantly, this counterfactual prediction – that banning exclusivity would hurt the entrant platforms – is not necessarily obvious nor implied by the model or counterfactual setup. Rather, the demand estimates in Lee (2010) indicate that despite certain exclusive titles on the incumbent platform being hits and selling far more copies than any title on the entrant platforms – thus raising the possibility of the incumbent using these titles to foreclose its competitors – these titles did not actually have as much of an impact on hardware sales as did the exclusive hit titles onboard the entrant platforms: i.e., in the observed historical contracting regime, the demand system suggests that the entrants able to secure exclusive access to "more valuable" games. If it were the case that in the data the incumbent had exclusive rights to the more valuable titles, then the predictions of the counterfactual would be reversed: i.e., banning exclusivity would have helped the entrants, as now the hit titles would then multihome and cause more entrant platforms to be sold.[2] Hence, the estimates from the demand system are integral in conducting this analysis.

Though this framework can be extended to allow for a greater range of dynamics and strategic choices, a full equilibrium model of dynamic contracting, investment, pricing, and entry/exit is beyond the scope of the paper. Consequently, the current analysis cannot fully model all potential equilibrium responses to a change in regime; at the same time, some robustness checks are conducted which partially relax some of these assumptions governing pricing, investment in quality of new software, and platform contracting. For example, the inability to integrate may have reduced investment in previously integrated "first-party" titles; if these integrated titles were no longer produced, not only do entrant platforms perform worse, but consumer welfare is predicted to fall by a $.9B. Indeed, consumer welfare also falls if entrant platforms were allowed to exit, or the incumbent raised prices on its console by $200 (which it would find profitable to do). Other robustness exercises include

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[2] Although this analysis cannot speak directly to the observed allocation of software titles in the data, I provide some arguments why this may have been the case later when discussing the counterfactual results.

modifying platform pricing rules, platform contracting royalty rates, and the investment and quality of entrant software titles. Although slight differences in predictions highlight the importance of accounting for a greater range of dynamic effects when evaluating welfare consequences, all of these robustness checks still predict that the lack of exclusionary vertical agreements seem to favor the incumbent platform provider and are not found to significantly affect the predictions of the paper.[3] Consequently, insights gleaned from focusing only on equilibrium adoption decisions by consumers and software firms may still prove useful for guiding future research and policy.

1.1 Other Related Literature

Previous empirical work on measuring the effects of exclusive contracting and vertical integration has primarily focused on supply-side consequences and the threat of "upstream" foreclosure (e.g., Chipty (2001), Asker (2004), Sass (2005); c.f. Lafontaine and Slade (2008)).[4] In contrast, this paper focuses on "downstream" competition, and how exclusivity interacts with the networked aspect of the industry to either deter or enable platform entry.

In the software supply section, I define and compute a new equilibrium for a dynamic network formation game in which every title is allowed to freely choose which platforms to develop for. The equilibrium is one in which each title employs a strategy that depends only on the value and evolution of certain "payoff-relevant" state variables, and beliefs of all agents over the evolution of product lifetime utilities are restricted to lie within the class of first-order Markov processes. Given the restriction on beliefs, the solution concept used is equivalent to Markov Perfect Nash Equilibrium (Maskin and Tirole (1988, 2001)) and the model is similar in spirit to Ericson and Pakes (1995) and the industry dynamics literature that follows. Using this framework, this paper is one of the first to account explicitly for the rematching process between contracting partners within a counterfactual regime, and to my knowledge the only one that does so in a dynamic environment.

1.2 Road Map

In the next section I describe the U.S. videogame industry, the role of exclusive vertical arrangements, and important stylized facts. Section 3 presents the dynamic demand model of

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[3] Importantly this analysis does not apply to "forced exclusive" contracts – in which a software developer is not allowed to release software for a hardware platform unless it did so exclusively – as these contracts have not been utilized within the videogame industry since the early 1990's (see Section 2 for more discussion); courts have ruled them to be anti-competitive in other industries (e.g., *U.S. v. Visa*).

[4] The literature on vertical restraints typically refers to an "upstream" firm as the supplier of a (possibly intermediate) good, and a "downstream" firm as a firm that uses the good to produce another product, or a wholesale or retail firm that resells the good to final consumers (Tirole (1988), ch. 4). I reference this structure when labeling software providers as "upstream" and hardware platforms as "downstream" entities.

hardware and software developed in Lee (2010). I introduce the dynamic network formation game in section 4, and discuss the recovery the underlying porting costs borne by software firms and computation of equilibrium. Finally, I analyze counterfactual regimes in which exclusive agreements are banned in section 6, and conclude in section 7.

2 Application: The U.S. Videogame Industry

Starting as a fringe industry in the early 1970's with the introduction of a home version of *Pong*, the U.S. videogame industry has since grown to reach \$21.3B in revenues in 2008.[5] Increasingly, as evidenced by the widespread adoption of the new generation of consoles introduced in 2006, videogames have broadened their appeal and user base from a child's hobby to something more mainstream: 69% of American heads of households engage in computer and videogames, with the average age of a player being 35 years old,[6] and market penetration of videogame consoles reached 41% of U.S. television households (45M) in 2006.[7]

A videogame system comprises a hardware platform (the "console") and software (its games). In the current and most recent generations, each console is and has been provided by one firm – the platform provider – as a tightly integrated and standardized device that is required in order to utilize any software provided for the system. Videogame software, on the other hand, is brought to market by two vertically related entities: *developers*, who undertake the programming and creative execution of each title; and *publishers*, who market and distribute each game. Publishers may be integrated into software development; although independent software development studios exist, as the costs of developing games have increased over time – average costs reached \$6M during the late 1990's – these studios often turn to software publishers for financing in exchange for distribution and publishing rights.[8]

Console manufacturers are also integrated into software publishing and development. Any title produced by the console maker's own studios or distributed by its own publisher is known as a *first-party* title, and is exclusive to that hardware platform. All other games are *third-party* titles and are published by other firms. Within a generation, games developed for one console are not compatible with others; in order to be played on another console, the game must explicitly be "ported" by a software developer and another version of the game created.[9] These porting costs for supporting an additional console, which includes additional development and distribution costs, are non-negligible, and range from a few

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[5] *Entertainment Software Association 2008 Sales, Demographic and Usage Data.*

[6] *2006 and 2008 Essential Facts*, Entertainment Software Association.

[7] *The State of the Console*, Nielsen Media Research. March 5, 2007

[8] Coughlan (2001).

[9] A notable exception is "backwards compatibility," which refers to the ability of a new console to use software developed for the previous version of that particular console.

hundred thousand to a few million dollars during the period analyzed in this paper.[10] The choice of which platforms to develop for is thus strategic: a third-party software developer can release a title on multiple platforms in order to reach a larger audience and pay additional costs, or it can develop exclusively for one console and forgo selling its game to consumers on other platforms. Even if a title chooses to be exclusive, it has multiple options: it can voluntarily be exclusive, enter into an exclusive publishing agreement with the console provider, or opt to sell the game or even entire studio outright.

Since consoles usually have little if any stand-alone value, consumers typically purchase them only if there are desirable software titles available. At the same time, software publishers release titles for consoles that either have or are expected to have a large installed base of users. These cross-side network effects and "two-sidedness" are manifest in most hardware-software industries, and are partly a reason for the complex form of platform pricing: most platform providers subsidize the sale of hardware to consumers, selling them close to or below cost, while charging publishers and developers a royalty for every game sold.[11] As a result, platform profits are derived primarily not from hardware, but rather from software sales.

As the dominant videogame platform provider during most of the 1980's and 1990's, Nintendo used to write forced exclusivity contracts with developers, committing them to two-year exclusive deals in exchange for the right to develop for its system. Nintendo dropped these practices following a 1992 antitrust investigation related to *Atari Games Corp v. Nintendo of America, Inc.* [975 F.2d 832 (1992)].[12] Since then, forced exclusivity contracts have not been observed within the industry. In their place, console manufacturers have primarily relied on internal development, integration, or favorable contracting terms to third party developers or publishers (e.g., lump sum payments or marketing partnerships) in order to secure exclusive titles. More recently, as development costs for games have been increasing and porting costs have fallen as a percentage of costs, most third-party titles have chosen to multihome in order to maximize the number of potential buyers; in turn, console providers have become more reliant on their own first-party titles to differentiate their platforms.

2.1 The Sixth Generation: 2000 - 2005

The videogame industry witnesses the release of a new set of consoles approximately every five years. Since hardware specifications remain fixed within a generation to ensure compatibility and standardization, it is only during generational shifts that new hardware with more powerful processing power and graphical abilities are introduced. In October 2000, Sony released its Playstation 2 (PS2) console, the first of the "sixth-generation" of videogame

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[10] Industry sources; Eisenmann and Wong (2005) cite \$1M as the porting cost for an additional console.

[11] Hagiu (2006), Evans, Hagiu, and Schmalensee (2006).

[12] Shapiro (1999), Kent (2001).

consoles.[13] The PS2 was a followup to the original Playstation (PS1), Sony's wildly successful entry in the previous generation. A year later, industry veteran Nintendo released its Gamecube (GC) console, and new entrant Microsoft brought its Xbox console to market. Sony sold 5M systems in its first year; additionally, since Sony's PS2 was "backwards compatible" and could utilize software developed for the PS1, it also possessed a software library of over 1000 titles before either Nintendo or Microsoft came to market. As a result, I refer to Sony as the incumbent of this generation, and Microsoft and Nintendo as the entrants. By the time the first seventh-generation console entered in October 2005, Sony's new console sold almost double the number of hardware devices of both its competitors combined.

This paper focuses on the sixth-generation for several reasons. First, it marked the arrival of a new competitor – Microsoft – to the industry. Itself a veteran and competitor in other platform industries, Microsoft acquired several software developers before entering the market; whether or not Microsoft would have been able to gain a foothold into the industry absent integration or exclusive contracting is an open question. Secondly, the three platform providers are the same as the current seventh-generation providers, providing timeliness to this line of inquiry. Finally, the sixth-generation placed the videogame industry squarely within the convergence battle between personal computers and other general consumer electronics; as a result, the success or failure of these platforms had and continue to have a dramatic impact on industries far removed from videogames.

2.2 Data and Descriptive Statistics

I use a new panel data set obtained from the NPD Group, a market research firm, containing monthly observations from September 2000 to October 2005. Each observation includes the average selling price and quantity sold for the three sixth-generation videogame consoles, and the average selling price, quantity sold, and other descriptive information for 1581 unique software titles released during this period (including genre and release date).[14] Prices are normalized using the Consumer Price Index. For the population of potential consumers, I use the number of television households provided on a yearly basis from Nielsen and interpolated to the monthly level. General descriptive statistics are provided in table 1. Additional stylized facts about the industry include:

Prices: Hardware prices were generally constant, interrupted only by two major discrete downward jumps (see Figure 1).Software prices, however, follow much more regular price drops, with price cuts usually following the first few months of a new title's release.

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[13] Sega's Dreamcast was discontinued on January 31, 2001, and is not considered in this paper.

[14] The data is collected from approximately two dozen of the largest retailers in the U.S., which account for approximately 85% of videogame sales, and is extrapolated by NPD for the entire U.S. market.

Seasonality: The videogame industry, like most markets, exhibits considerable seasonality both in consumer demand and software supply. Figure 1 shows the number of total hardware consoles sold each month; during holiday months (November and December) the number of consoles sold is easily double or triple the average number sold in other months. Furthermore, in some months, over 100 new titles are released across systems; in others, less than 5.

Exclusivity and Multihoming: There is significant variation in software exclusivity across platforms: although nearly 64% of all unique software titles are exclusive to one console, the majority are located on the PS2. On the other hand, the majority of GC tiles are available on all systems. Table 2 lists the top 10 titles on each console: note that these top titles on the GC are all exclusive, whereas the PS2 are primarily non-exclusive.

Concentrated Software Sales: As with motion pictures, the videogame industry is primarily hit-driven with sales concentrated among a few top-selling games. Despite there being over 1500 unique titles released for the three consoles, the top 10 listed in Table 2 on the PS2, Xbox, and GC accounted respectively for 13%, 16%, and 20% of platform software sales. The concentration of software sales also occurs early in a title's life, with on average over 50% of total sales occurring within the first 3 months of release.

Significant Consumer Heterogeneity: The heaviest using 20% of videogame players account for nearly 75% of total videogame console usage (by hours played), averaging 345 minutes per day. However, the fastest growing segment of users are known as "casual gamers" who spend less than 5 hours a week playing games.

3 Consumer Demand

This section summarizes the structural model of dynamic consumer demand for both hardware and software in the videogame industry developed in Lee (2010). The model is used to recover how consumer demand for hardware responds to changes in availability of *any individual* software title, which in turn affects the incentives that govern each software title's decision of which platform(s) to develop for in the first place.

3.1 The Model

Let $\mathbf{J}_t$ denote the set of hardware consoles and $\mathbf{K}_{j,t}$ the set of software products on console j available for purchase at time t. Each month, a consumer may purchase any console she has not previously purchased; consumers can only purchase one console per month.[15] Denote consumer i's inventory of hardware consoles already owned at time t by $\iota_{i,t} \in \mathbf{I} \equiv \{0,1\}^3$.

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[15] Lee (2010) also estimates a model in which consumers can purchase multiple consoles in a month; results do not change significantly.

After purchasing console j, a consumer may then purchase any software title $k \in \mathbf{K}_{j,t}$ that she has not previously purchased. Consumers can delay purchase and do not purchase the same product twice; thus, they face a dynamic optimization problem of when, if ever, to purchase any given platform or software title. I present the hardware adoption decision first, and then discuss software purchase.

3.1.1 Hardware Adoption

The lifetime expected utility of consumer i with inventory ι who purchases platform $j \notin \iota$ at time t is given by:

$$u_{i,j,t,\iota} = \underbrace{\alpha_i^x x_{j,t} - \alpha_i^{p,hw} p_{j,t} + \Gamma_{j,t}(\alpha_i^p, \alpha_i^\gamma; \iota) + D(\iota) + \xi_{j,t}}_{\delta_{i,j,t,\iota}} + \epsilon_{i,j,t} \qquad , \tag{1}$$

where $\{\alpha^x, \alpha_i^{p,hw}, \alpha^{p,sw}, \alpha_i^\gamma\}$ are (possibly individual specific) coefficients that reflect how intensely a consumer prefers platform characteristics, price, and software; $x_{j,t}$ are observable characteristics of platform j at time t (which include a platform-specific and monthly fixed effects, age, age squared, and the current platform installed base); $p_{j,t}$ is the platform's price; $\Gamma_{j,t}(\cdot;\iota)$ is the expected present-discounted value of being able to purchase software for the platform in the current and future periods (which depends on an individual's preferences and inventory); $D(\iota)$ is a term that denotes any complementarity or substitutability effects that may exist with ownership of multiple consoles; $\xi_{j,t}$ is a product characteristic observable to the consumer but not to the econometrician; and $\epsilon_{i,j,t}$ is an individual-platform-time specific component that represents idiosyncratic consumer heterogeneity unobservable to the econometrician but realized by the consumer only at time t. Let $\delta_{i,j,t,\iota}$ denote individual i's expected lifetime utility from platform j at time t given inventory ι, net of her idiosyncratic unobservable. It can be thought of as the price-adjusted quality for platform j, and if $\epsilon_{i,j,t}$ were mean zero, it would represent the *mean utility* of such a purchase.

The actual functional form of $\Gamma_{j,t}(\cdot;\iota)$ comes from the software adoption portion of the model described in the next subsection; the only restriction made here is that $\Gamma_{j,t}(\cdot;\iota)$ differs across agents only as a function of their price sensitivity and software preference $\{\alpha_i^{p,sw}, \alpha_i^\gamma\}$, and enters linearly into the utility specification. The model restricts $D(\cdot) = D$, a constant, if a consumer owns at least one other console, and $D(\cdot) = 0$ otherwise.

In each period, a consumer chooses her optimal action – buy today or wait until next period (in which case she consumes an inventory-specific outside good yielding utility $u_{i,0,t} = \epsilon_{i,0,t}$) – given her inventory ι, preferences, current product qualities, prices, software availability, and expectations over future values of these characteristics. A consumer's value function from being on the market for a hardware platform, conditional on following her optimal policy, is given by:

$$V_i(\iota, \epsilon_{i,t}, \Omega_{i,t}) \;=\; \max\Bigg\{ \underbrace{\max_{j\in\mathbf{J}_t, j\notin\iota} u_{i,j,t,\iota}(\Omega_{i,t}) + \beta E[V_i(\iota\cup\{j\}, \epsilon_{i,t+1}, \Omega_{i,t+1}|\Omega_{i,t})],}_{\text{Buy best platform today, return next period with new inventory,}} \underbrace{u_{i,0,t} + \beta E[V_i(\iota, \epsilon_{i,t+1}, \Omega_{i,t+1})|\Omega_{i,t}]}_{\text{Consume outside good, return next period.}} \Bigg\} \qquad (2)$$

where $\epsilon_{i,t} \equiv \{\epsilon_{i,j,t}\}_{j\in\{\mathbf{J_t}\cup\{0\}\}}$, and $\Omega_{i,t}$ includes current product attributes, the time of year (seasonality), and any other market characteristics which may affect firm product pricing, entry, exit, or attributes. In general, it includes all variables at time t in a consumer's information set that affect her utility or value from waiting.

To reduce the state space Lee (2010) assumes that consumers perceive the mean utilities $\delta_{i,j,t,\iota}$ for each console to evolve according to a first-order process that depends on previous values of itself, *in addition to* $\{\delta_{i,j',t,\iota}\}_{j'\neq j}$ *of all other competing hardware platforms*, as well as the time of year:

Assumption 3.1. *For all consumer types i and inventory states $\iota \in \mathbf{I}$, consumers perceive that $\{\delta_{i,j,t,\iota}\}_{j\in\mathbf{J}_t,\forall t}$ can be summarized by a first-order Markov process:*

$$F(\{\delta_{i,j,t+1,\iota}\}_{j\in\mathbf{J}_{t+1}}|\Omega_{i,t}) = F_{i,\iota}(\{\delta_{i,j,t+1,\iota}\}_{j\in\mathbf{J}_{t+1}}|\{\delta_{i,j,t,\iota}\}_{j\in\mathbf{J}_t}, m(t)) \qquad , \qquad (3)$$

where $m(t)$ represents the month at time t, and $F_{i,\iota}$ is individual and inventory-state specific.

In particular, $\{\delta_{i,j,t,\iota}\}_{j\in\mathbf{J}_t,\iota\in\mathbf{I}}$ is assumed to take the following form:

$$\begin{aligned} &F_{i,\iota}(\delta_{i,j,t+1}|\{\delta_{i,j,t,\iota}\}_{j\in\mathbf{J}_t}, m(t)) = \qquad (4)\\ &\qquad \varphi_{i,j,\iota,0} + \sum_{j'=1}^{3} \varphi_{i,j,\iota,j'}\delta_{i,j',t,\iota} + \sum_{m=1}^{11} \varphi_{i,j,\iota,m+3}\chi_m(t) + \upsilon_{i,j,\iota,t} \qquad , \end{aligned}$$

where $\chi_m(t)$ are indicator variables if t is in month m, and coefficients φ are estimated.

Finally, $\epsilon_{i,t}$ is assumed to be independently and identically distributed with the extreme value distribution, which allows (2) to be analytically integrated over ϵ to provide an "expected" value function (EV) for consumer i (McFadden (1973); Rust (1987)). Combing this with assumption 3.1, a consumer's expected value function can be written as:

$$EV_i(\{\delta_{i,j,t,\iota}\}_{j\in\mathbf{J}_t,\iota\in\mathbf{I}},\iota_{i,t},m(t)) = \int_{\epsilon_{i,t}} V_i(\iota_{i,t},\epsilon_{i,t},\{\delta_{i,j,t,\iota}\}_{j\in\mathbf{J}_t,\iota\in\mathbf{I}},m(t)) = \tag{5}$$

$$\ln\Bigg(\sum_{j'\notin\iota_{i,t}}\big(\exp(\delta_{i,j',t,\iota}+\beta E[EV_i(\{\delta_{i,j,t+1,\iota}\}_{j\in\mathbf{J}_{t+1},\iota\in\mathbf{I}},\iota_{i,t}\cup\{j'\},m(t+1)|\{\delta_{i,j,t,\iota}\}_{j\in\mathbf{J}_t,\iota\in\mathbf{I}})])\big)$$

$$+\exp(\beta E[EV_i(\{\delta_{i,j,t+1,\iota}\}_{j\in\mathbf{J}_{t+1},\iota\in\mathbf{I}},\iota_{i,t},m(t+1))|\{\delta_{i,j,t,\iota}\}_{j\in\mathbf{J}_t,\iota\in\mathbf{I}}])\Bigg)$$

3.1.2 Software Adoption

The software purchase decisions for a consumer is modeled to form the "software quality" function $\{\Gamma_{j,t}(\cdot;\iota)\}_{j\in\mathbf{J}_t,\iota\in\mathbf{I},\forall t}$ in (1). Lee (2010) assumes each consumer makes the decision to purchase a title k independently of her decision to purchase any other title $k'\neq k$.[16,17] Under this assumption, each consumer after solving her appropriate dynamic policy for hardware purchase can solve an independent optimal stopping problem for each individual piece of software.

A consumer's lifetime expected utility from buying title k on platform j in period t (provided she already owns the platform) is then given by:

$$v_{i,j,k,t} = \tilde{\alpha}_i^{\gamma} + \tilde{\alpha}^{w} w_{j,k,t} + \tilde{\eta}_{j,k,t} - \tilde{\alpha}_i^{p,sw} p_{j,k,t} + \tilde{\epsilon}_{i,j,k,t} \qquad , \tag{6}$$

where $w_{j,k,t}$ are observable software characteristics (which include a game-specific fixed effect, monthly fixed effects, as well as age, age squared, and the current installed base of previous purchasers), $\tilde{\eta}_{j,k,t}$ is an software characteristic unobservable to the econometrician (but observable to the consumer), $p_{j,k,t}$ the price, and $\tilde{\epsilon}_{i,j,k,t}$ is an individual-software-time specific utility shock. $\tilde{\alpha}_i^{\gamma}$ is an individual specific preference for "gaming" reflected in the increase in utility of any particular piece of software, and $\alpha_i^{p,sw}$ represent a consumer's price sensitivity for software.[18] A consumer can also decide not to buy a piece of software at time t and return to the market in the next period, yielding the outside option utility $v_{i,j,k_0,t} = \tilde{\epsilon}_{i,j,k_0,t}$.

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[16] Lee (2010) contains robustness checks and finds that controlling for the release of other hit titles or titles in the same genre does not substantially change estimates, and yields insignificant impacts for the vast majority of titles. Nair (2007) also finds empirically that videogames are not strong substitutes for one another. Both are consistent with there being a large number of titles (even within a particular genre), each with its own distinct idiosyncracies, plot, characters, and style of play.

[17] Furthermore, relaxing this assumption should not dramatically change the main implications of the counterfactual exercises conducted later in this paper: in this industry "hit" titles are less affected by any potential substitution effects, and demand estimates show that only the contracting decisions for hit titles are shown to affect platform market shares.

[18] I use different hardware and software price coefficients for flexibility; the restriction $\alpha^{p,hw} = \sigma_\epsilon \alpha^{p,sw}$ is not rejected in estimation for the full model, but is rejected in other specifications.

Mirroring the hardware side, I also assume the individual-specific utility shocks are independently and identically distributed from the extreme value distribution. I will allow for the variance to be scaled by a factor of σ_ϵ^2 for software; this scaling must be accounted for when combining measures of utility for hardware and software.[19] I thus re-express the software utility in (6) by multiplying and dividing through by σ_ϵ:

$$v_{i,j,k,t} = \sigma_\epsilon(\underbrace{\alpha_i^\gamma + \alpha^w w_{j,k,t} + \eta_{j,k,t} - \alpha_i^{p,sw} p_{j,k,t}}_{\zeta_{i,j,k,t}} + \epsilon_{i,j,k,t}) \qquad , \tag{7}$$

where $\{\alpha_i^\gamma, \alpha^w, \alpha_i^{p,sw}, \eta_{j,k,t}, \epsilon_{i,j,k,t}\} = \{\tilde{\alpha}_i^\gamma, \tilde{\alpha}^w, \tilde{\alpha}_i^{p,sw}, \tilde{\eta}_{j,k,t}, \tilde{\epsilon}_{i,j,k,t}\}/\sigma_\epsilon$, and $\zeta_{i,j,k,t}$ represents the (scaled) lifetime expected utility of purchasing a piece of software net of individual-specific-unobservable $\epsilon_{i,j,k,t}$, and may also be referred to as individual i's price-adjusted quality or mean-utility for software k at time t.

A consumer's optimal stopping problem for purchasing software title k is given by:

$$W_i(\Omega_{i,t}, \epsilon_{i,j,k,t}) = \max\{v_{i,j,k,t}, v_{i,k_0,t} + \beta E[W_i(\Omega_{i,t+1}, \epsilon_{i,j,k,t+1})|\Omega_{i,t}]\} \qquad . \tag{8}$$

Again, to reduce the dimensionality of the state space, the following assumption is made on the evolution of each software-title's mean-utility:

Assumption 3.2. *Consumers perceive that* $\{\zeta_{i,j,k,t}\}_{\forall k,t}$ *can be summarized by a first-order Markov process:*

$$G(\zeta_{i,j,k,t+1}|\Omega_{i,t}) = G_{i,j}(\zeta_{i,j,k,t+1}|\zeta_{i,j,k,t}, m(t)) \qquad , \tag{9}$$

where $G_{i,j}$ *is specific to individual* i *and console* j*.*

$G_{i,j}$ is, however, not title specific, and thus all software titles on a given platform are perceived by consumers to follow the same evolutionary path contingent on their price-adjusted quality and time of year. The particular functional form used is:

$$G_{i,j}(\zeta_{i,j,k,t+1}|\zeta_{i,j,k,t}) = \varphi_{i0}^j + \varphi_{i,1}^j \zeta_{i,j,k,t} + \varphi_{i,2}^j (\zeta_{i,j,k,t})^2 + \sum_{m=1}^{11} \varphi_{i,m+2}^j \chi_m(t) + \upsilon_{i,j,k,t}^j \qquad . \tag{10}$$

Using assumption 3.2, the expected value function – or "option value" – of being able to purchase and use title k on platform j at time t can be obtained by integrating (8) over $\epsilon_{i,j,k,t}$:

$$\begin{aligned} EW_{i,j}(\zeta_{i,j,k,t}, m(t)) &= \int_{\epsilon_{i,j,k,t}} W_{i,j}(\zeta_{i,j,k,t}, m(t), \epsilon_{i,j,k,t}) dP_\epsilon \\ &= \sigma_\epsilon \ln(\exp(\zeta_{i,j,k,t}) + \exp(\beta E[EW_{i,j}(\zeta_{i,j,k,t+1}, m(t+1))|\zeta_{i,j,k,t}, m(t)])) \qquad , \end{aligned}$$

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[19] C.f. Train (2003), ch. 2 for further discussion.

which imbeds consumer i's expectations over future prices and characteristics for title k.

To close the software adoption portion of the model, $\Gamma_{j,t}(\cdot;\iota)$ is linked to the value of being on the market for software on platform j. This "total software utility" on platform j can be separated into two parts: (i) the utility from software available in the present period, and (ii) the utility from new software that will arrive in future periods, which will be denoted as $\Lambda_{j,t}(\alpha_i^p,\alpha_i^\gamma)$. Let $\tilde{\mathbf{K}}_{j,t}(\iota)\equiv\mathbf{K}_j\setminus\{\mathbf{K}_j\cap\{\mathbf{K}_{j'}\}_{\forall j'\in\iota}\}$ denote the set of software titles available on platform j at time t but not available on any platform $j'\in\iota$. Assume a user does not value titles on a new console that she could access on consoles that she already owns. Then $\Gamma_{j,t}$ is given by:

$$\Gamma_{j,t}(\alpha_i^p,\alpha_i^\gamma;\iota)=\underbrace{\left[\sum_{k\in\tilde{\mathbf{K}}_{j,t}(\iota)}EW_{i,j}(\zeta_{i,j,k,t},m(t))\right]}_{\text{(i) Current Software Utility}}+\underbrace{\Lambda_{j,t}(\alpha_i^p,\alpha_i^\gamma;\iota)}_{\text{(ii) (Expected) Future Software Utility}}\quad, \tag{11}$$

where the first term provides an internally-consistent measure of the utility from currently available software by aggregating their computed option values.

To define the second term, assume that consumers believe that a console will continue to have software released in the next period with probability β_γ, constant across time and consoles. Conditional on β_γ, if a consumer had perfect information over all future titles that would be released up to the terminal date T, future utility would be given by

$$\tilde{\Lambda}_{i,j,t}(\cdot;\iota)=\sum_{t'=1}^{T-t}(\beta_\gamma\times\beta)^{t'}\left(\sum_{k\in\tilde{\mathbf{K}}^R_{j,t+t'}(\iota)}EW_{i,j}(\zeta_{i,j,k,t+t'},m(t+t'))\right)\quad, \tag{12}$$

where $\tilde{\mathbf{K}}^R_{j,t}(\iota)$ represents the set of software titles released at time t on platform j that are not available on platform $j'\in\iota$. Since a consumer does not know exactly the number nor quality of future titles, assume consumers have rational expectations consistent with the observed data, and condition on current observed market variables and product characteristics; i.e., $\Lambda_{i,j,t}=E[\tilde{\Lambda}_{i,j,t}|\Omega_{i,t},\beta_\gamma]$. In estimation, Lee (2010) uses a nonparametric series regression of (12) on console characteristics and software availability to form an approximation of consumers' expectations.

3.1.3 State Variables

To summarize the model, each consumer i at time t solves multiple dynamic decision problems governing her purchase decisions over hardware and software that she does not already own, conditioning on the following state variables:

- $m(t)$: the month at time t,
- $\iota_{i,t}$: consumer i's inventory of hardware currently owned,
- $\{\delta_{i,j,t,\iota}\}_{\forall j \in \mathbf{J}_t, \iota \in \mathbf{I}}$: the set of all hardware "mean-utilities" at every inventory state,
- $\{\zeta_{i,j,k,t}\}_{\forall j \in \mathbf{J}_t, k \in \mathbf{K}_{j,t}}$: the set of software "mean-utilities" for all titles on all platforms.

4 Hardware-Software Network Formation

In the previous section, the set of software products on each platform has been conditioned on in the data. However, when institutional features of an industry change – as is the case when hardware platforms cannot vertically integrate into software provision or offer contracts contingent on exclusivity – it is unlikely that the contracting relationships between parties will remain the same. This section develops a model of software "demand" for hardware in order to determine how these relationships will change.

4.1 Software Expected Profits

I first focus on the computation of each software title's expected profits had it chosen any set of platforms to develop for. Consider the decision faced by a third-party software title k that is released at time r_k. Assume that τ months in advance, at time $r_k - \tau$, title k must choose a strategy $\mathbf{s}_k \in \mathbf{S} \equiv \{\{0,1\}^3\}$, which indicates which set of the three platforms k will develop for.[20] Each title faces the following tradeoff: on the one hand, developing and releasing a title for a platform provides access to that console's base of users, which in turn may yield greater sales; on the other hand, such development requires the outlay of significant porting costs, which may or may not be recouped.

For a given strategy $\mathbf{s}_k$, title k's expected discounted profits are given by (where, abusing notation slightly, $\mathbf{s}_k$ also represents the corresponding subset of platforms):

$$E[\pi_k(\mathbf{s}_k;\theta_C)|\Omega_{k,r_k-\tau}] = E\Big[\Bigg(\sum_{t=r_k}^{T} \beta^{\tau+t-r_k} \sum_{j \in \mathbf{s}_k} Q_{j,k,t}((1-rmkup)p_{j,k,t}-mc_j)\Bigg)|\Omega_{k,r_k-\tau}\Big] - C_k(\mathbf{s}_k;\theta_C) \quad , \tag{13}$$

where $Q_{j,k,t}$ is the quantity of title k sold on platform j at time t, *rmkup* denotes the markup captured by retailers, mc_j is the marginal cost of production on console j (which includes

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[20] Recall that each videogame software title needs to be specifically developed for a particular console in order to be used on that hardware system. If a title has agreed to an exclusive contract or is a first-party title, the decision of which platform to support has already been made; otherwise, a third-party title chooses the set of platforms that maximizes its expected profits.

royalties paid to the platform provider), and $C_k(\mathbf{s}_k; \theta_C)$ are the costs of producing title k for all platforms within $\mathbf{s}_k$ which depend on some vector of parameters θ_C. In addition to development and programming costs, $C_k(\cdot)$ contains all other fixed costs related to the production of the game including distribution and marketing. I assume these costs are known to the software title at time $r_k - \tau$ but not to the econometrician. Finally, expectations are conditional on $\Omega_{k,r_k-\tau}$, software title k's information set at time $r_k - \tau$, which includes any factors affecting market characteristics and consumer demand.

To compute software quantities, there is a significant complexity: in a platform market, a piece of software released for one platform induces more consumers to join that platform, which in turn may induce more titles to join, thereby driving more consumer adoption, and so on. Each software title thus must account for how consumers and other software titles react to its own actions and those of others.

However, recall that software titles compete in independent markets and platform mean-utilities $\{\delta_{j,t}\}_{j\in\mathbf{J}_t,t}$ are sufficient statistics for determining hardware demand, where $\delta_{j,t}$ is the set of hardware mean-utilities for all consumer types i and inventory states ι. Consequently, a software title is affected by the actions of other titles only if they affect the installed base of each console, and this can only occur through changes in $\{\delta_{j,t}\}_{j\in\mathbf{J}_t,t}$. Thus, beliefs over the evolution of $\{\delta_{j,t}\}_{j\in\mathbf{J}_t,t}$ are sufficient for each title to internalize and condition on the future responses of consumers and other software titles. I make the following assumptions:

Assumption 4.1. *Software titles perceive* $\{\delta_{i,j,t,\iota}\}_{\forall i,j\in\mathbf{J}_t,t,\iota\in\mathbf{I}}$ *can be summarized by the first-order Markov process* $F(\cdot) \equiv \{F_{i,\iota}(\cdot)\}_{\forall i,\iota}$ *given by* (3).

Assumption 4.2. *Each software title perceives its own* $\{\zeta_{i,j,k,t}\}_{\forall i,j\in\mathbf{J}_t,t}$ *can be summarized by the first-order Markov process* $G(\cdot) \equiv \{G_{i,j}(\cdot)\}_{\forall i,j}$ *given by* (9).

These are the parallels to assumptions 3.1 and 3.2 used for consumer demand analysis, and imply that software titles share the same beliefs as consumers over the evolution of both $\{\delta_{j,t}\}_{j\in\mathbf{J}_t,t}$ and $\{\zeta_{j,k,t}\}_{j\in\mathbf{J}_t,k,t}$. Thus as long as title k knows the transition processes $F(\cdot)$ and $G(\cdot)$, then (i) the month, (ii) the installed base of consumers on each platform at time $r_k - \tau$, (iii) hardware mean-utilities $\{\delta_{j,r_k-\tau}\}_{j\in\mathbf{J}_t}$, and (iv) the title's own starting qualities $\{\zeta_{j,k,r_k}\}_{j\in\mathbf{J}_t}$ and prices are all that are required to compute the number of copies $\{Q_{j,k,t}\}_{j\in\mathbf{J}_t,t\geq r_k}$ that each title expects to sell on every platform it joins.

I assume that every software title knows its initial price and quality at the time of release, and a title believes that it impacts the level of $\delta_{j,t}$ if it joins platform j, but not the transition processes $F(\cdot)$ and $G(\cdot)$. I also assume that the retailer markup is fixed at 35% and marginal costs are constant across platforms at \$10 (reflecting royalty rates of approximately \$7 and production costs of \$3 per game disc). These figures are consistent with information provided by industry and public sources.[21] Appendix A.1 provides further details.

4.2 Recovery of Development and Porting Costs

In order to compute a title's expected profits from choosing any particular action $\mathbf{s}_k$, one final issue remains: development and porting costs $C_k(\cdot;\theta_C)$ are unobserved. I use a methods of moments estimator based on inequality constraints developed in Pakes, Porter, Ho, and Ishii (2006) to estimate these unobserved costs.

Consider again the decision of a third-party title k that decided τ months in advance of release which platforms to develop for. The key assumption used to generate the moments for estimation is that for each title brought to market by a third-party publisher, the expected profits from developing for the set of platforms it chose in the data were higher than developing for any other set of platforms, *holding fixed the actions of all titles released up to that point in time*:[22]

Assumption 4.3. *For each third-party software title k, the observed choice of platforms $\mathbf{s}_k^o$ maximized its expected profits:*

$$E[\pi_k(\mathbf{s}_k^o;\theta_C)|\Omega^o_{k,r_k-\tau}] \geq E[\pi_k(\mathbf{s}'_k;\theta_C)|\Omega^o_{k,r_k-\tau}]\ \forall\ \mathbf{s}'_k \in \mathbf{S} \qquad ,$$

where $\Omega^o_{k,r_k-\tau}$ denotes the observed *state of each title's information set at time $r_k-\tau$.*[23]

I use a parsimonious specification for $C_k(s_k;\theta_C)$:

$$C_k(\mathbf{s}_k;\theta_C) = c^g(\mathbf{s}_k) + \nu_k^c \qquad , \tag{14}$$

and $\theta_C \equiv \{\{c^g(\mathbf{s})\}_{\forall \mathbf{s}\in\mathbf{S}\setminus\{0\}^3}\}$, where g represents the genre of title k. ν_k^c represents title-specific costs that affect all strategy choices equally.[24] The difference in costs between two different titles are thus assumed to be contained within differences in genres and some unobservable title-specific component.

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[21] E.g. Takahasi (2002).

[22] For the purposes of this analysis, I will assume that the decision of which platforms to join is made independently for each title, even if the title is released by a third-party publisher with multiple titles.

[23] I assume that the econometrician's estimate and a title's estimate of expected profits are the same. As long as this error is mean zero across titles and strategy choices and independent of instruments chosen, the following analysis does not change (Pakes, Porter, Ho, and Ishii (2006)).

[24] The alternate specification:

$$C_k(\mathbf{s}_k;\theta_C) = c_0^g(\mathbf{s}_k) + \sum_{j\in\mathbf{s}_k} c_j^g \alpha^w_{0,j,k} + \nu_k^c \qquad ,$$

where $\alpha^w_{0,j,k}$ represents the software fixed effect for title k on platform j perceived by the mean consumer (estimated from the demand side), was also employed; estimates from this specification did not significantly change results of the counterfactual exercises in the next section.

Given assumption 4.3 and the specification of porting costs given by (14), the expected difference in profits between the observed strategy chosen and any alternative should be positive for all titles:

$$E_k\left[E[\pi_k(\mathbf{s}^o_k;\theta_C)|\Omega_{k,r_k-\tau}] - E[\pi_k(\mathbf{s}';\theta_C)|\Omega_{k,r_k-\tau}]\right] \geq 0 \;\forall\; \mathbf{s}' \in \{\mathbf{S} \setminus \{0,0,0\}\} \qquad .$$

Since I do not observe software products that are not released on any platform, I restrict attention to strategies that involve joining at least one platform.

Let $\mathbf{K_s}$ denote the set of titles that choose strategy $\mathbf{s}$. For each $\mathbf{s} \neq \{0\}^3$ and $\mathbf{s}' \notin \{\mathbf{s} \cup \{0\}^3\}$, converting expectations into sample means yields the following inequality moments:

$$\frac{\sqrt{\#\mathbf{K_s}}}{\#\mathbf{K_s}} \sum_{k\in\mathbf{K_s}} (E^o\pi_k(\mathbf{s};\theta_C) - E^o\pi_k(\mathbf{s}';\theta_C)) \otimes g(\omega_{k,t-\tau}) \geq 0 \tag{15}$$

for any $\omega_{k,r_k-\tau} \in \Omega_{k,r_k-\tau}$, where $\otimes$ represents the Kronecker product and $g(\cdot)$ is any positive valued function. I weight by the square root of the number titles that choose each particular strategy $\mathbf{s}$ in order to account for the fact that there should be less expectational noise in expected profits for strategies chosen by many titles.

Equation (15) defines 42 inequalities (7 non-zero strategies, each with 6 alternative strategy comparisons) to be used in estimation for each choice of instrument. If there are multiple values of θ_C that satisfy the inequalities, all values are admissible and a set estimate is provided; otherwise, the value $\hat{\theta_C}$ that minimizes the absolute value of deviations in the inequalities is obtained.[25,26] Since only strategies that involve joining at least one platform are compared, only relative differences between $c_0(\mathbf{s})$ and $c_0(\mathbf{s}')$ are identified. Nonetheless, for the purposes of the subsequent analysis, relative differences are all that are required in order to determine the optimal choices for software titles. In estimation, $c_0(\{1,0,0\})$ (i.e., the constant cost for developing only for the PS2) is fixed to be 0.

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[25] When constructing the inequality estimators, I also omit "high-quality" exclusive titles brought to market by third-party publishers, which I assume to be those with values of $\alpha^w_{0,k}+\eta_{k,r_k}$ in the top 25% of the estimated distribution. The reason for this restriction is that these exclusive titles, although not first-party, may have been subject to unobserved exclusive deals involving lump sum payments, development assistance, or joint marketing promotions. The underlying assumption is that all other titles – those that multihomed were of low enough quality – did not receive any exclusive contracts or preferential treatment from console providers.

[26] Point estimates despite the absence of error between estimated profits by the econometrician and agents may indicate that ν^c_k should be choice-specific in (14). However, Pakes (2008) shows in another empirical application that this type of specification error does not yield significant bias.

4.3 Dynamic Network Formation Game

I now specify a dynamic network formation game in which each software title selects which platforms to develop for having formed expectations over the future profitability of each potential strategy. The setup allows for contracting partners and consumer demand to change over time with past actions influencing future decisions. I will focus here only on changes in contracting partners, assuming that the set of available hardware and software products is given, and porting costs, royalty rates, retailer markups, and release dates do not change. In the next section when I estimate a counterfactual regime, I discuss potential ways of relaxing some of these restrictions.

Setup and Timing

In each period t, there is a set of software products $\mathbf{K}_t^R$ that will be released on at least one console. At time $t-\tau$, every title $k \in \mathbf{K}_t^R$ simultaneously commits to a set of consoles $\mathbf{s}_k$ on which it will be released τ periods in the future. This decision is private, and is not observable or known to any other industry participant until the title is released at time t. Each title observes the number of each type of consumer both off and onboard each platform, knows its own initial qualities $\{\zeta_{j,k,t}\}_{\forall j}$ and release prices $\{p_{j,k,t}\}_{\forall j}$, but does not have any information about future software releases or availability $\{\mathbf{K}_{t'}^R\}_{\forall\, t'>t-\tau}$. Finally, platforms have no strategic actions, and each offers a fixed contract to all titles specifying a common royalty rate.[27]

At each period t, the timing of actions is as follows:

1. All titles $k \in \mathbf{K}_t^R$ are released and added to the stock of existing software products for each platform according to $\{\mathbf{s}_k\}_{\forall k \in \mathbf{K}_t^R}$;
2. Characteristics for all platforms and released software titles are determined (which are contained within $\{\delta_{j,t}\}_{j\in\mathbf{J}_t}$ and $\{\zeta_{j,k,t}\}_{\forall j,k\in\{\cap_{t'\leq t}\mathbf{K}_{t'}^R\}}$);
3. Consumers make hardware and software purchase decisions;
4. All titles $k \in \mathbf{K}_{t+\tau}^R$ choose which set of platforms $\mathbf{s}_k$ to join.

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[27] Platforms are not assumed to be strategic agents other than setting the prices for their own consoles, which is internalized in the evolution $\{\delta_{j,t}\}_{j\in\mathbf{J}_t,\forall t}$. Without exclusive deals or vertical integration, I rule out any preferential treatment by platform providers towards individual software titles since these deals are primarily made in exchange for exclusivity. Additionally, platforms typically pre-announce and commit to royalty rates that are charged to third-party software developers in advance of a system's release (Kent (2001), Hagiu (2006)), and I assume that these royalty rates not only do not change in counterfactual environments.

Equilibrium and Computation

Given assumptions 3.2, 3.1, 4.1, and 4.2 on consumer and firm beliefs, a *first-order Markov equilibrium* of this game will contain a set of strategies $\{\hat{\mathbf{s}}_k\}_{\forall k}$ and first-order Markov transition processes $\hat{F}$ and $\hat{G}$ such that:

1. For every title k, $\hat{s}_k$ maximizes its expected profits at time $r_k - \tau$:

   $$E[\pi_k(\hat{\mathbf{s}}_k; \theta_C)|\Omega_{k,r_k-\tau}] \geq E[\pi_k(\mathbf{s}'_k; \theta_C)|\Omega_{k,r_k-\tau}] \; \forall \; \mathbf{s}'_k \in \mathbf{S} \setminus \{0,0,0\}$$

   with each title's expected profits given by (13), and beliefs over the evolution of $\{\delta_{j,t}\}_{j\in\mathbf{J}_t,\forall t}$ and $\{\zeta_{j,k,t}\}_{\forall j,t>r_k}$ given by $\hat{F}$ and $\hat{G}$;

2. Consumers purchase hardware and software according to the dynamic model provided in section 3, with software availability given by $\{\hat{\mathbf{s}}_k\}_{\forall k}$ and beliefs over the evolution of $\{\delta_{j,t}\}_{j\in\mathbf{J}_t,\forall t}$ and $\{\zeta_{j,k,t}\}_{\forall j,t>r_k}$ given by $\hat{F}$ and $\hat{G}$;

3. Transition processes $\hat{F}$ and $\hat{G}_j$ are consistent with realized values of $\{\delta_{j,t}\}_{j\in\mathbf{J}_t,t}$ and $\{\zeta_{j,k,t}\}_{j\in\mathbf{J}_t,k\in\mathbf{K}_{j,t},t}$ implied by $\{\hat{\mathbf{s}}_k\}_{\forall k}$ and consumer behavior.

In this equilibrium, each software title conditions only on its own mean qualities, prices, and other "payoff-relevant" state variables when determining its optimal strategy; additionally, a consumer's decision to purchase a particular platform or software title – as on the demand side – is only a function of her own characteristics and the product's mean-quality ($\delta_{j,t}$ or $\zeta_{j,k,t}$). A *first-order Markov equilibrium* is thus a *Markov-Perfect Nash Equilibrium* in the sense of Maskin and Tirole (1988, 2001) with the additional restriction that agents' beliefs over the transition probabilities $\hat{F}$ and $\hat{G}$ are contained within the class of first-order Markov processes. These transition probabilities will be different from those originally estimated in the demand system since they account for resultant changes in contracting partners from those observed in the data; in this sense, they are internally consistent (subject to the first-order restriction). Furthermore, this equilibrium is also subgame perfect: as long as every agent chooses its optimal action as a function only of its own payoff-relevant state variables as specified, any agent's porting or purchasing decision remains optimal and is a best-response even when considering more general deviations (e.g., non-Markovian strategies such as conditioning choices explicitly on the previous actions of others).

Nonetheless, it may be the case that there are multiple equilibria: e.g., different beliefs over the evolution of each hardware platform's quality may sustain different actions, which in turn rationalize those beliefs. In computation, the space of beliefs are restricted to the parameterizations of F and $\{G_j\}_{\forall j}$ used on the demand side given by (4) and (10); additionally, there are bounds on the set of sustainable beliefs in equilibrium since there are minimum and maximum attainable values of $\{\delta_{j,t}\}_{j \in \mathbf{J}_t, \forall t}$ for each platform, which correspond to hardware mean-utilities without any or with all software titles onboard. To partially account for the possibility that there may still be multiple equilibria, I run the algorithm described in Appendix A.2 to compute the equilibrium using multiple starting beliefs.

5 Porting Cost Estimates and Fit of Model

5.1 Estimates

Table 5 presents porting cost estimates for developing for different sets of consoles, where $\tau = 5$ (i.e., titles make their decision 5 months prior to release) and porting costs are allowed to vary across different software genres. Costs for developing solely for the PS2 are fixed to be 0 separately for each genre, and thus these estimates reflect the *relative* costs of porting to a particular set of consoles. As a result, although the estimates themselves cannot be compared across genres directly, the differences can be. For example, estimates suggest that for Action games, developing solely for the Xbox is \$1M cheaper than developing for the PS2; developing for the Xbox and the PS2 requires an outlay of an additional \$1.2M if the PS2 version was already developed, or \$2.2M if the Xbox version was already developed.[28] On the other hand, Family and Shooter games have much lower additional porting costs.

In general, developing for two consoles is found to be generally more expensive than developing for one, but still cheaper than developing for all three. Depending on the genre, porting a title can cost between \$200K to \$2.6M to port to a second console and between \$540K and \$4.4M for the third; averaging across genres and platforms, the cost to port to an additional console is approximately \$1.3M. These are in line with figures provided by industry sources.[29] Finally, consistent with institutional details, estimates suggest the Xbox and GC are to be significantly cheaper to develop for than the PS2.[30]

5.2 Fit of Dynamic Network Formation Model

To evaluate the fit of the model, I first compute a new equilibrium holding fixed the actions of all first-party software titles, but allow third-party titles to re-optimize and choose a new set of platforms to support. Table 6 presents a comparison between the observed data and the computed equilibrium. Confidence intervals are constructed via parametric bootstrap of

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[28] These figures are obtained by examining the differences in the estimates.

[29] Repeating the exercise for different values of τ (including 9 and 12 months) and using different sets of instruments changed porting cost estimates, but did not affect the following counterfactual analysis.

[30] E.g., the PS2 with a new CPU architecture had a reputation of being difficult to develop for, whereas the Xbox was essentially an Windows-Intel PC using APIs with which many developers were already familiar.

demand system estimates reported in table 3, where software expected profits, porting costs, and a new equilibrium are recomputed for each draw.

The model predicts installed bases and market shares for platforms to be close to the data. Although the PS2 is predicted to have fewer titles and the Xbox and GC more, restricting attention to only "hit" titles – defined alternatively as titles selling over 100K or 1M copies on a given console – indicates a far better fit. This may imply that although any estimation or specification error in porting costs affect the actions chosen by small titles, it is less of an issue for popular games. Since the actions of these hit titles are the only ones that significantly affect platform market shares, as long as their actions are accurately predicted, estimated aggregate industry figures such as market shares and installed base will be similar to those observed. Finally, the model predicts the total software sales on each platform to be close to the data with the exception of the GC, which is predicted to sell slightly more titles. In general, these figures are important to match since royalties on software sales comprise most of each platform's profits, and thus translate directly into the success of each platform.

In all simulated runs, using different starting beliefs did not change the computed equilibrium. This is likely due to the fact that for each title, the decision of which consoles to support is typically robust to small fluctuations in beliefs over the evolution of $\{\delta_{j,t}\}_{j\in\mathbf{J}_t,\forall t}$. Only hit titles can shift the value of $\{\delta_{j,t}\}_{j\in\mathbf{J}_t,\forall t}$ for any given console in any significant way, and the strategy of these titles is not significantly influenced by the strategies of other software titles: as long as there are sufficient numbers of consumers onboard each platform at a given moment, most hit titles will join all platforms. On the other hand, for most mid and low-quality titles, the impact of porting costs on profits typically dwarfs the impact of any small shifts in expected installed bases across consoles caused by changes in beliefs.

6 Policy Experiment: Banning Vertical Integration and Exclusive Contracting

Using the estimates so far obtained, I proceed in this section to examine a counterfactual environment in which console providers are prevented from integrating into software development, and are unable to offer exclusive contracts to third-party titles. However, third-party titles still may voluntarily choose to be exclusive if they find the costs of porting too high.

As discussed, a change in the contracting space that eliminates contractual exclusivity may change other industry features, including investment incentives and the entry and exit of new hardware and software products. For example, without integration, investment in previous first-party software may not occur. To account partially for this possibility, I consider two counterfactuals: (i) first-party titles are assumed still to enter the market as third-party titles; (ii) all first-party titles no longer are produced and thus do not enter. These two alternatives can be used as potential bounds for what actually may occur absent exclusivity and integration.

Some caveats remain. Although software providers form expectations over the future quality and prices of products when deciding which platforms to join, I assume that prices are the same as actual price paths in the data when computing the outcomes of the counterfactual regimes. Without a full model governing the dynamic price-setting behavior of firms, these counterfactual price paths become difficult to determine.[31] Furthermore, I assume that all platforms offer the same non-exclusive contracts to each software title and do not change their royalty rates. Relaxing this last assumption requires a model of bilateral oligopoly bargaining model, which is outside the scope of the paper and the subject of future work.

6.1 Industry Structure

The results from the counterfactual simulations are presented in table 7. In the first specification when former first-party titles still enter the market as third-party titles, Sony's PS2 is predicted to increase its market share from 55% to 60% and sell over 200M more copies of software over the five-year period (which, at \$7 in royalties per game, is \$1.5B in additional profit): this is primarily a result of the PS2 now having significantly more "hit" titles, many having been previously exclusive to its competitors.On the other hand, both Microsoft's Xbox and Nintendo's Gamecube perform worse, selling approximately 2M fewer consoles and almost 100M fewer copies of games each.

The second counterfactual also prohibits exclusive arrangements, except it now removes all former first-party titles and assumes that they were never produced. Here, the industry as a whole does worse since many of the first-party titles were blockbuster hits; nonetheless, both because the PS2 did not originally have many first-party hits and because previously exclusive third-party hits on other consoles now port to the PS2, Sony fares as well in the counterfactual as it did in the observed data. However, now both the Xbox and GC are predicted to do even worse: each entrant sells 3M fewer consoles, and fewer than 8M total software titles (down from 118M and 80M, respectively, representing profit reductions of $\$.7 - .8$B each) during the five-year period. Since both Xbox and GC had a number of hit first-party titles (e.g., recall table 2 shows that nine of the top ten titles sold on GC were first-party titles), it is unsurprising that the number of titles sold on the entrant platforms falls so drastically when first-party titles are eliminated.

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[31] Nair (2007) details one approach to modelling a firm's dynamic pricing decision. Nesting this type of optimization problem within this paper's existing framework is too computationally burdensome for implementation. Nonetheless, I also compute the counterfactual simulations assuming software prices follow a first-order Markov process estimated in the appendix, and find that the results do not substantially change.

One of the main reasons that the PS2 benefits instead of the Xbox and Gamecube in software sales is that in both counterfactuals, consumers with high values of α^γ – many who had previously multihomed in order to access exclusive hit titles on on each console – by and large now only purchase the PS2 since they can access all hit titles on the PS2: whereas approximate70% of the top quintile of consumers in the original demand model were estimated to have multihomed, less than 5% are estimated to do so in the counterfactuals.

6.2 Consumer Welfare

Without exclusive arrangements, consumers onboard each platform would have access to a larger selection of high quality titles. To analyze consumer welfare gains, I calculate the compensating variation for consumers who are predicted to purchase a console in each counterfactual environment.

In the first regime when first-party titles still enter the market, I find that total consumer welfare increases over the course of the generation by approximately \$1.5B *holding fixed hardware and software prices and entry.* Practically all of this increase is realized by those consumers who would have purchased a videogame console in the previous regime, and these consumers receive approximately \$27 on average in surplus. However in the second regime when first-party titles are no longer produced, consumer welfare actually falls by approximately \$.9B.

Both of these calculations again ignore the possibility that Microsoft or Nintendo may have exited the market, or Sony, with its increased market power, may have increased prices. For example, in the first regime if Microsoft and Nintendo did not enter at all due to the inability to integrate or obtain exclusive titles, total consumer welfare would be predicted to have *fallen* despite having all titles onboard a single console. Similarly, I find that Sony – holding the prices fixed for the Xbox and GC – would have found it profitable to raise the price of its PS2 unit by over \$200, again leading to consumer welfare losses.

6.3 Further Robustness Tests

[FORTHCOMING]

6.4 Discussion and Policy Implications

Counterfactual experiments suggest that vertical integration and exclusive contracts harmed the incumbent and aided entry at the platform level. Since the PS2 had already captured an installed base of 5M users before its two competitors entered a year later, without exclusive arrangements the Xbox and GC may likely only have been able to induce a developer to release a title for their consoles after a version had already been developed for the PS2. Hence, both entrants would have been unable to obtain much software advantage over the incumbent, would have sold far fewer software products, and – since software royalties comprise almost the entirety of platform profits – may potentially have exited.

Furthermore, with Sony predicted to command a dominant position in the market in the absence of exclusive contracts or integration, it may have sustained higher prices. Combine this with the possibility that Microsoft and Nintendo may not have remained in the videogame industry and subsequently not produced their seventh-generation consoles in 2006, any immediate consumer gains from increased access to software may very likely have been offset by these dynamic consequences. Although welfare calculations are sensitive to the assumptions used concerning entry, exit, and price setting behavior, the implications governing industry structure, market concentration, and platform competition appear to be robust.

It is worth stressing that although exclusive arrangements may have encouraged *platform* competition, this does not necessarily imply that they encouraged *software* competition. In the videogame industry, without explicitly modelling the entry and exit of new titles, the effect on software entry is ambiguous: e.g., having only a single monopoly platform to support might have reduced porting costs required for a third-party developer since only one console would have to be developed for, but a more competitive environment with multiple integrated platform providers might have increased investment in first-party software or led to fiercer competition among platforms for titles through reduced royalty rates or increased development and marketing assistance.

In other industries, the impact of vertical integration and exclusivity on software competition may be more clear. For example, Microsoft's integration of its platform (Windows OS) into the browser and media application space was ruled by courts in both *U.S. v. Microsoft* and *European Union v. Microsoft* to have foreclosed competing software vendors (e.g., Netscape and Real Networks). Although both the videogame industry and the PC industry are hardware-software environments, the fact that PC applications are very close substitutes for one another (e.g., consumers typically only use one word processor, browser, media player, or spreadsheet program) whereas videogames are not may indicate that "upstream" software foreclosure may be more of a concern with software substitutability. However, it still may be the case that vertical integration and exclusivity into software development aids other *platform providers* (such as MacOS and Linux) in obtaining market share.

One suitable comparison to the videogame industry is in television distribution. In the U.S., DirecTV's exclusive contracts with certain content providers – notably with the National Football League for a package of its out-of-market games – substantially contributed to its success and ability to induce consumers to substitute away from cable. The impact of this competition was substantial: Goolsbee and Petrin (2004) estimate that entry by satellite providers reduced cable prices by about 15% and encouraged improvements in cable quality, yielding aggregate welfare gains of approximately $5B. In this regard, the U.S. Senate's recent actions preventing an exclusive deal between Major League Baseball and DirecTV – an intervention motivated mainly by a static efficiency desire to expand consumer access – may have negatively affected competition in the industry.[32]

At the same time, in certain cases platform competition may not be desirable. Often this is true when a platform provider cannot raise prices or otherwise exercise market power upon establishing a dominant position. E.g., consider the recent standards competition between next generation DVD formats Blu-ray and HD-DVD: regardless of which standard won or "monopolized" the market, neither standard sponsor (Sony or Toshiba) could increase prices as both had already committed to licenses and royalty rates with hardware manufacturers and movie studios. Furthermore, having a single clear standard emerge as the dominant platform would have effectively removed uncertainty from the marketplace and likely spurred consumer adoption much earlier, thereby increasing total welfare.[33] As a consequence, integration and exclusive contracting between the standard sponsors and motion picture studios (e.g., Sony's ownership of Columbia Pictures or Toshiba's exclusive deal with Paramount) – although potentially "pro-competitive" in having encouraged the existence of multiple formats – may very well have contributed to an undesirable and lengthy standards battle.

7 Concluding Remarks

This paper has shown that integration and exclusive contracting between console manufacturers and software developers in the videogame industry likely aided platform entry. Evidence suggests that in this and other platform markets where upstream foreclosure is not a concern and where forced exclusivity contracts are not permitted, intervention or regulation may not be necessary. Furthermore, when evaluating the possibility of foreclosure or entry deterrence in dynamic networked environments, traditional static analysis may fail to uncover pro-competitive effects of exclusive vertical arrangements.

Although counterfactual simulations indicate that the industry appears more concen-

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[32] The comparison here is between videogames and television programs, as both are perishable and are continually replaced; consequently, to some extent the results of this paper relies on the incumbent platform repeatedly competing with entrants for new content. Television channels or networks are less perishable, however, which raises the possibility that an incumbent television distributor could potentially foreclose entry by acquiring exclusive access to certain key channels. Since new "hit" channels are less frequently created, an entrant distributor would find it difficult to secure content. As a result, legislation prohibiting vertically integrated media companies (e.g., TimeWarner) from denying access to its own content (e.g., CNN) to rival distributors may actually encourage entry when content production is limited.

[33] See, e.g., Farrell and Saloner (1985) and Katz and Shapiro (1986).

trated when exclusive arrangements are prohibited, consumers may still have benefited from access to a wider selection of software onboard each platform. Whether or not consumers would have been better or worse off depends crucially on whether the incumbent would have raised prices, and whether other platforms or software titles would have exited. Any of these effects are shown to have been sufficient to eliminate any consumer welfare gains.

This paper also focused on developing a framework to measure empirically the impact of these exclusive arrangements. I presented a consumer demand system that accounts for the dynamic selection of forward-looking, heterogeneous consumers across and onto platforms; the demand system also recovers the contribution of an individual title to a platform. Additionally, I detailed and estimated a computationally tractable dynamic network formation game that allows agents to anticipate the future actions of other players by conditioning on a small dimensional set of state variables. By explicitly modelling the platform adoption decisions of individual consumers and firms, the framework here can be applied structurally to analyze other related industries that exhibit similar indirect network effects; it can also be used as a launching point for even more sophisticated models with dynamic pricing, investment, and entry and exit, which may be necessary to fully characterize the impact of exclusivity in networked industries.

For tractability, a few key assumptions were made and carried throughout the analysis. First, I assumed the independence of titles; in other types of platform industries, there may be stronger substitution effects across "software" products. Secondly, to model the dynamic decisions for both consumers and firms, I restricted agents' beliefs over the evolution of product mean-utilities to the class of first-order Markov processes. Finally, I abstracted away from product entry and exit and dynamic pricing decisions by hardware and software providers. Some robustness checks and alternative formulations were explored. Though it is unlikely that relaxing these assumptions would change the main implications of this paper, doing so may be necessary for other empirical applications.

A Hardware-Software Network Formation: Details

A.1 Computation of Profits

To describe how expected profits are computed, I rewrite (13) as:

$$E[\pi_k(\mathbf{s}_k;\theta_C)|\Omega_{r_k-\tau}] = \left(\sum_{t=r_k}^{T} \beta^{\tau+t-r_k} \sum_{j\in\mathbf{s}_k} E[M_{j,k,t}s_{j,k,t}((1-rmkup_t)p_{j,k,t}-mc_j)]\right) - C_k(\mathbf{s}_k;\theta_C)$$

where now $Q_{j,k,t}$ has been broken into two different components: $s_{j,k,t}$, which represents the share of consumers who purchase title k, and $M_{j,k,t}$, which represents the number of consumers on platform j who have not yet purchased title k. $s_{j,k,t}$ is solely a function of $\zeta_{k,t}$ and the distribution of consumer types onboard platform j who have not yet purchased the title. If $IB_{j,t}$ is the number of consumers who own console j at time t, and $IB_{j,k,t}$ the number of consumers who own title k on platform j, then $M_{j,k,t} = IB_{j,t} - IB_{j,t}^k$, where $IB_{j,t}^k = IB_{j,t-1}^k + M_{j,k,t-1}s_{j,k,t-1}$. From the demand side, recall a sufficient statistic for determining $IB_{j,t}$ is $IB_{j,t-1}$ and $\{\delta_{j,t}\}_{j\in\mathbf{J}_t}$.[34]

To form the first part of $E[\pi_k(\mathbf{s}_k);\theta_C]$, only expected values of $\{\{\delta_{j,t}\},\{\zeta_{j,k,t}\},\{p_{j,k,t}\}\}_{j\in\mathbf{J}_t,t>r_k-\tau}$ are first required. I obtain these using a simulated frequency approach as in Pakes (1986): multiple sample paths of these variables are created via forward simulation using the estimated transition processes from the demand system (given by (4), (10), and table 8), and the appropriate quantities $M_{j,k,t}$ and $s_{j,k,t}$ are calculated at each point in time, again from the demand system. At release date r_k, the predicted hardware mean utilities $\{\delta_{j,t}\}$ are increased by the amount software k contributes to each platform it joins, as determined by its choice of strategy $\mathbf{s}_k$.

To simulate each title's expected price path, I assume each software title perceives it to also follow a first-order Markov process, and depend only on its own previous value. Table 8 provides an OLS regression of software prices on lagged prices, and shows that previous prices explain over 90% of the variation in next period prices. Additionally, although the number of copies sold in the previous period is also a significant factor in determining next period's prices, its inclusion in simulating price paths did not significantly affect results; this is unsurprising given the limited improvement in the R^2 of the initial regression.[35]

A.2 Computation of Equilibrium

- Fix the transition processes governing the evolution of $\{\delta_{j,t}\}_{j\in\mathbf{J}_t,\forall t}$ and $\{\zeta_{j,k,t}\}_{j\in\mathbf{J}_t,k\in\mathbf{K}_{j,t},\forall t}$ to starting beliefs F^0 and $\{G_j^0\}_{j\in\mathbf{J}_t}$. For robustness, I used 5 different sets of starting beliefs F^0 which govern the evolution of hardware qualities δ: one which assumes no software title joins any console, one which all titles join every console, and three different sets in which all titles join only one console.
- In each iteration n, I proceed forward from $t = 0$ and at every period: update $\{\delta_{j,t}^n\}_{j\in\mathbf{J}_t,\forall t}$ for each console based on the set of new titles released and their chosen strategies; evaluate consumer demand over the set of hardware and software products; and compute the optimal strategy $\mathbf{s}_k^n$ for each title $k\in\mathbf{K}_{t+\tau}$ to be released τ months in the future.
- After the optimal actions for all titles in every period are computed, I use the implied paths of $\{\delta_{j,t}^n\}_{j\in\mathbf{J}_t,\forall t}$ and $\{\zeta_{j,k,t}^n\}_{j\in\mathbf{J}_t,k\in\mathbf{K}_{j,t},\forall t}$ to update the transition processes according to (4) and (10), obtain new estimates for F^{n+1} and $\{G_j^{n+1}\}_{\forall j}$, and repeat the simulation until no software title changes its chosen action from the previous iteration and the estimated transition processes converge.

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[34] Although for notational simplicity I have omitted discussing the distribution of consumer heterogeneity and inventory states, these concerns are not ignored in estimation.

[35] Note that ζ includes price, and yet is assumed to evolve in an independent process from price itself. To address this concern, I also estimate an alternative specification in which I assume software mean quality net of price (i.e., $\widetilde{\zeta_{i,k,t}} = \zeta_{i,k,t} + \alpha_i^{p,sw}p_{k,t}\ \forall\ i$) evolves according to a Markov process, and proceed in a similar fashion (where $\zeta_{k,t}$ is constructed in each period from the separate evolution in $\widetilde{\zeta_{k,t}}$ and $p_{k,t}$). Results do not change in any significant way.

Table 1: Industry Summary Statistics

	PS2	XBOX	GC	ALL
HARDWARE				
Release Date	Oct. 2000	Nov. 2001	Nov. 2001	
Months Active	61	48	48	
Price				
Average	$213.46	$185.47	$127.79	
Std. Dev	62.72	47.36	36.50	
Max	316.29	299.97	199.85	
Min	147.37	146.92	92.37	
Quantity (M)				
Average	0.49	0.28	0.20	0.87
Std. Dev	0.44	0.25	0.23	0.86
Max	2.69	1.08	1.16	4.31
Min	0.18	0.08	0.04	0.18
Installed Base (Oct 2005)	30.07	13.32	9.83	53.22
SOFTWARE				
Total Quantity Sold (M)				
Average	0.26	0.16	0.16	0.21
Std. Deviation	0.10	0.07	0.07	0.08
Median	0.50	0.30	0.28	0.41
Max	6.69	4.82	2.96	6.69
Min	0.00	0.00	0.00	0.00
Starting Price				
Avg.	$40.83	$39.63	$39.72	$40.24
Std. Deviation	11.22	10.69	9.83	10.80
Total # Titles Released	1161	749	487	1581
% Exclusive	52.4	33.4	27.5	62.7
% Exclusive, First Party	8.9	8.4	9.2	13.3
% Also on PS2		63.4	67.6	73.4
% Also on XB	40.9		56.3	47.4
% Also on GC	28.3	36.6		30.8
% On all 3 Consoles	21.6	33.5	51.5	15.9
# Titles Released Per Month				
Average	19	13	8	37
Max	54	45	38	127
Min	2	0	0	5

Notes: Summary statistics for the PS2 are for the 61-month period between October 2000 and October 2005; statistics for the other two consoles are for a 48-month period beginning on November 2001.

Table 2: Top 10 Videogame Titles for Each Platform by Quantity Sold

Console	Title	Publisher	Release Date	Exclusive?	Quantity ('000s)
PS2	GTA: Vice City	Take 2	Oct 2002	No[a]	6,687
	GTA: San Andreas	Take 2	Oct 2004	No[b]	5,797
	GTA 3	Take 2	Oct 2001	No[c]	5,588
	Gran Turismo 3: A-Spec	Sony	Jul 2001	Yes	3,764
	Madden NFL 2004	EA	Aug 2003	No	3,446
	Madden NFL 2005	EA	Aug 2004	No	3,199
	Madden NFL 2003	EA	Aug 2002	No	2,728
	Need for Speed: UG	EA	Nov 2003	No	2,533
	Kingdom Hearts	Square	Sep 2002	Yes	2,460
	Medal of Honor: Frontline	EA	May 2002	No	2,325
Xbox	Halo 2	Microsoft	Nov 2004	Yes	4,822
	Halo	Microsoft	Nov 2001	Yes	4,157
	T. Clancy's Splinter Cell	Ubisoft	Nov 2002	No	1,521
	GTA Pack	Take 2	Oct 2003	No	1,379
	Madden NFL 2005	EA	Aug 2004	No	1,223
	Project Gotham Racing	Microsoft	Nov 2001	Yes	1,216
	Star Wars: KOTR	Lucasarts	Jul 2003	Yes	1,210
	ESPN NFL 2K5	Take 2	Jul 2004	No	1,200
	Fable	Microsoft	Sep 2004	Yes	1,125
	T. Clancy's Ghost Recon	Ubisoft	Nov 2002	No	998
GC	Super Smash Bros	Nintendo	Dec 2001	Yes	2,961
	Super Mario Sunshine	Nintendo	Aug 2002	Yes	2,157
	Zelda: Wind Waker	Nintendo	Mar 2003	Yes	2,000
	Mario Kart: Double Dash	Nintendo	Nov 2003	Yes	1,922
	Luigi's Mansion	Nintendo	Nov 2001	Yes	1,748
	Metroid Prime	Nintendo	Nov 2002	Yes	1,312
	Sonic Adventures 2	Sega	Feb 2002	Yes	1,188
	Animal Crossing	Nintendo	Sep 2002	Yes	1,099
	Pokemon Colliseum	Nintendo	Mar 2004	Yes	979
	Mario Party 4	Nintendo	Oct 2002	Yes	979

Notes: Total quantity sold is for the 61-month period between October 2000 and October 2005. [a,b,c] Although non-exclusive, the PS2 had a window of exclusivity for these three titles: GTA: Vice City and GTA: 3 were not released on the Xbox until 2003 (well after they had both become blockbusters for the PS2), whereas GTA: San Andreas, though initially developed for both Xbox and PS2, was not released for the Xbox until 6 months after the PS2 game's release.

Table 3: Estimated Parameters of Demand System

		No Consumer Heterogeneity				Consumer Heterogeneity			
		Static Model Singlehoming (i)		Dynamic Model SingleHoming (ii)		Dynamic Model Singlehoming (iii)		Dynamic Model Multihoming (iv)	
	Variable	Parameter Estimate	Standard Error	Parameter Estimate	Standard Error	Parameter Estimate	Standard Error	Parameter Estimate	Standard Error
Global	ρ^{hw}			0.619	0.028	0.818	0.037	0.722	0.033
Parameters	ρ^{sw}			0.766	0.005	0.778	0.006	0.773	0.006
	σ_{α^γ}					2.576	0.507	3.529	0.552
	σ_ϵ	1.429	0.409	1.143	0.131	0.545	0.296	1.322	0.214
	β_γ			0.902	0.050	0.993	0.021	0.951	0.007
	D							-3.255	1.137
Hardware	$\alpha_0^{p,hw}$	-0.007	0.001	-0.008	0.001	-0.015	0.004	-0.014	0.002
Parameters	d_{PS2}	-19.479	1.907	-1.354	1.128	4.736	1.412	2.186	1.096
	d_{XBOX}	-27.195	3.237	-6.767	0.790	-4.464	0.865	-5.534	0.683
	d_{GC}	-26.258	3.442	-6.526	0.712	-4.964	0.790	-5.598	0.620
	age	-0.129	0.023	0.009	0.016	-0.039	0.037	-0.062	0.014
	age^2	0.001	0.000	0.000	0.000	0.000	0.001	0.000	0.000
	IB_{PS2}	0.148	0.068	0.054	0.047	0.087	0.061	0.084	0.054
	IB_{XBOX}	0.123	0.064	-0.002	0.059	0.078	0.071	0.057	0.066
	IB_{GC}	-0.124	0.097	-0.334	0.072	-0.294	0.088	-0.297	0.086
Software	$\alpha_0^{p,sw}$	-0.012	0.001	0.001	0.007	-0.031	0.010	-0.015	0.009
Parameters	age	-0.224	0.002	-0.156	0.007	-0.153	0.007	-0.148	0.007
	age^2	0.001	0.000	0.000	0.000	0.001	0.000	0.001	0.000
	IB_{PS2}	0.111	0.016	0.049	0.004	0.058	0.004	0.052	0.004
	IB_{XBOX}	0.193	0.022	0.015	0.004	0.027	0.005	0.022	0.005
	IB_{GC}	0.321	0.018	0.036	0.006	0.046	0.006	0.040	0.006
GMM Objective		21597.403		119.326		6.883		4.151	
# HW Obs. (n^{hw})		154		154		154		154	
# SW Obs. (n^{sw})		57923		57923		57923		57923	

Notes: ρ^{hw} and ρ^{sw} are the estimated coefficients on the autoregressive processes for $\xi_{j,t}$ and $\eta_{j,k,t}$ in (**??**); σ_γ is the standard deviation of consumer heterogeneity for gaming intensity α^γ; σ_ϵ is the variance of consumer idiosyncratic errors for software as well as the scaling coefficient between hardware and software utility; β_γ is the additional decay coefficient for future software utility in (12). $\alpha_0^{p,hw}$ and $\alpha_0^{p,sw}$ are the price sensitivity coefficients for the mean consumer. For the remaining hardware and software coefficients contained within α^x and α^w, d_j are fixed effects for platform j, age and age^2 are monthly decay effects, and IB_j are platform specific log installed base coefficients. For the full model (iv), IB_{PS2}, IB_{XB}, are not statistically significant and $\alpha_0^{p,sw}$ is significant at the 10% level. All other coefficients are significant at the 1% level.

Table 4: Estimated Parameters of Demand System (continued): Month Effects

	Variable	Parameter Estimate	Standard Error		Variable	Parameter Estimate	Standard Error
Hardware All Systems	d_{Feb}	-0.515	0.079	Software Xbox	d_{Feb}	0.094	0.011
	d_{Mar}	-0.222	0.081		d_{Mar}	0.090	0.016
	d_{Apr}	-0.455	0.081		d_{Apr}	-0.226	0.019
	d_{May}	-0.461	0.080		d_{May}	-0.349	0.021
	d_{Jun}	-0.262	0.086		d_{Jun}	0.077	0.021
	d_{July}	-0.263	0.082		d_{July}	0.033	0.023
	d_{Aug}	0.614	0.061		d_{Aug}	-0.059	0.023
	d_{Sep}	1.501	0.087		d_{Sep}	-0.012	0.022
	d_{Oct}	-0.197	0.035		d_{Oct}	-0.167	0.022
	d_{Nov}	0.202	0.030		d_{Nov}	-0.046	0.021
	d_{Dec}	0.142	0.023		d_{Dec}	0.985	0.013
Software Playstation 2	d_{Feb}	0.077	0.009	Software Gamecube	d_{Feb}	0.052	0.013
	d_{Mar}	0.048	0.013		d_{Mar}	0.030	0.019
	d_{Apr}	-0.221	0.014		d_{Apr}	-0.288	0.024
	d_{May}	-0.273	0.015		d_{May}	-0.378	0.025
	d_{Jun}	0.093	0.016		d_{Jun}	0.026	0.025
	d_{July}	0.080	0.018		d_{July}	0.009	0.027
	d_{Aug}	-0.053	0.018		d_{Aug}	-0.034	0.027
	d_{Sep}	0.034	0.017		d_{Sep}	-0.035	0.027
	d_{Oct}	-0.137	0.018		d_{Oct}	-0.105	0.027
	d_{Nov}	0.106	0.016		d_{Nov}	0.261	0.024
	d_{Dec}	1.094	0.011		d_{Dec}	1.199	0.016

Notes: Coefficients on month dummies for both hardware and software from the full dynamic demand model (specification (iv) in Table 3).

Table 5: Porting Cost Estimates, By Genre

	(i) Action			(ii) Family			(iii) Fighting		
	Estimate	95% CI		Estimate	95% CI		Estimate	95% CI	
PS2	0.000	*0.000*	*0.000*	0.000	*0.000*	*0.000*	0.000	*0.000*	*0.000*
XBOX	-1.011	*-1.279*	*-0.912*	-0.948	*-0.982*	*-0.877*	-1.072	*-1.324*	*-0.659*
PS2 & XBOX	1.197	*0.850*	*1.399*	0.326	*0.296*	*0.383*	0.435	*0.210*	*0.604*
GC	-0.825	*-0.850*	*-0.659*	-0.057	*-0.110*	*-0.008*	-0.964	*-1.127*	*-0.460*
PS2 & GC	1.379	*1.036*	*1.546*	0.442	*0.359*	*0.553*	0.624	*0.494*	*1.083*
XBOX & GC	-0.620	*-0.636*	*-0.466*	0.193	*0.114*	*0.360*	-0.421	*-0.641*	*-0.082*
All 3	3.717	*3.000*	*3.926*	1.108	*0.926*	*1.482*	3.944	*3.628*	*5.192*
# Titles	*241*			*100*			*77*		

	(iv) Platformer			(v) Racing			(vi) RPG		
	Estimate	95% CI		Estimate	95% CI		Estimate	95% CI	
PS2	0.000	*0.000*	*0.000*	0.000	*0.000*	*0.000*	0.000	*0.000*	*0.000*
XBOX	-1.151	*-1.270*	*-0.982*	-1.018	*-1.140*	*-0.934*	-0.762	*-0.865*	*-0.661*
PS2 & XBOX	0.222	*0.180*	*0.299*	1.280	*0.476*	*1.341*	0.642	*0.472*	*0.783*
GC	-0.566	*-0.771*	*-0.414*	-0.894	*-0.912*	*-0.207*	-0.680	*-0.783*	*-0.572*
PS2 & GC	0.900	*0.641*	*1.048*	0.940	*0.559*	*1.342*	0.632	*0.576*	*0.834*
XBOX & GC	-0.140	*-0.140*	*5.385*	-0.871	*-0.892*	*-0.398*	-0.182	*-0.217*	*0.192*
All 3	1.438	*1.179*	*1.566*	2.220	*1.438*	*2.359*	2.237	*2.060*	*2.436*
# Titles	*103*			*197*			*173*		

	(vii) Shooter			(viii) Sports			(ix) Other		
	Estimate	95% CI		Estimate	95% CI		Estimate	95% CI	
PS2	0.000	*0.000*	*0.000*	0.000	*0.000*	*0.000*	0.000	*0.000*	*0.000*
XBOX	-0.389	*-1.968*	*-0.388*	-1.343	*-1.387*	*-1.017*	-1.179	*-1.293*	*-1.043*
PS2 & XBOX	0.611	*0.434*	*1.792*	1.284	*0.475*	*1.311*	0.323	*0.310*	*0.440*
GC	-0.362	*-1.940*	*-0.362*	-1.308	*-1.358*	*-0.997*	-1.196	*-1.228*	*-0.986*
PS2 & GC	0.615	*0.626*	*2.357*	1.177	*0.396*	*1.264*	0.737	*0.497*	*0.926*
XBOX & GC	1.286	*-0.223*	*2.823*	-1.060	*-1.100*	*-0.668*	-0.562	*-0.562*	*3.952*
All 3	2.434	*1.188*	*3.032*	2.754	*1.795*	*2.814*	0.940	*0.874*	*1.086*
# Titles	*163*			*308*			*207*		

Notes: Estimates of θ_C used to specify porting costs in (14) (units in \$M), separately estimated by genre. Estimates are only *relative* differences in costs for supporting different platforms, and thus the porting cost for the PS2 is normalized to 0. 95% confidence intervals are constructed taking 40 sample draws from the empirical distribution of the moment inequalities and re-estimating costs (see Pakes, Porter, Ho, and Ishii (2006) for details).

Table 6: Dynamic Network Formation Game: Predicted Fit of Model

		Observed Data	Predicted Data		
			Estimate	*Conf.*	*Interval*
Installed Base (M)	PS2	30.07	30.38	*29.98*	*31.01*
	XB	13.32	13.51	*12.97*	*13.87*
	GC	9.83	10.67	*10.20*	*11.12*
% Market Shares	PS2	56.50	55.69	*0.55*	*0.57*
	XB	25.03	24.76	*0.24*	*0.25*
	GC	18.47	19.55	*0.19*	*0.20*
# of Titles	PS2	1161	615	*592*	*639*
	XB	749	1032	*1000*	*1093*
	GC	487	853	*781*	*877*
# of "Hit" Titles (Sales > 100K)	PS2	578	500	*492*	*533*
	XB	296	282	*205*	*321*
	GC	290	236	*207*	*264*
# of "Hit" Titles (Sales > 1M)	PS2	67	83	*78*	*99*
	XB	9	7	*2*	*10*
	GC	8	13	*11*	*15*
Total Titles Sold (M)	PS2	305.09	310.79	*300.27*	*349.71*
	XB	118.05	115.15	*83.60*	*133.32*
	GC	79.17	108.19	*92.50*	*118.73*

Notes: Predicted data obtained by fixing strategic platform choices for first-party titles, but allowing third-party titles to re-optimize. Porting cost estimates are from table 5. Confidence intervals are constructed via parametric bootstrap of demand system estimates reported in table 3, where software expected profits, porting costs, and a new equilibrium are recomputed for each draw.

Table 7: Counterfactual: Banning Vertical Integration and Exclusivity

		Observed	(i) CF #1: First Party Titles			(ii) CF #2: No FP Titles		
		Data	Estimate	*Conf.*	*Interval*	Estimate	*Conf.*	*Interval*
Installed Base (M)	PS2	30.38	32.29	31.82	33.08	30.36	29.98	30.97
	XB	13.51	10.53	*10.05*	*10.90*	9.97	*9.75*	*10.21*
	GC	10.67	8.50	*7.85*	*8.85*	7.71	*7.26*	*7.98*
% Market Shares	PS2	55.69	0.63	*0.62*	*0.65*	0.63	*0.63*	*0.64*
	XB	24.76	0.21	*0.20*	*0.21*	0.21	*0.21*	*0.21*
	GC	19.55	0.17	*0.15*	*0.17*	0.16	*0.15*	*0.16*
Number of Titles	PS2	615	782	*733*	*810*	680	*613*	*712*
	XB	1032	922	*853*	*1047*	593	*523*	*768*
	GC	853	1046	*901*	*1072*	658	*330*	*785*
# of “Hit” Titles	PS2	500	676	*667*	*716*	544	*515*	*576*
(Sales $>$ 100K)	XB	282	23	*13*	*58*	8	*2*	*40*
	GC	236	23	*16*	*34*	2	*2*	*12*
# of “Hit” Titles	PS2	83	153	*141*	*175*	91	*80*	*108*
(Sales $>$ 1M)	XB	7	3	*2*	*3*	0	*0*	*0*
	GC	13	3	*1*	*3*	0	*0*	*0*
Total Titles Sold (M)	PS2	310.79	532.37	*518.43*	*594.44*	333.14	*318.03*	*378.96*
	XB	115.15	21.22	*16.61*	*28.43*	7.48	*2.94*	*17.32*
	GC	108.19	21.10	*17.74*	*24.04*	5.94	*2.77*	*11.99*

Notes: Counterfactual results allow all titles to re-optimize and choose the optimal set of platforms. CF #1 assumes first-party titles are still produced and enter the market; CF #2 assumes all first-party titles are eliminated. Estimates are computed using porting cost estimates from table 5. Confidence intervals are constructed via parametric bootstrap of demand system estimates reported in table 3, where software expected profits, porting costs, and a new equilibrium are recomputed for each draw.

Table 8: Software Price Regressions

Explanatory Variable	Parameter Estimate	Standard Error	Parameter Estimate	Standard Error	Parameter Estimate	Standard Error
price_{t-1}	0.922	0.001	0.868	0.002	0.862	0.002
$(\text{price}_{t-1})^2$			0.001	0.000	0.001	0.000
Q_{t-1} (10^-3)					0.008	0.000
d_{Feb}	0.659	0.073	0.645	0.073	0.817	0.073
d_{Mar}	0.560	0.073	0.545	0.072	0.717	0.072
d_{Apr}	-0.108	0.072	-0.115	0.071	0.049	0.071
d_{May}	0.569	0.071	0.547	0.071	0.726	0.071
d_{Jun}	0.497	0.071	0.476	0.071	0.659	0.071
d_{July}	-0.315	0.071	-0.338	0.070	-0.169	0.070
d_{Aug}	1.227	0.070	1.175	0.070	1.345	0.070
d_{Sep}	0.249	0.070	0.221	0.070	0.391	0.070
d_{Oct}	-0.296	0.069	-0.327	0.069	-0.157	0.069
d_{Nov}	-0.062	0.076	-0.078	0.075	0.082	0.076
d_{Dec}	1.299	0.074	1.280	0.073	1.398	0.073
Constant	0.671	0.059	1.438	0.064	1.359	0.064
R^2	0.924		0.925		0.926	
# Observations	58337		58337		58337	

Notes: See Appendix B. OLS Regression of prices on lagged prices and quantities for each software title, pooled across all platforms.

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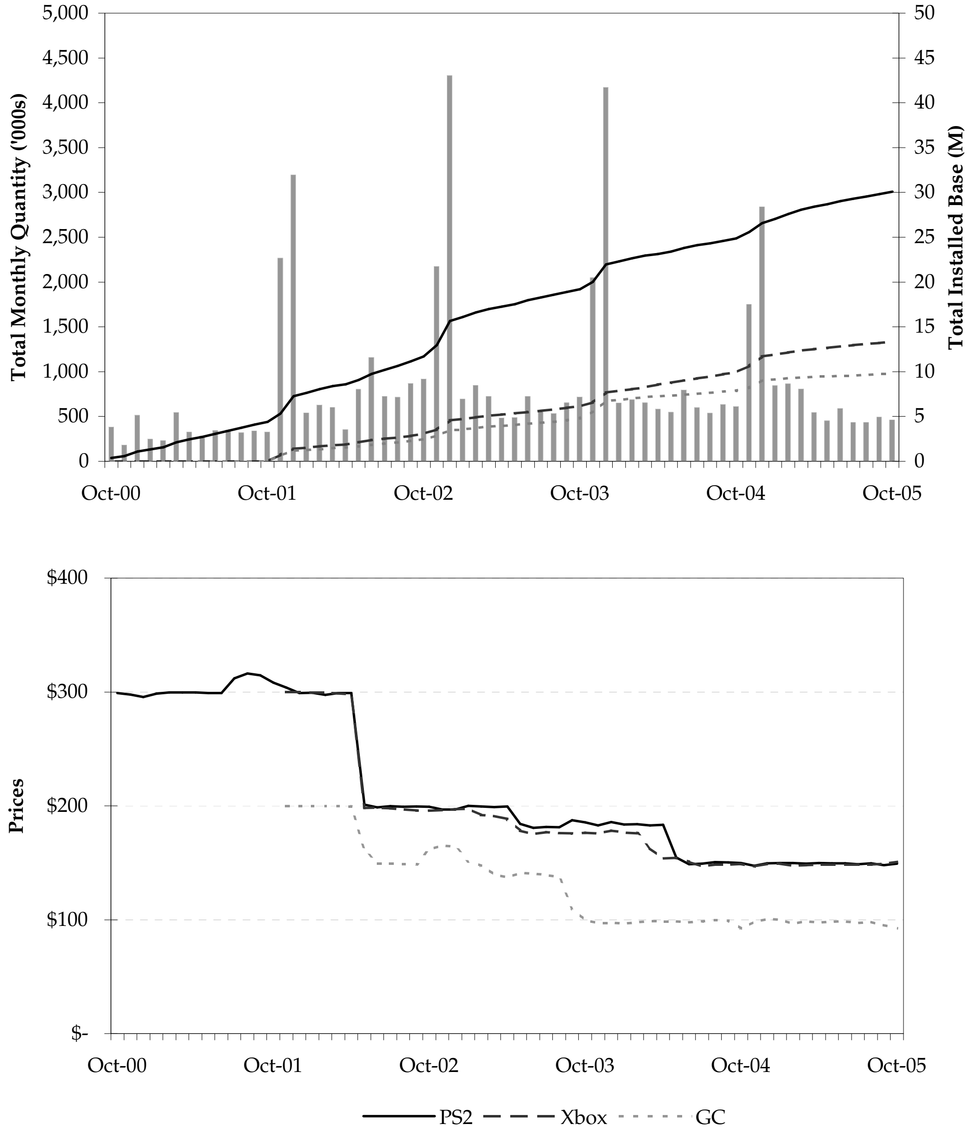
Figure 1: Hardware Quantities, Installed Bases, and Prices



Notes: In the top graph, bars represent the total number hardware consoles sold across all three platforms in each month in thousands (scale on left); lines graphs indicate the total installed base for each console in millions (scale on right). The bottom graph provides average monthly (nominal) prices faced by consumers in retail stores for each platform. The PS2 and Xbox started retailing for $300, but in May 2002 both simultaneously cut their prices by $100 prior to the "E3" industry trade show. Nintendo followed with a $50 price cut of its own from $200 to $150. Microsoft and Sony again dropped prices in the same month two years later.

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