Technological Tying and the Intensity of Competition: An Empirical Analysis of the Video Game Industry

Timothy Derdenger*

Tepper School of Business

Carnegie Mellon University

October 13, 2010

Abstract

Using data from the 128 bit video game industry this paper evaluates the intensity of console price competition when integrated firms tie their produced software to their own hardware. Tying occurs when a console hardware manufacturer produces software which is incompatible with rival hardware. There are two important trade-offs to an integrated firm implementing a technological tie. The first is an effect which increases console market power and forces prices higher. The second, an efficiency effect due to the integration of the firm, drives prices lower. Counterfactual exercises determine a technological tie of integrated hardware and software increases console price competition and is due to console makers subsidizing consumers in order to increase video games sales, in particular their tied games, where the greatest proportion of industry profits are made.

Keywords: integration, platform markets, tying, video game industry

*__Corresponding Address:__ Tepper School of Business, Carnegie Mellon University, Pittsburgh, PA 15213; Email: derdenge@cmu.edu

1 Introduction

In many high technology industries the variety and quality of complementary products play a sizeable role in a consumer's adoption of a product. For instance, in the home video game console market a consumer must choose between a PlayStation 3, Microsoft Xbox 360 or Nintendo Wii before he able to play any video games. Yet, many of these video games are compatible with multiple consoles and thus create little additional differentiation across consoles. There are complements that are exclusive to one platform–to play *The Conduit* consumers must purchase the Nintendo Wii video game console or to play *Gran Turismo 5* consumer must purchase a Sony PlayStation 3.[1] Exclusive complements bring added differentiation to platforms which subsequently increases a console manufacturer's market power and its incentive to increase console price through the increased variety of its complementary products (Church and Gandal (2000)). A video game console manufacturer can also replicate the added differentiation and increased market power associated with exclusive contracts through integrating into the software market and creating a technological tie between its console and games. A technological tie occurs when a hardware manufacturer produces software which is incompatible with rival hardware. Hence, for a consumer to consume console produced software he must also purchase the complementary hardware. Examples are Nintendo's production of the Super Mario Brothers video game series or Microsoft's production of Halo. Although these examples are not in a traditional sense vertically integrated, the same economic principles can be extended to sellers of two complementary products where software can be thought of as the input or upstream supplier to the production of the downstream hardware (Salop (2005)). Consequently, integration also produces efficiency effects associated with the pricing of complementary products which create an incentive to decrease console price (Cournot 1838). The net competitive price effect of an integrated firm tying its software to its hardware is thus ambiguous and is an important empirical antitrust question.

Using data from the 128-bit video game industry, which consists of Nintendo GameCube, Sony PlayStation 2 and Microsoft Xbox, I empirically quantify the change in the intensity of console price competition when a console producer integrates into the software market and ties its hardware and software. I contribute to the literature by i) presenting a structural model which captures the complementary relationship between hardware and software while accounting for video game variety, differentiation and *competition*[2] , ii) determine the marginal impact an individual game has on console demand and iii) jointly estimate demand

[1] These exclusive complements are exclusive due to a formal contract between producers of complementary goods.

[2] See i.e. Nair, Chintagunta and Dube (2004), Clements and Ohashi (2004), Prieger and Hu (2007), Corts and Lederman (2007) and Dube, Hitsch and Chingtagunta (2007) for papers which assume software are homogenous products

and supply for complementary products.

There are several economic forces at play when a console manufacturer technologically ties its software to its hardware. The first is a result of the tie foreclosing rival console manufacturers access to games produced by a console while the second is a consequence of the console manufacturers electing to design and produce video games themselves. More specifically, in order for a consumer to play a *first party* title (games produced by console manufacturers) he has to purchase the respective console which increases the console manufacturer's market power. This consequently generates an incentive to raise console price from the relative increases in utility given that rival consoles have one less available game. Additionally, when a console manufacturer elects to design and produce video games as well as produce consoles its price structure adjusts to reflect its decision. Integration generates a third profit stream which leads to further discounting of console price by the profit the console producer receives from designing, producing and selling its own video games when one more console is sold. Therefore, integration levies added pressure on price or generates an incentive for console manufacturers to lower console price because lower prices lead to an increase in the demand for consoles which consequently generates greater demand for video games, in particular their own video games. The intensity of console price competition thus depends upon the trade-off between higher hardware or software profits.

Given there is no natural experiment in the data to analyze the impact of tying integrated hardware and software on video game console price competition, I perform "policy simulations to study the economic consequences of alternative strategic options" (Liu 2009). In the spirit of this approach I estimate a structural model which allows me to simulate counterfactual experiments. With the use of two counterfactual exercises I determine that the implementation of technological tying in the home console market increases console price competition from the fact that a console manufacturer is willing to forego the incentive to raise console price in order to increase the demand for its console and in particular their own integrated video games, where the largest proportion of industry profits are made.

It is important to disclose that in the underlying empirical model and all counterfactual experiments a consumer's choice of video games and console is static (but with decreasing aggregate demand for consoles) and that firms also take a static approach to setting prices of consoles and video games. Now although the model assumes firm prices are statically set, I certainly recognize that console producers may be forward looking and account for the impact period $t's$ price has on future periods such as Nair (2007) or that consumers are forward looking as well (Lee 2010). However, the interest in dynamic pricing is outside the scope of this paper as the main focus is on capturing the complementary relationship between hardware and software in both the demand and supply models. Additionally, I do not fully account for any changes in software availability or investment in console or software quality. I do not capture the change in incentives of independent software developers to produce for each console when integrated video games are eliminated, for instance. The counterfactual results below consequently capture only partial effects. It is not to say, however, the below work does not provide any insight into the impact technological tying has on console price competition. The reader should instead view this paper as a starting point for the analysis of a very complex and understudied problem.

The structure of this paper is as follows. First, an overview of the 128-bit video game industry and the data used in my analyses is provided. Sections 3, 4, and 5 present the structural empirical model, estimation technique and model results, respectively. Section 6 presents the counterfactual scenarios and the simulation results. Lastly, I review the innovations of my work and results of my analyses.

2 Related Literature

The literature regarding technological tying is relatively sparse. Yet, there is an extensive line of literature on tying.[3] The Chicago School's traditional argument on tying is famously classified as the "single-monopoly-profit theorem" which debunks leverage theory by stating that a monopolist with an essential good has no incentives to tie because it can extract all potential surplus by leaving a monopoly price. However , the post-chicago literature refines leverage theory and identifies some circumstances under which tying could be strategically profitable, taking into account Chicago School's intellectual argument. Moreover, numerous authors have shown that tying can be used by a monopolist to foreclosure rivals, deter entry of competitors and extend their monopoly power into complementary markets (see Whinston (1990), Choi and Stefanadis (2001), and Carlton and Waldman (2002). There also is a growing line of literature which directs its attention to the effects of tying on R&D incentives (Carlton and Waldman (2005), Riordan and Gilbert (2007)).

The most related literature to my research is that of Church and Gandal (2000) who study the possibility of technologically tying integrated hardware and software and find that doing so can be an equilibrium outcome.[4] Moreover, they study a market structure which is quite similar to what is seen in the present video game industry and in this structure multiple hardware producers integrate into the software market and foreclose rival hardware makers from their integrated software. Church and Gandal find technologically tying to be pro-competitive, prices fall relative to a non tying equilibrium. However, they determine total surplus to be greater in the un-tied industry structure than in the tied equilibrium.

Lastly, as is evident from above, the surrounding literature on the topic of technological

[3] See Posner (1976), Bork (1978), Whinston (1990), Farrell and Katz (2000) and Carlton and Waldman (2002)

[4] In their paper they address technological tying as when a hardware firm merges with a software firm and the integrated firm makes its software incompatible with a rival technology or system

tying mostly encompasses theoretical works. It is my belief that I am the first to empirically analyze the competitive price effects associated with technological tying.[5]

3 The Video Game Industry

The structure of the video game industry is a prototypical platform market where a video game console acts as a platform to two different end users, consumers and game developers.[6] A console permits two end users to interact via its platform creating externalities for each side of the market where the demand-side indirect network effects pertain to the effect that a game title has on a console's value to the consumer as well as the benefit a game developer receives when an additional consumer joins the console's owner base. Determining the size of these cross group externalities depends on how well the console performs in attracting the other side. Within the console market there are three classes of players: the consoles, consumers, and game developers. A consumer purchases a console in order to play games. Moreover, a consumer pays a fixed fee p_c for the console and a fixed price p_g for video game g. However, in order for a consumer to play a video game, the developer of the game is required to pay the console a royalty rate r for the rights to the code which allows the developer to make his game compatible with the console. This royalty rate is not a fixed one-time fee. Rather, a developer pays a royalty fee for each copy of its game that is bought by a consumer as well as a one time fee for a software developers kit (SDK).[7,8] The price of the SDK is quite small–for the current PS3 the price is $10,250 per developer. I, therefore, ignore this profit stream in the model below.[9] No other transfers occur between software developers and console makers in practice. Figure 1 presents an illustration of the discussed market structure.

[5] An additional stream of literature is one which focuses on the video game industry: see i.e. Nair, Chintagunta and Dube (2004); Clements and Ohashi (2004); Prieger and Hu (2007); Corts and Lederman (2007); Dube, Hitsch and Chingtagunta (2007) and Lee (2009) for such research

[6] See i.e. Kaiser (2002), Caillaud and Jullien (2003), Rochet and Tirole (2004), Rysman (2004), Kaiser and Wright (2005), Armstrong (2006), Hagiu (2006) and for general literature on two-sided platform markets

[7] Console manufacturers actually manufacture all video games themselves to ensure control over the printing process and to track sales for royalty collection.

[8] The price of the software developers kit is a one time fee a developer pays to design a video game for a given console. The firm only pays this fee once and can design as many games as it likes.

[9] I could not determine the SDK price for any of the relevant consoles.

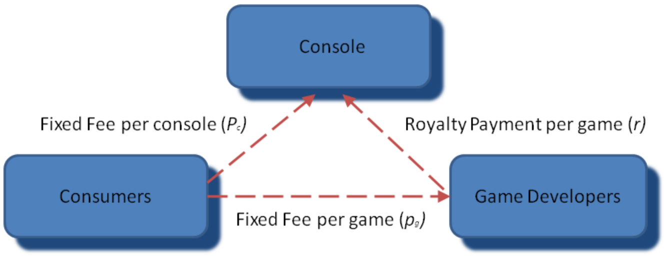

Figure 1: Video Game Market Structure

The above figure describes a very generalized industry structure. A more tailored structure makes a distinction between two different types of video games. The first is what the industry and I note as *first party* games. These games are produced by the console's in house design studio. The second type of video game are games produced by independent firms not associated with the producing consoles. I denote these developers as *third party.* Typically, *third party* vendors make games accessible to all consoles as a result of the high fixed costs of production whereas *first party* games are tied to its maker's console. The average fixed cost for a game on Nintendo GameCube, Sony PlayStation 2 or Microsoft Xbox is roughly two and half to four million dollars (Pachter and Woo).

Indirect network effects play a vital role in the adoption and diffusion of video game consoles and many other platforms. The literature (empirically and theoretically), however, has defined indirect network effects as a function of the *number* of other users who are in the same "network" (Katz and Shapiro (1985)) and has consequently abstracted away from the fact that quality of the complementary products may also play an important role in the formation of the indirect network effect.[10] By assuming the indirect network effect is only a function of variety one implicitly assumes all complementary products are homogeneous. This perhaps is a nice approximation in some industries but in the video game industry it is not. For instance, one of the driving forces for why the video game industry imploded in the early 1980s was a direct result of Atari allowing to many video game developers to produce to many low quality games. Accounting for differentiated video game or quality is an important aspect of console demand; a 2002 study by Forrester Research concluded 96% of people surveyed believed the quality of video games was an important characteristic in choosing a game console. To understand how important software quality is in constructing console demand consider the following: assume two competing consoles with two games each are identical except that the first console's games are both of mediocre quality while the second console has one mediocre game and one of higher quality. Under a demand model

[10]Many empirical studies do so due to the limited availability of the necessary data to incorporate quality in the formation of the indirect network effect. See i.e. Nair, Chintagunta and Dubé (2004); Clements and Ohashi (2004); Hu and Prieger (2008) , Liu (2009), Dubé , Hitsch and Chingtagunta (2007) and Shankar and Bayus (2003) .

which only accounts for the number of games compatible to a console, demand for each console would be identical. A more flexible model which accounts for differentiated video games would provide greater demand for console two than for console one, resulting in a different equilibrium outcome from model one. It is therefore essential to incorporate video game differentiation into the network effect.

During the 128-bit video game console (2000-2006) life cycle the video game industry saw three of the most revolutionizing consoles come to market, the Sony PlayStation 2, Microsoft Xbox and Nintendo GameCube. These consoles brought larger computing power, more memory, enhanced graphics, better sound and the ability to play DVD movies. In addition, the producing firms each launched an expansive line of accessories to accompany their platform.

Sony enjoyed a yearlong first mover advantage with its launch of PlayStation 2 debuting in October 2000. Its success was attributed to moving first but more significant was its large catalog of games which were exclusively produced for its console by its development studio and by *third party* developers. Many of its biggest software hits were exclusive to PlayStation 2 but only one was Sony produced.

Microsoft Xbox launched in very late October 2001 and was by far the most technologically advanced console. It was technically superior to the dominant Sony PlayStation 2, possessing faster processing speed and more memory. Microsoft, however, struggled to gain market share as a result of its inability to attract developers to its platform to produce software titles exclusively for Xbox, in particular the many prominent Japanese developers (Pachter and Woo 2006). The inability to secure *third party* exclusive games forced Microsoft to design and produce video games internally.

Within weeks of the Microsoft Xbox launch Nintendo GameCube was introduced (November of 2001). The GameCube was the least technically advanced of the three consoles. Instead of competing in technology with Sony and Microsoft, Nintendo targeted its console to younger kids. "The GameCube's appeal as a kiddie device was made apparent given the fact that the device did not include a dvd player and its games tilt[ed] towards an E rating" (Pachter and Woo 2006). The GameCube's limited success was a result of Nintendo leveraging its "internal development strength and target[ing] its loyal fan base, composed of twenty somethings who grew up playing Nintendo games and younger players who favored more family friendly games" (Pachter and Woo 2006).

3.1 Data

The data used in this study originates from three data sources two of which are proprietary independent sources and one public data source. They are NPD Funworld, Forrester Research Inc. and the March 2005 United States Consumer Population Survey (CPS). Data from the marketing group NPD Funworld track sales and pricing for the video game industry and are collected using point-of-sale scanners linked to over 65% of the consumer electronics retail stores in the United States. NPD extrapolates the data to project sales for the entire country. Included in the data are quantity sold and total revenue for the three consoles of interest and all of their compatible video games, roughly 1200. The second proprietary data set is from Forrester Research, which reports consumer level purchase/ownership of video game consoles. The North American Consumer Technology Adoption Study surveyed 10,400 US and Canadian households in September of 2005. But, since sales data from NPD only tracks US sales I restrict the survey sample to only US households. In addition to ownership information the survey also provides key household demographic data. The last data set originates from the 2005 March CPS and provides demographic information on the United States population.

The first data set covers 35 months starting in January 2002 and continuing through November 2004. The remaining two data sets, Forrester Research and the CPS, are one time snapshots of consumers in 2005.

General statistics about the video game industry are provided in Table 1.

Table 1: Summary Statistics

	GameCube	Xbox	PlayStation 2
Release Date	Nov. 2001	Oct. 2001	Oct. 2000
Hardware			
Installed Base (Nov. 2004)	8,223,000	10,657,000	25,581,000
Price			
Average	$133.18	$190.54	$240.10
Max	199.85	299.46	299.54
Min	92.37	146.92	180.66
Sales			
Average	200,420	264,140	522,860
Max	1,158,200	1,079,400	2,686,300
Min	58,712	77,456	188,670
DVD Playability	no	yes	yes
Max Number of Controllers	4	4	2
Average Family size	3.6725	3.7206	3.59876

Below I briefly discuss two important facts regarding the industry. The first is that the video game industry exhibits a large degree of seasonality in both console and video game sales. Figures 2 and 3 illustrate the total number of consoles and video games sold in each month, both of which increase considerably in the months of November and December. It is, therefore, important to account for the large degree of seasonality in estimation.

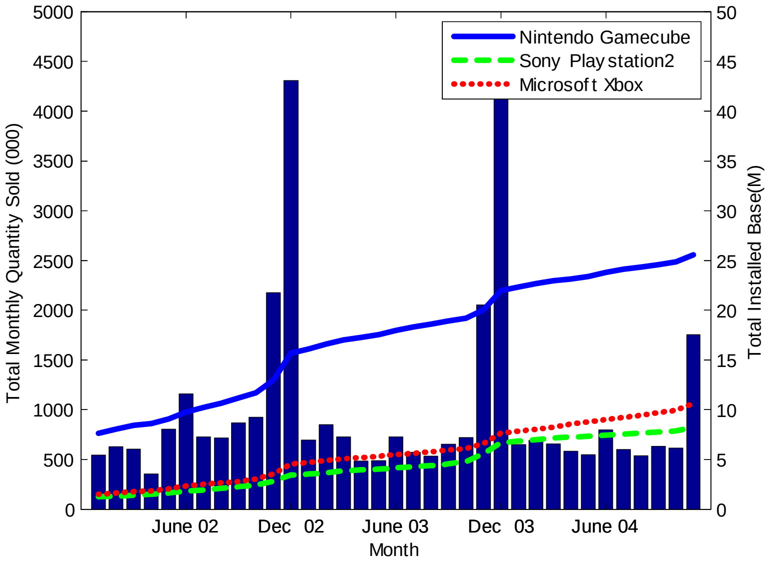

Figure 2: Console Sales and Installed Base

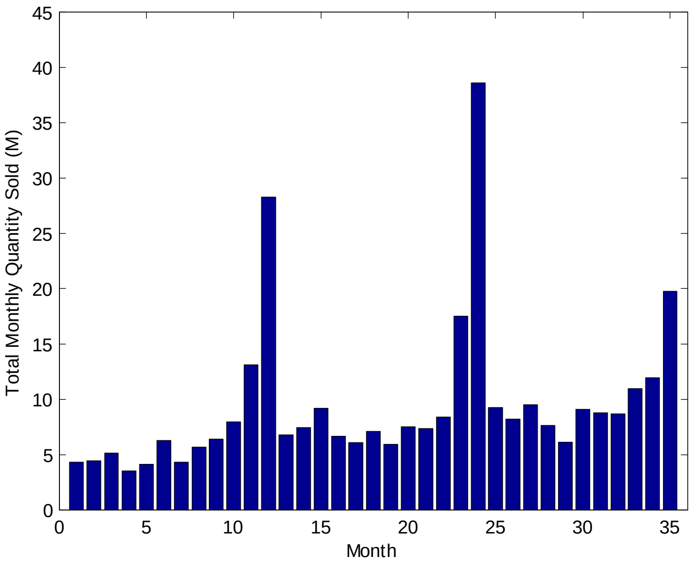

Figure 3: Software Sales per Month

The second fact is that video games are differentiated goods, which is quite evident by walking into the nearest consumer electronic store and looking at their video game shelves. There are seven genres of games which range from action to simulation. The largest is action games with 24% of the market, and simulation games is the smallest genre with only 1%. Video game sales for individual games also range in the number of units sold. There are large "hits" such as *Grand Theft Auto: Vice City* which has cumulative sales of over six million on PlayStation 2 and "busts" like *F1 2002* which sold only 48,000 units on the same console. It is this differentiation that is the driving factor for the construction of a console demand model which accounts for video game heterogeneity.

I also present statistics regarding technological tying in the video game market to further support a model which accounts for differentiated video games. Table 2 indicates the total units sold of *technologically tied* games for each console in January of the reported years as well as the number of *technologically tied* games and a "pseudo" HHI.[11] The HHI index measures the concentration of tied games for each console. A small index indicates *technologically tied* games have little impact on video game sales while a large index signifies the opposite. The HHI is a more encompassing measure of *technologically tied* game importance as compared to the number of games or the total units sold because these two measures do not measure the quality of available games whereas the latter also does not indicate the number of games available. Table 2 also brings light to the relative importance of tied games for Nintendo and Microsoft. In January 2002 both Nintendo's and Microsoft's HHIs are on the magnitude of 500 and 300 times the size of Sony's and by January 2004 the magnitude decreased to only five and three times Sony's, respectively.

Table 2: First Party Game Statistics

Platform	Units Sold of *Technologically Tied* Games		
	2002	2003	2004
GameCube	179,011	193,347	427,153
PlayStation 2	267,545	925,290	546,351
Xbox	382,599	234,258	414,333
	Number of *Technologically Tied* Games		
GameCube	5	12	21
PlayStation 2	24	45	66
Xbox	10	20	38
	Pseudo HHI of *Technologically Tied* Games		
GameCube	535.94	59.49	54.44
PlayStation 2	10.28	55.29	8.02
Xbox	305.02	17.39	29.09

Note: Statistics calculated for January of the corresponding year.

4 The Empirical Model

In this section I discuss the structural model which capture the complementary relationship between consoles and video games, which include demand and supply models for both

[11] The HHI measure is calculated by summing the squared market shares of each integrated game.

hardware and software. The model also incorporates software competition into the software demand and supply models.[12] Below I first present the empirical model describing the consumers decision process and follow with the hardware and software pricing models.

4.1 The Demand Models

In each period a potential consumer purchases or chooses not to purchase a video game console. After consuming a console a consumer decides which game to purchase, if any, from a set of available games. Once a consumer has purchased a video game console he exits the market for consoles but continues to purchase video games in future periods. I assume consumers exit the console market entirely given the fact that data from The North American Consumer Technology Adoption Study determines the fraction of the US gaming population who own two or more video game consoles of the same console generation is less than 4.5%. I, therefore, assume multihoming in consoles in not an important factor.

A consumer derives utility when he purchases a given video game. This utility must be accounted for in the utility he receives when consuming a specific console. Moreover, at the stage in which a consumer decides to purchase a console he is uncertain about the utility he receives from video games. The consumer only realizes the utility after the purchase of a video game console. It is thus important to link the realized video game demand with the expected utility from video games in console demand.

Given the sequential nature of the model and the model assumptions, a nested logit structure is employed for console demand. The use of the nested logit structure provides a natural extension for the inclusive value to link video game demand to console demand in addition to it being consistent with the model assumptions. Furthermore, it eliminates a significant selection issue due to video game sales data being determined by consumers who already purchased a respective console.[13] The formation of the inclusive value is generated from the assumption that video game demand is a discrete choice in each month and is of multinomial logit form. Thus, the underlying software demand model accounts for differentiated video games and competition.

The consumer decision process is as follows. In time t, each consumer makes a discrete choice from the set of $\mathcal{J}$ available consoles. If a consumers elects to purchase console $j \in (0, ..., J)$ where 0 is the outside option of not purchasing, he then purchases complementary video games which are compatible to console j. In choosing a console, a consumer only considers the expected maximum utility generated from the set of available video games in period t as a result of the consumer's uncertainty of the utility each video game generates at

[12] In the Appendix I present the results of several model which help further strengthen my assumptions that video games compete and that a dynamic demand model is not of great concern.

[13] this method is similar to Dubin and McFadden (1984) in which they study residential electric appliance holdings and consumption

the stage in which he elects to purchase a console yet is able to continue to purchase software in subsequent periods. The timing is as follows:

Stage 1: Consumers choose which console to purchase $j \in \mathcal{J}$

Stage 2a: Consumers realize the utility video games generate

Stage 2b: Consumers may purchase one video game which is compatible to console j in period t and each subsequent period.

Consumers are indexed by i, consoles by j and time by t. A consumer's indirect utility for console j is characterized by console price P_{jt}, a set of observed physical characteristics X_{jt}, the indirect network effect Γ_{jt}, unobserved product characteristics ξ_{jt} (the econometric error term) and an individual taste parameter ε_{ijt}, distributed i.i.d. type-1 extreme value across i, j and t. A consumer's indirect utility for console j in market t is

$$\begin{aligned} u_{ijt} &= \alpha_i^{hw} P_{jt} + \beta_i^{hw} X_{jt} + \phi \Gamma_{ijt} + \xi_{jt} + \varepsilon_{ijt} \qquad (1) \\ \begin{pmatrix} \alpha_i^{hw} \\ \beta_i^{hw} \end{pmatrix} &= \begin{pmatrix} \overline{\alpha}^{hw} \\ \overline{\beta}^{hw} \end{pmatrix} + \Sigma v_i + \Pi D_i \qquad v_i \backsim N(0, I_{k+1}) \end{aligned}$$

where α_i^{hw} and β_i^{hw} are $K+1$ individual specific parameters, K is the dimension of the observed characteristics vector, D_i is a $d \times 1$ vector of demographic variables, Π is a $(K+1) \times d$ matrix of parameters that measure how consumer taste characteristics vary with demographics and Σ is a vector of scaling parameters. The model parameters are $\theta^{hw} = (\theta_1^{hw}, \theta_2^{hw})$. θ_1^{hw} contains the linear parameters of the model $(\overline{\alpha}^{hw}, \overline{\beta}^{hw})$ and $\theta_2^{hw} = (\Sigma, \Pi, \phi)$ the nonlinear parameter.[14]

Examples of physical characteristics are advertising expenditure, processing speed, graphics quality, volume of the console, CPU bits and number of controllers. Unobserved characteristics include other technical characteristics and market specific effects of merchandising. I control for these unobserved product characteristics as well as observed characteristics which do not vary over time with the inclusion of console specific fixed effects. In the attempt to capture some dynamic aspects of the consumer's valuation for consoles over time, I allow the console fixed effects to be year specific. I also control for the large seasonal spikes during holiday months with a seasonal indicator variable taking value one for months of November and December and zero otherwise. By employing fixed effects the econometric error term transforms from ξ_{jt} to a console–year–month specific deviation, $\Delta\xi_{jyt}$, because I characterize the unobserved product characteristics as $\xi_{jt} = \xi_{jy} + \Delta\xi_{jyt}$ where ξ_{jy} is captured by year specific console fixed effects. Lastly, I assume consumers observe all console characteristics and take them into account when making a console purchase decision.

In order to predict console market shares and determine a consumer's indirect utility from

[14]Software utility enters linearly into the utility function for consoles so the expected utility of software is a sufficient statistic for calculating utility for hardware.

a console purchase I must examine the utility consumers receive from purchasing software in order to define $\Gamma_j(\cdot)$, the software index. Consider a consumer who has already purchased console j in period t or in some previous period. The indirect utility consumer i receives when purchasing software k_j compatible with console j in period t takes the familiar logit form. To allow for unobserved heterogeneity in tastes for game prices, I assume the intrinsic consumer preference toward price has the following normal distribution:

$$\begin{aligned} \alpha_i^{sw} &= \overline{\alpha}^{sw} + \sigma_\alpha^{sw} \upsilon_i \\ \upsilon_i &\backsim N(0,1) \ . \end{aligned}$$

The indirect utility for a given game k_j compatible with console j in period t takes the form:

$$\begin{aligned} u_{ik_jt} &= \alpha_i^{sw} p_{k_jt} + x'_{k_jt}\beta^{sw} + \psi_{k_jt} + \eta_{ik_jt} \\ u_{ik_jt} &= \delta_{k_jt} + \sigma_\alpha^{sw} \upsilon_i p_{k_jt} + \eta_{ik_jt} \end{aligned} \tag{2}$$

where p_{k_jt} is software k's price, x_{k_jt} is vector of game characteristics, ψ_{k_jt} is the unobserved software characteristics, σ_α^{sw} is the standard deviation of consumer preference for software price, and η_{ik_jt} is a type-1 extreme value distributed random variable which is independently and identically distributed across individuals, software, console and time. The model parameters are $\theta^{sw} = (\theta_1^{sw}, \theta_2^{sw})$ where θ_1^{sw} contains the linear parameters of the model $(\alpha^{sw}, \beta^{sw})$ and $\theta_2^{sw} = (\sigma_\alpha^{sw})$ the nonlinear parameter. Now although the above model is specific to consumers who have already purchased a console it is important to note the above indirect software utility also characterizes the utility for consumers who have yet to purchase a console–software preference do not change once a consumer has purchased a unit of hardware.

A consumer makes his decision based upon the notion that titles are substitutes for each other. And, with this in mind in addition to a consumer knowing which games are available on a console but not the utility a game provides at the console selection stage, the consumer forms an expectation as to the utility he would receive from video games. The expectation of software utility forms the indirect network effect and equals the expected maximum utility from choosing from a set of available and compatible video games for console j in market t:

$$\Gamma_{ijt} = E(\max_{k_j \in \mathcal{K}_j} u_{ik_jt}) = \ln\left(\sum_{k_j=0}^{K_j} \exp[\delta_{k_jt} + \sigma_\alpha^{sw}\upsilon_i p_{k_jt}]\right) + \varphi. \tag{3}$$

Given the above functional form for the software index consumers make their console purchase decisions in period t on the available video games in the same period; they are not forward looking nor form expectations of future prices or available video games. Additionally, some readers might believe there is a disconnect between the software and hardware model given the assumption that consumers remain in the video game market after purchasing a console but only make a console purchase decision from the current periods software index. In the appendix I present results of a logit demand model which assumes consumers have perfect foresight of next period's prices and video game availability by simply including them as additional covariates in the consumer's utility function. If consumers are forward looking, in at least one period ahead, there should be a positive and significant coefficient associated with t+1 period's software indices and price. Yet, what I determine are insignificant parameter estimates.[15] The above model therefore performs quite well in capturing the main drivers of a consumer's console purchase and does not exhibit a disconnect between software and hardware purchase decisions.

I complete the demand model with the specifications of the outside goods or the option of not purchasing a console or game. The indirect utility from not purchasing hardware is

$$u_{i0t} = \xi_0 + \sigma_0 v_{i0} + \pi_0 D_i + \varepsilon_{i0t}$$

which is normalized to zero by setting (ξ_0, σ_0, π_0) equal to zero and

$$u_{i0_j t} = \eta_{i0_j t}$$

for not purchasing software compatible with console j.

4.2 The Supply Models

4.2.1 The Console Supply Model

The profit function of a console manufacturer differs from that of a standard single product firm. Console firms face three streams of profits (selling consoles, selling video games and licensing the right to produce a game to game developers) and take each into consideration when setting console price. Assume each console producer set all product prices simultaneously in order to maximize profits and that they act statically.[16] Furthermore, assume console producers face a marginal cost of \$2 when interacting with game developers (this cost is associated with the production and packaging of video games).[17] Additionally, a developer's marginal cost for a game equals the royalty rate charged by a console and is set at \$10 per game. I thus treat a console's royalty rate as exogenous and therefore it is not a strategic variable for consoles.

[15] I also include tests of whether future console prices in period t+1 affect current utilities. I determine that they do not.

[16] I make such an assumption for computational reasons. The computational power needed to solve a dynamic oligopoly model given that there are over 1200 unique video games produced at the end of my data set would be emense

[17] Game developers do not actually create the physical disk which is sold to consumers. Instead, the console manufacturer stamps all video games for quality control purposes.

Assumption 1: Console producers are static decision makers

Assumption 2: Console firms face a marginal cost of two dollars when interacting with game developers

Assumption 3: Console producers set royalty rates at ten dollars per game title sold.[18]

Console maker $j's$ profit function in time t is

$$\Pi_{jt} = (P_{jt} - MC_{jt}) M_t S_{jt}(P, X, \Gamma; \theta^{hw}) + \sum_{d \in F} \underbrace{(IB_{jt-1} + M_t S_{jt}(P, X, \Gamma; \theta^{hw}))}_{\text{Potential Market for game d=IB}_{jt}} s_{dt}(\delta)(p_{dt} - mc_{dt}) + \sum_{k_j \notin F} \underbrace{(IB_{jt-1} + M_t S_{jt}(P, X, \Gamma; \theta^{hw}))}_{\text{Potential Market for game k=IB}_{jt}} s_{k_j t}(\delta)(r - c)$$

where P_{jt} is the console price, mc_{jt} the console marginal cost, M_t the potential market for consoles, S_{jt} is the average probability consumers purchase console j, IB_{jt-1} is the number of j consoles sold up to and including period $t-1$, S_{dt} is the probability game d, which is produced by the console manufacturer, is purchased by consumers and S_{kt} is the probability consumers purchase game k, a *third party* game. Lastly, IB_{jt} is the installed base of console j and the potential market size for a video game.

The above profit function differs from a standard single product profit function in that there are two additional profit streams. The first term is the usual single product profit. The second and third terms are profits the console maker receives from interacting with game developers and selling its own games. Specifically, the second term is the profit from creating and selling its own games and the third term is the profit it receives from *third party* developers. The resulting first order condition for firm j in period t assuming firms compete in a Bertrand-Nash fashion, is

$$S_{jt}(P, X, \Gamma; \theta^{hw}) + (P_{jt} - MC_{jt} + \Omega_{jt}) \frac{\partial S_{jt}(\cdot)}{\partial P_{jt}} = 0 \tag{4}$$

$$\Omega_{jt} = \sum_{d \in F} s_{dt}(\delta)(p_{dt} - mc_{dt}) + \sum_{k_j \notin F} s_{k_j t}(\delta)(r - c)$$

where Ω_{jt} is the marginal profit a console producer receives from *third party* developers and selling *first party* games when one additional console is sold. The above first order condition can be inverted to solve for console price-cost markups given integrated software markups which then can be used to estimate marginal cost. Assume marginal cost takes the form

$$MC_{hw} = W\tau + \varpi \tag{5}$$

[18] Assumption two is made from an industry expert's inside knowledge.

where W is a $J\times\ H$ matrix of console observed cost side characteristics and ϖ is an unobserved component of marginal cost. Cost side observables are console indicator variables, a console specific time trend, and month of year indicator variables.

4.2.2 The Software Supply Models

In the software market there are two types of video game producers. As I mentioned earlier, there are *first party* games which are produced by console manufacturers and are always technologically tied to the console. The second type of manufacturer is an independent firm which designs, produces and sells games. These games are typically available across multiple consoles. I first begin with describing a console manufacturer's supply model for video games and follow with the independent firms' model. I also make similar assumptions to those presented in the above console supply model for tractability reasons.

Assumption 4: Software firms (independent or integrated) are static decision makers

Assumption 5: Independent developer's marginal cost equals the royalty rates charged by console manufacturer which is set at ten dollars per game plus any additional time varying incremental

Assumption 6: Independent software firms who produce games for multiple consoles are treated as separate entities.

Console Software Supply Model As presented above a console maker $j's$ profit function in time t is

$$\begin{aligned}\Pi_{jt}= {} & (P_{jt}-MC_{jt})M_tS_{jt}(P,X,\Gamma;\theta^{hw}) \\ & + \sum_{d\in F}\underbrace{(IB_{jt-1}+M_tS_{jt}(P,X,\Gamma;\theta^{hw}))}_{\text{Potential Market for game d=IB}_{jt}}s_{dt}(\delta)(p_{dt}-mc_{dt}) \\ & + \sum_{k_j\notin F}\underbrace{(IB_{jt-1}+M_tS_{jt}(P,X,\Gamma;\theta^{hw}))}_{\text{Potential Market for game k=IB}_{jt}}s_{k_jt}(\delta)(r-c)\end{aligned}$$

Yet, instead of maximizing its profit with respect to console price it now does so with respect to each of its produced *first party* video game prices.

The resulting first order condition assuming software firms compete in a Bertrand-Nash fashion is

$$\frac{\partial \Pi_{jt}}{\partial p_{dt}} = \frac{\partial S_{jt}}{\partial p_{dt}} M_t (P_{jt} - MC_{jt}) +$$

$$M_t \frac{\partial S_{jt}}{\partial p_{dt}} \left[\sum_{r \in F} (p_{rt} - mc_{rt}) s_{rt} \right] + (IB_{jt-1} + M_t S_{jt}) \left[\sum_{r \in F} (p_{rt} - mc_{rt}) \frac{\partial s_r}{\partial p_{dt}} + s_{dt} \right] +$$

$$M_t \frac{\partial S_{jt}}{\partial p_{dt}} \sum_{k_j \notin F} s_{k_j t} (r - c) + (IB_{jt-1} + M_t S_{jt}) \left[\sum_{k_j \notin F} (r - c) \frac{\partial s_{k_j}}{\partial p_{dt}} \right] = 0$$

which captures the complementary relationship of hardware and software. For instance, when setting software prices a console manufacturer internalizes the effect a change in the software price has on console demand and its effect on console margin, software margin and royalties. The first order conditions for console hardware and software pricing are therefore interrelated and need to be solved simultaneously.

Independent Software Supply Model An independent software developer's profit function is quite different from the above *first party's*–they only have one stream of profit which is from selling its own produced games. Its profit is a function of the potential market size which is equivalent to the installed base of the console the game is compatible with, the market share of the video game and its price and marginal cost. Independent software firms maximize its profit with respect to price assuming video game developers compete in a Bertrand Nash fashion and set prices simultaneously with integrated software producers and console manufacturers. Its profit function takes the form:

$$\Pi_{ft} = \sum_{k \in F} \underbrace{(IB_{jt-1} + M_t S_{jt}(P, X, \Gamma; \theta^{hw}))}_{\text{Potential Market for game d=IB}_{jt}} s_{kt}(\delta)(p_{kt} - mc_{kt})$$

where the corresponding first order condition is

$$\frac{\partial \Pi_{ft}}{\partial p_{kt}} = M_t \frac{\partial S_{jt}}{\partial p_{kt}} \left[\sum_{k \in F} (p_{kt} - mc_{kt}) s_{kt} \right] + (IB_{jt-1} + M_t S_{jt}) \left[\sum_{r \in F} (p_{rt} - mc_{rt}) \frac{\partial s_r}{\partial p_{kt}} + s_{kt} \right] = 0$$

which differs substantially from that of a traditional independent market via the first term. Given video game demand is a function of console demand, a software firm must internalize the effect software prices have on console demand when maximizing profits.

Because prices and video game market shares are observed and markups are determined from the first order conditions, console marginal costs can be estimated. Assume the functional form for marginal cost follows

$$mc_{sw} = W_{sw} \lambda + \upsilon \tag{6}$$

where W_{sw} is a $J\times\ H$ matrix of software observed cost side characteristics and υ is an unobserved component of marginal cost. Cost side observables are firm and genre dummy variables, and console specific month fixed effects. With the inclusion of the firm fixed effect, I allow for integrated software manufacturers to have a lower marginal cost since they incur no royalty payment where the console specific month dummy variables captures differences in costs across consoles and months.

Now although the above model assumes firm prices are statically set, I certainly recognize that console and software producers may be forward looking and account for the impact period $t's$ price has on future periods. I, nonetheless, show in the estimation section that the above model does an excellent job in predicting console and software markups. [19] Consequently, dynamic demand and supply may not be as significant a factor in predicting prices and markups as previous empirical research leads one to believe. I conjecture that the leading driver of console and software pricing is the complementary relationship and the resulting trade-offs between console and software profits. Given this paper is the first to capture the complementary pricing relationship among consoles and video games, I recommend that future research should explore the affect dynamics plays in predicting console markups while simultaneously estimating hardware and software demand and supply and whether doing so adds any significant improvements in predicting console markups.

5 Estimation

The estimation procedure I use to recover the structural model parameters follows that of Berry, Levinsohn and Pakes (1995), henceforth BLP. I jointly estimate console and video game demand and supply models to further aid in identification in the model parameters. Assuming that the observed data are equilibrium outcomes I estimate the parameters $\theta^{hw} = (\theta_1^{hw}, \theta_2^{hw}, \tau)$ and $\theta^{sw} = (\theta_1^{sw}, \theta_2^{sw}, \lambda)$ with simulated method of moments. There are, however, several issues which arise in estimation.

The estimation of video game demand follows a multinomial logit structure; consumers substitute between video games and can only purchase one video game per period. Yet, it is important to note in order to introduce competition I must also allow consumers to repurchase an already owned title. Software $k_j's$ potential market size is therefore the cumulative sum of console j sales up to and including period t. Consequently, I do not adjust the potential market size downward to account for software previously sold. I make this assumption for the mere fact a logit model of game demand becomes computationally

[19] I am able to make such a statement regarding the prediction power of my model with respect to console markups given there are numerous reports which state console markups are negative at the infancy of the console life cylce and increase over time. Moreover, the estimated markups are in the same magnitude and follow the same trend as Liu (2010) reports with a dynamic console supply model.

infeasible to estimate when a more precise tracking mechanism of the potential market size for each video game is accompanied with the assumption of competition among video games. This is due to the necessity of tracking each individual's video game purchases. Finally, it is important to discuss how I resolve the issue in which monthly software sales for a given console is greater than the number of consumers who own that particular console. Given the issue arises twice for Xbox and Playstation 2 and only in the month of December (2002 and 2003) I assume the potential market size for video games in these months are greater than the number of console owners. I do so by assuming the potential video game market size incorporates consumers who do not own a console but purchase a video game as a gift during these holiday months.[20] I assume the potential market size for video games in these months are 1.25 times the console specific installed base measure.[21] With this assumption I explicitly account for gifting of video games during the holiday period, it would be naive to assume gifting does not occur. In order to do so, however, I must make the assumption consumers who purchase a video game as a gift have the same preferences toward software as the mean consumer who owns a console and is purchasing software for himself.

I am aware of the assumption which allows consumers to repurchase a previously purchased game is particularly strong. And, how such an assumption might biases downward the quality of games over time. To illustrate such bias I present a simple example. Suppose Xbox sells 1 million consoles in the first month of its release and in the next period it sells an additional million units (think of these two months being the first two of its life cycle). Furthermore assume a superstar hit game sells 500k units in month one but only 100k units in period 2. Under the scenario in which the potential market size is precisely tracked for the game, in period 1 demand is 50% but in period two it falls to 6.66%. Yet, when I allow consumers to repeat purchase the demand changes to 50% in period 1 and 5% in period 2. Consequently, I under estimate the quality of games in order to introduce competition (note that the bias associated with imprecisely tracking the potential market size of software declines as game sales decrease). In order to illustrate how prevalent this bias is I determine the number of observations in the software data set which have sales over 500k and 100k units. I find that only 29 and 451 of 36136 observations in the entire software data set have sales over 500k and 100k, respectively. This very small bias therefore only affects a limited number of software title observations. Consequently, I find it quite reasonable to accept this bias in order to introduce what I believe is a vital characteristic of the industry, software competition.[22]

[20] Due to the extreme seasonality of video game sales I also apply the same logic to the month of November.

[21] For robustness I run models which assume the potential market size of gifters is .33 and .5 times the installed base. .25 was choosen since this is the minimum number of holiday gift shoppers which restricts the share of the outside good to be positive.

[22] Futher support of software competition is presented in the Appendix

5.1 The Estimator

There are four sets of moments that I employ in estimation–they are typical macro BLP type moments for hardware and software demand and supply. For expositional reasons I limit my discussion of four sets of moments and lead the reader to BLP (1995) for reference.

After the formation of each of the four sets of moments I formulate the objective function to be minimized, which is $\Lambda' Z A^{-1} Z' \Lambda$, where A^{-1} is the weighting matrix that is a consistent estimate of the inverse of the asymptotic variance-covariance matrix of the moments, $[Z'\Lambda\Lambda' Z]$ and Z are instruments orthogonal to the model error term, Λ. Let $Z^{d,hw}, Z^{s,hw}, Z^{d,sw}, Z^{s,sw}$ be instruments for the BLP and micro moment residuals, respectively. The corresponding sample moments are

$$Z'\Lambda = \begin{bmatrix} \frac{1}{C}\sum_{c=1}^{C} \mathbf{Z}_c^{d,hw} \boldsymbol{\Delta\xi}_c \\ \frac{1}{C}\sum_{c=1}^{C} \mathbf{Z}_c^{s,hw} \boldsymbol{\omega}_c \\ \frac{1}{G}\sum_{g=1}^{G} \mathbf{Z}_g^{d,sw} \psi_g \\ \frac{1}{G}\sum_{g=1}^{G} \mathbf{Z}_g^{s,sw} \upsilon_g \end{bmatrix}. \tag{7}$$

With joint estimation I am able to find more efficient parameter estimates as a result of accounting for any cross equation restrictions on parameters that affect both supply and demand.[23] However, this does come with a computational cost.

5.2 Instruments & Identification

In order to properly estimate a consumer's sensitivity to price for hardware and software I use instrumental variables to correct for there endogeneity. For instance, if prices are positively correlated with quality then the price coefficients will be biased upward. I resolve this correlation through the use of console and game indicator variables. Even with the use of fixed effects the proportion of the unobservable which is not accounted for may still be correlated with price as a result of consumers and producers correctly observing and accounting for the deviation.[24] Under this assumption, market specific markups will be

[23] As in BLP (1995), standard errors are corrected for simulation errors. I assume the population sampling error is negligible given the large sample size of over 78 million households. Simulation error, however, cannot be ignored as a result of the need to simulate the integral which defines console market share S_{jt}. Geweke (1998) shows antithetic acceleration reduces the loss in precision from simulation by an order of 1/N (where N is the number of observation) and thus requires no adjustment to the asmpototic covariance matrix.

[24] See Nevo 2001 for futher explanation.

influenced by the deviation and will bias the estimate of console or software price sensitivity. Berry (1994) and BLP both show that proper instruments for price are variables which shift markups. I deviate from standard BLP type estimates with instruments which proxy for marginal cost. I use a one month lag of the Japanese to US exchange rate and a one month lag of the producer price index for computers as console price instruments. The foreign exchange rate is a suitable instrument given most of the manufacturing of consoles occurred in Japan and would consequently effect retail console price in the US. A one month lag of the exchange rate is employed to allow for the duration between shipping, displaying and purchasing of the console. Lastly, I interact each instrument with console indicator variables to allow each variable to enter the production function of each console differently.[25] Similarly for video games, I use the software producer price index as an instrument for software cost. The producer price index is interacted with a three additional variables to capture cost differences between game age, genre and rating. The three software price instruments are software PPI interacted with video game age and genre, software PPI interacted with video game age and rating and lastly software PPI interacted with video game age, genre, and rating. The implementation of such instruments allows for the capturing of variable software costs among young and old games, across genre and quality.

One might also suppose the software index in addition to console and software price is endogenous. In order to properly identify the parameter associated with the software index I assume the residuals of the structural error terms, $\boldsymbol{\Delta\xi}_{jt}$, are independent of each other. This assumption negates any impact an aggregate demand shock in period $t-1$ has on the software index in period t and hence eliminates the need for instrumental variables. The assumption is quite reasonable given that video game developers commit to the release date for a game well in advance. Moreover, the time it takes a game to come to fruition, from concept to production, is a substantive period ranging from twelve to eighteen months. I consequently treat the software index as an exogenous product characteristic which implicitly implies the number of *first* and *third* party games is also exogenous. The above assumption regarding the strict exogeneity of the software index and correspondingly the number of games allows for the identification of ϕ

There too is a need for supply side instruments. I suspect ϖ and υ to be correlated with $\boldsymbol{\Delta\xi}_{jyt}$ and $\psi_{k_j t}$, respectively, since a console or software with a high unobserved quality might be more expensive to produce. Instruments include cost shifters, W^{hw}, W^{sw} which instrument for themselves, the predicted markup instrumenting for the markup and the predicted market share instrumenting for the market share. With "the predicted markup a function of exogenous demand side characteristics and the associated instruments [I am] effectively instrumenting for markup with demand shifters."[26] (Crawford and Yurukoglu

[25] This method is similar to that of Villas Boas (2007)

[26] See BLP (2004)

(2008))

6 Structural Estimation Results

Parameter estimates from the hardware demand and supply models are presented in Table 3 while the results from the software models are in Table 4. I first begin with discussing the hardware results.

There is significant variation in taste across consumers toward numerous console characteristics. Column two presents the mean parameter $\theta_1^{hw} = \{\overline{\alpha}, \overline{\beta}, \overline{\phi}, \tau\}$ and the remaining columns provides estimates of unobserved and observed consumer heterogeneity about these means $\theta_2^{hw} = \{\Sigma, \Pi\}$. Let me first describe the random demand parameters results and follow with the non random demand estimates. I estimate the mean and standard deviation for console price (Price) and only the standard deviation of consumer taste toward the maximum number of controllers a console is able to be played with. Additionally, I interact the maximum number of controllers with the number of family members within the same household to capture how family size affects console purchase decisions. The mean price parameter is negative and significant at the 95% confidence interval, (-0.0346). Consumers, therefore, have significant marginal disutility to console price, as would be expected. Furthermore, the associated standard deviation in which consumer taste toward price is distributed is positive and significant indicating there is significant unobserved consumer heterogeneity toward console price sensitivity (0.0091). A consumer's taste toward the maximum number of controllers is partially captured by household size (0.1568), but there still remains a significant estimate of the standard deviation (0.9289). These results would indicate that larger households gain more utility for consoles which have a larger number of controllers but the parameter estimate of the observed heterogeneity is insignificant.

Below the random coefficient results in Table 3 are the non-random demand and marginal cost parameters. First, note the magnitude of the seasonal indicator variable is positive and significant capturing the effect the holiday time period has on console demand, which consists of the months of November and December. Second, notice the parameter associated with console age is negative. This negative parameter reflects the fact that consumer perceptions of console quality are decreasing with time and is perhaps due to product obsolescence. To conclude, the cost side estimates are below the demand estimates. A large number of the parameters hold the proper sign and are significantly different from zero. Most notably are the initial cost estimates for Sony and Microsoft are substantially larger than Nintendo's. This result is consistent with industry information.

Table 3: Model Results

Variable						
Utility Parameters	Coefficient	Std. Error	Std. Dev.	Std. Error	Household Size	Std. Error
Price	-0.0346**	0.0071	0.0091**	0.0019		
Controllers			0.9289**	0.4359	0.1568	0.1853
Software Index	0.6921**	0.1726				
Seasonal	1.8454**	0.1646				
Age	-0.0909**	0.0203				
GameCube_2002	-3.4344**	0.1672				
GameCube_2003	-2.9406**	0.4119				
GameCube_2004	-2.4943**	0.6480				
Playstation2_2002	1.8350**	0.4597				
Playstation2_2003	1.4226*	0.8493				
Playstation2_2004	1.9153**	0.9145				
Xbox_2002	-6.0973**	0.2636				
Xbox_2003	-5.9344**	0.4406				
Xbox_2004	-4.7877**	0.6519				
Cost Side Parameters						
Nintendo GameCube	170.9341**	7.5626				
Sony PlayStation2	274.8550**	9.5304				
Microsoft Xbox	223.3440**	13.6175				
Nintendo GameCube*trend	-2.9570**	0.1956				
Sony PlayStation2*trend	-3.9490**	0.2931				
Microsoft Xbox*trend	-3.3891**	0.4980				
GMM Objective Function				48.7285		

Notes: **indicates significant at 95%; *indicates significant at 90%; month of year FE not reported for Cost estimates

I now discuss the results of the software demand and marginal cost estimates. It is important to note that the heterogeneity in software price sensitivity was found to be statistically insignificant and the reported results correspond to a model which sets $\sigma_\alpha^{sw} = 0$. Additionally, to curb any concerns regarding biased estimates of software price sensitivity due to over crowding in the market using a standard logit model, I follow Ackerberg and Rysman (2005) and include the log number of available games in a given market as a regressor to capture the fact that the standard logit error assumption implies unrealistic welfare gains from new products (Petrin 2002). I also included game age as a regressor. The negative and significant estimate captures the decline in popularity or desire to play a particular software title as it movies through its life cycle. I also incorporate indicator variables for Nintendo and Sony's console. These regressors capture any differences in unexplained video game quality across the three consoles. Lastly, from the marginal cost estimates I determine that higher consumer rated games are more expensive to produce while sports games are the least costly genre of games.

Table 4: Software Model Results

Variable		
Software Utility Parameters	Coefficient	Std. Error
Price	-0.0292**	0.0022
log(number of games)	-1.3638**	0.395
Age	-0.1241**	0.0019
GameCube	-0.4062**	0.0205
PlayStation2	0.4077**	0.0285
Cost Side Parameters		
Rating	2.1611**	0.0537
Action	1.0927**	0.2295
Family	1.1950**	0.2281
Fighting	1.0927**	0.2562
Other	3.0567**	0.3581
Racing	0.3519*	0.1999
Shooter	1.8103**	0.2404

Notes: ** indicates significant at 95%; * indicates significant at 90%;
Game FE and Month of year FE not reported in Demand Model
Month of year FE and Firm FE not reported for Cost estimates
Genre costs are relative to the sports genre

6.1 Substitution and Margins

The estimation of a structural model supplies necessary and sufficient information to find consumer substitution patterns, which in part helps determine console and software markups. Table 5 provides own and cross price console semi-elasticities estimates. The model predicts that a permanent ten percent reduction in the price of a console would lead to an approximately 26-28% increase in the total number of consoles sold during the time period. Where as the cross prices elasticities range from approximately 3-19%. As the table indicates, all the diagonal elements are negative and greater than one. The estimates are consistent with oligopolistic behavior in which firms price on the elastic portion of the demand curve. Moreover, the off-diagonal elements are positive and the estimated cross-price elasticity measures are consistent with the beliefs of an industry insider regarding the relative competition among video game consoles.

Table 5: Console Semi-Elasticities

	GameCube	PlayStation 2	Xbox
GameCube	26.8411	-15.9181	-7.2620
PlayStation2	-3.3727	29.7353	-5.9951
Xbox	-4.7238	-19.8020	28.3042

Note: Cell entry i, j, where i indexes row and j column, gives the percent change in total quantity of brand i with a ten percent change in the price of j.

In order to gain further insight into the firm pricing I estimate console marginal cost and recover console margins. Figure 4 depicts the estimated wholesale console margin given an industry standard twenty percent retail margin. It is evident from Figure 4 margins are near zero for all consoles at the infancy of the life cycle and slowly increase over time. Furthermore, the resulting magnitudes and trend of console margins are in-line with public reports.[27]

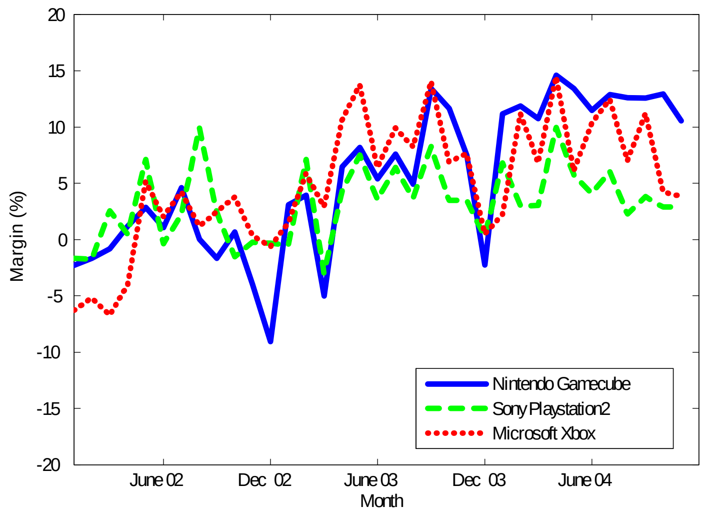

Figure 4: Console Margins

In Figure 5 I present the estimated margins from an alternative model which only estimates console demand and supply and does not allow console producers to internalize the effect of console price on revenues from software–one can view these estimates originating from a standard single product firm. I illustrate these estimates to highlight the importance of jointly estimating console and software supply and demand as well as the imprecision a model which does not allow for the internalization of software profits on console price

[27] See the WSJ article titled " Cost Cutting Pays Off at Sony" 2/5/2010 for reports of margins and cost of Sony's current console. One might expect such the same for generation of console in which this study analyzes.

when recovering console margins. From these figures it is evident the alternative model overestimates console margin by two to three orders of magnitude.

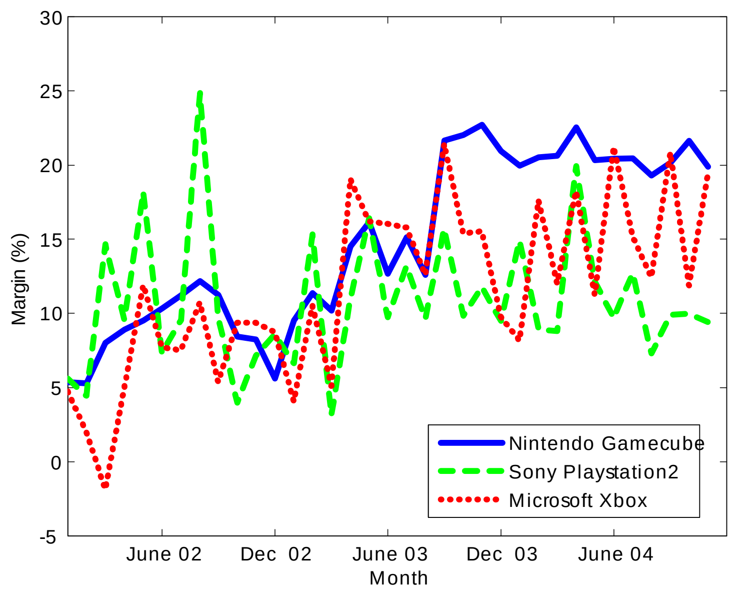

Figure 5: Console Margin–Alternative Model

The estimating the above model also performs quite well in recovering software margins without imposing any additional constraints. For instance, my model predicts an average margin, which includes the standard twenty percent markup for the retail, of 50.65% for new games priced above $49.00 while Patcher and Woo (2006) reports the average margin to be 57%. Ideally, I would be in possession of additional subsegments but unfortunately I am not. Nonetheless, the data from Patcher and Woo provide a nice check for the model results.

7 Counterfactual Simulations

After recovering console and video game demand and supply model primitives I employ these parameter estimates with the implementation of two counterfactual scenarios in order to evaluate the change in the intensity of video game console price competition when a console producer integrates and ties it hardware and software. The first counterfactual analyzes the role integrated games play in determining console prices by eliminating all games created by console manufacturers. Thus, the only games which remain are independent. The second assumes all integrated video games are untied and are compatible with all three consoles–one can view this as an example of forced compatibility.

A priori, the effect of a console producer integrating and tying its hardware and software on console price competition is unclear. There are two important trade-offs. The first is a tying effect. Because a *first party* game is tied to the producing console maker it forecloses rival consoles from this game. In order for a consumer to play a *first party* title he has to first purchase the respective console. The tying of the game increases the console manufacturer's market power which generates an incentive to raise console price. One can also think of the tying effect as increasing differentiation among consoles. The production of a *first party* game and its tie to hardware has an apparent benefit for the producing console because it increases the value of its console relative to the others through the indirect network effect. The added differentiation consequently forces prices higher.

There is also an efficiency effect. Under efficiency-based theory, integration increases price competition among consoles. When a console manufacturer elects to design video games as well as produce consoles its price structure adjusts to reflect its decision. Without integration console prices are discounted by the profit console manufacturers receive from their interactions with developers when an additional consumer purchases a console. A third profit stream is created with integration. Price is further discounted by the profit the console producer receives from designing, producing and selling its own video games when one more console is sold. Integration, therefore, levies added pressure on price or generates an incentive for console manufacturers to lower console price because lower prices lead to an increase in the demand for consoles which consequently generates greater demand for video games, in particular their own video games. Note that the efficiency effect does not include any other synergies that might be a result of a firm being integrated, i.e. economies of scale or learning by doing. Thus, the presented efficiency effect is a lower bound to the actual measure of efficiency. If, however, the smaller measure of efficiency dominates the tying effect in each of the counterfactual experiments then the reported price effects will in fact also be lower bounds to the intensity of competition.

It is important to remind the reader that in the empirical model above and all counterfactual experiments below a consumer's choice of video games and console is static (but with decreasing aggregate demand) and that firms also take a static approach to setting prices of consoles and video games. Moreover, I do not fully account for any changes in software availability or investment in console or software quality. For instance, I do not capture the change in incentives of independent software developers to produce for each console when integrated video games are eliminated. The counterfactual results below consequently capture only partial effects.

Elimination of *First Party* Games:

The results of counterfactual simulations are presented in Table 6 and Table 9. The results of counterfactual one indicate the efficiency effect dominates the tying effect leading to an increase in console price competition when a console manufacturer integrates and ties its software to its hardware. Moreover, *first party* games benefit Microsoft and Nintendo more than Sony. The first counterfactual predicts a mean increase of 3.3789 percent in the price effect (change in console price) for GameCube while Microsoft's Xbox mean change in price is an increase of 1.4034 percent and 0.5945 percent for Sony. The increase in console price for all three consoles lead to decreases in the total number of consoles for the observed time period. Nintendo's console the GameCube and Microsoft's Xbox where the most impacted from the elimination of first party games. There respected quantities decreased by 19.6% and 4.46% while Sony's PlayStation 2 roughly remained constant (decreasing by only .2052%). An explanation as to why the price effect is greater for Microsoft and Nintendo than for Sony is a result of these two console makers producing "hit" *first party* games. To illustrate this fact Table 7 shows the ten leading titles on each platform for the given time period, nine of which are *first party* titles for Nintendo and four for Microsoft.

Table 6: Counterfactual Results

		Counterfactual
Mean % Change in Consoles Price $\frac{(p_{new}-p)}{p}$	GameCube	3.3789%
	PlayStation 2	0.5945%
	Xbox	1.4034%
% Change in Consoles Sold (Jan02-Nov04)	GameCube	-19.6012%
	PlayStation 2	-0.2052%
	Xbox	-4.4665%
	Outside	4.91%
% Change in Game Profits (Jan02-Nov04)	GameCube	-69.1582%
	PlayStation 2	-30.2545%
	Xbox	-48.8439%
% Change in Console Profits (Jan02-Nov04)	GameCube	0.3526%
	PlayStation 2	3.5176%
	Xbox	3.6407%

When these top selling *first party* games in addition to all other *first party* titles are eliminated a console maker's market power deceases because the remaining games are available on multiple consoles.[28] Moreover, the attractiveness of the console decreases because the indirect network effect is smaller. This drives price lower. Yet, the elimination of all *first party* games also creates an incentive to increase console prices though the reduction of additional profit console makers receive from developers when one more console is sold. The firm's profit function is now only a function of its interactions with *third party* developers. Its important to note that by eliminating integrated games the market shares of the remaining independent games change and thus impacts the expected profit a firm receives from *third party* games. Fortunately, for the console, this offsets some of the lost profits it experiences when *first party* games are eliminated. But, this effect is only present due to

[28] There will remain some exclusive *third party* games available on each console resulting in the retention of some console market power through foreclosure.

the inclusion of video game competition. If competition was excluded then there would be no substitution effect resulting in an over estimate of the efficiency effect. I determine the efficiency effect is a significantly more important driver of price than the tying effect. Thus, prices rise and rise more for Nintendo and Microsoft.

Table 7: Top 10 Video Game Titles

Console	Title	Publisher	Quantity
GameCube	MARIO KART: DOUBLE	NINTENDO	1,731,903
	SUPER SMASH BROTHER MELEE	NINTENDO	1,028,343
	ANIMAL CROSSING	NINTENDO	799,842
	MARIO PARTY 5	NINTENDO	774,623
	SOUL CALIBUR II	NAMCO	718,395
	LUIGI'S MANSION	NINTENDO	702,401
	POKEMON COLOSSEUM	NINTENDO	698,449
	SUPER MARIO SUNSHINE	NINTENDO	600,091
	ZELDA: THE WIND WAKER	NINTENDO	547,067
	METROID PRIME	NINTENDO	499,929
PlayStation 2	GRAND THEFT AUTO:VICE CITY	TAKE 2 INTERACTIVE	6,315,099
	GRAND THEFT AUTO 3	TAKE 2 INTERACTIVE	5,194,262
	GRAND THEFT: ANDREAS	TAKE 2 INTERACTIVE	3,590,284
	MADDEN NFL 2004	ELECTRONIC ARTS	3,419,157
	GRAN TURISMO 3:A-SPEC	SONY	2,781,235
	MADDEN NFL 2003	ELECTRONIC ARTS	2,727,112
	FINAL FANTASY X	SQUARE ENIX USA	2,192,461
	MEDAL HONOR FRONTLINE	ELECTRONIC ARTS	2,185,916
	KINGDOM HEARTS	SQUARE ENIX USA	2,120,314
	NEED FOR SPEED: UNDERGROUND	ELECTRONIC ARTS	2,111,249
Xbox	HALO	MICROSOFT	3,789,232
	HALO 2	MICROSOFT	1,777,697
	HALO 2 LIMITED ED	MICROSOFT	1,489,406
	T.CLANCY'S SPLINTER	UBISOFT	1,483,843
	GRAND THEFT AUTO PACK	TAKE 2 INTERACTIVE	1,200,618
	PROJECT GOTHAM RACING	MICROSOFT	1,188,976
	T.CLANCYS GHOST RECON	UBISOFT	965,620
	ESPN NFL 2K5	TAKE 2 INTERACTIVE	938,203
	DEAD OR ALIVE 3	TECMO	885,781
	STAR WARS: KNIGHTS	LUCASARTS	881,740

In addition to illustrating that Nintendo and Microsoft are quite reliable on their production of "hit" *first party* games through a list of top ten video games, I also show the benefit each game brings to its respective console. In Table 8 I provide console elasticities from losing the console's top selling *first party* video game. The elasticities show the change in console share in the first month in which the "hit" game was released. I also show how consoles benefit when a competing console loses a "hit" title. The table depicts the sizable impact such a loss has on GameCube's and Xbox's console shares.

Table 8: Console-Game Elasticities From Losing the Top First Party Game

	Mario Kart Double Dash	Grand Theft Auto 3	Halo
GameCube	-4.9333	0.0545	0.2330
PlayStation2	0.4147	-0.5508	0.3278
Xbox	0.5600	0.1252	-3.8316

Note: Cell entry i, j, where i indexes row and j column, provides the percent change in market share of brand i upon losing the top first party selling game in the first month of its release. Titles are Nintendo's Super Smash Brother, Sony's Gran Turismo 3 and Microsoft's Halo

After establishing that the efficiency effect is the dominant factor I analyze console manufacturer profits. I find that total profits decrease. Intuitively, video game profits decline substantially. When console makers technologically tie software to hardware it drives console prices lower which in turn raises console sales and increases video game demand. Console makers therefore use technological tying in order to drive sales of video games, in particular their own *first party* games, where the greatest proportion of industry profits are made.[29]

In summary, the efficiency effect is the dominate factor affecting the intensity of console price competition. Prices of consoles with a larger degree of concentration in integrated games rise more than consoles with less when integration is prohibited.

Forced Compatibility:

In order to mitigate concerns that in the above counterfactual it is unrealistic to assume *first party* games are no longer produced I implement a second counterfactual simulation which forces all produced *first party* video games to be compatible with each and every console.

The second counterfactual differs substantially from the above scenario due to a significant change in the console manufacturers profit function. Unlike the above counterfactual which eliminated profits from *first party* games this scenario does not. The console manufacturer instead remains able to sell its games but incurs an additional cost associated with forced compatibility. The platform's games are no longer tied to its console; it has to pay a royalty fee for each game sold on a competitor's console thus reducing its markup for its game sold on competing consoles. A platform now must balance three incentives: an incentive to change price due to i) a change in the software ii) software profits changing to reflect an increase in video game competition and additional compatible titles on board its console, and iii) profits from selling its first party games on other competing consoles. The profit function of the manufacturer of console j is:

[29]See Cournot (1838)

$$
\begin{aligned}
\Pi_{jt} = & (P_{jt} - MC_{jt}) M_t S_{jt}(P, X, \Gamma; \theta^{hw}) \\
& + \sum_{d \in F} (\underbrace{IB_{jt-1} + M_t S_{jt}(P, X, \Gamma; \theta^{hw})}_{\text{Potential Market for game d=IB}_{jt}}) s_{dt}(\delta)(p_{dt} - mc_{dt}) \\
& + \sum_{k_j \notin F} (\underbrace{IB_{jt-1} + M_t S_{jt}(P, X, \Gamma; \theta^{hw})}_{\text{Potential Market for game k=IB}_{jt}}) s_{k_j t}(\delta)(r - c) \\
& + \sum_{c \neq j} \sum_{d \in F} (\underbrace{IB_{ct-1} + M_t S_{ct}(P, X, \widehat{\Gamma}; \theta^{hw})}_{\text{Potential Market for game d=IB}_{jt}}) \widehat{s}_{d_c t}(\delta)(p_{d_c t} - mc_{d_c t} - r)
\end{aligned}
$$

where the fourth line corresponds to the profit associated with selling its *first party* games on rival consoles. Likewise, the consoles' first order conditions incorporate an additional term Ψ, which captures this profit.

$$
S_{jt}(P, X, \Gamma; \theta^{hw}) + (P_{jt} - MC_{jt} + \Omega_{jt}) \frac{\partial S_{jt}(\cdot)}{\partial P_{jt}} + \Psi_{jt} = 0 \tag{8}
$$

$$
\Omega_{jt} = \sum_{d \in F} s_{dt}(\delta)(p_{dt} - mc_{dt}) + \sum_{k_j \notin F} s_{k_j t}(\delta)(r - c)
$$

$$
\Psi_{jt} = \sum_{c \neq j} \sum_{d} \frac{\partial S_{ct}(\cdot)}{\partial P_{jt}} \widehat{S}_{d_c t}(\delta)(p_{d_c t} - mc_{d_c t} - r) \tag{9}
$$

When console manufacturers are forced to untie there software it introduces another strategic variable, the price of a untied video game on a competing console. To remain consistent with the above estimation methodology I assume console manufactures do not fully internalize the effect software price of untied games has on software profits of games compatible with alternative consoles (e.g. price of a Sony produced game which is untied and compatible with the Xbox does not impact sales of games on alternative consoles such as the PS2 or GameCube). The first order condition for an untied game released on a competitor's console is as follows:

$$
\begin{aligned}
\frac{\partial \Pi_{jt}}{\partial p_{d_c t}} = & \frac{\partial S_{jt}}{\partial p_{d_c t}} M_t (P_{jt} - MC_{jt}) + \\
& M_t \frac{\partial S_{jt}}{\partial p_{d_c t}} \left[\sum_{r_c \in F} (p_{r_c t} - mc_{r_c t}) s_{r_c t} \right] + (IB_{jt-1} + M_t S_{jt}) \left[\sum_{r_c \in F} (p_{r_c t} - mc_{r_c t}) \frac{\partial s_{r_c}}{\partial p_{d_c t}} + s_{d_c t} \right] = 0
\end{aligned}
$$

Similarly,the first order condition for an untied game released on its producer's console is identical to first order condition present above in the console software supply model section.

Table 9 reports the results. What is evident is that the price effect for all three consoles are that they remain positive but smaller in magnitude than counterfactual one, indicating console prices increase when games are untied. The intuition for such a result is a bit more intricate and complex than the above analysis. Lets first discuss the incentives for Nintendo. In Nintendo's case the software profits from games compatible with its console when an additional GameCube is sold decreased due to more competition in the video game market from the other consoles' high quality *first party* games being compatible with its console creating a smaller incentive to decrease console price. Likewise, the ability for Nintendo to sell its high quality games on competing consoles creates an additional incentive to increase its console price in order to drive to sale to its competitors' consoles and recover extensive profits from its high quality games sold on these consoles. These incentives consequently dominate the incentive to decrease price as a result of its software index decreasing, which is due to a decline in mean software utility from more congestion. For Sony, its incentives to increase price are quite different than those of Nintendo's given that it has very few high quality *first party* titles. Consequently, its incentive to increase console price to drive sales to its competitors and recover software profits from its games is quite small. Sony, nonetheless, has incentives to increase price. They originate from the fact that Microsoft's and Nintendo's high quality video games are now available on its console creating a larger software index even in the face of increased congestion. This leads to greater demand for Sony's PlayStation2. Moreover, since Sony produced very few high quality video games the introduction of competing games had limited impact on software profits when an additional console is sold. Lastly, Microsoft's incentives to increase console price fall in between Nintendo's and Sony's. Like Nintendo, Microsoft produce a large number of high quality video games and consequently has an incentive to increase price of its console in order to drive sales in particular to Sony's console and extract profits from Sony's large base of consumers. Like Nintendo, Microsoft's incentive to decrease the price of its console in order to increase sales of its first party games declined due to the introduction of Nintendo's superior games. However, Microsoft also benefits from having Nintendo's games compatible with its console which leads to a greater software index and demand for its console.

I now move my attention to the change in hardware quantity. Given the above intuition as to why console prices react the way they do when technological tying is banned, it should not be a surprise to see the number of GameCube consoles sold decrease by 10% while Microsoft's and Sony's demand increases. It is important to note that the decline in Nintendo's sales is not a result of consumers switching to the outside option (since its change in quantity is roughly unchanged) but to Sony and Microsoft produced consoles. One of the consequences of the banning technological tying is increased market concentration. Now although the results do not predict the complete foreclosure of Nintendo from the console market the results do illustrate a partial foreclosure of Nintendo (higher console prices, smaller console sales and profits). Consequently, technological tying increases console price competition.

Table 9: Counterfactual Three Results

		Counterfactual
Mean % Change in Consoles Price $\frac{(p_{new}-p)}{p}$	GameCube	1.3191%
	PlayStation 2	0.6545%
	Xbox	0.4966%
% Change in Consoles Sold (Jan02-Nov04)	GameCube	-9.9572%
	PlayStation 2	2.9138%
	Xbox	2.1568%
	Outside	0.1713%
% Change in Game Profits (Jan02-Nov04)	GameCube	90.5074%
	PlayStation 2	16.4715%
	Xbox	44.4464%
% Change in Console Profits (Jan02-Nov04)	GameCube	-1.0553%
	PlayStation 2	4.1278%
	Xbox	5.9102%

With the use of two counterfactual scenarios I determine the intensity of console price competition increases when integrated firms tie their hardware and software. Moreover, I conclude that prices of consoles with a larger degree of concentration in integrated games rise more than consoles with less concentration. High quality integrated games are thus a leading factor as to why price competition intensifies. With the existence of high quality *first party* games, firms are willing to forego the incentive to raise console prices in order to increase the demand for consoles and their own *first party* video games, where the greatest proportion of industry profits are made.

8 Conclusion

In order to understand the impact tying of complementary products, by an integrated firm, has on console price competition the above analysis extends the literature by constructing a model which allows consumer demand for video game consoles to depend upon the set of available video games rather than only the number of games. The estimation technique differs from prior research by incorporating video game differentiation and software competition into the demand for consoles as well as jointly estimating console and software demand and supply in order to recover more precise model parameters.

In this paper I empirically quantify the change in the intensity of console price competition when a console producer integrates and ties its hardware and software. From two counterfactual experiments I conclude the tying of complementary products by integrated firms intensifies console price competition from the fact that console manufacturers are willing to forego the incentive to raise console prices in order to increase the demand for their console and in particular their own integrated video games, where the largest proportion of industry profits are made. Although I cannot generalize these results to other similar type industries, such as the DVD/DVD player market, because the question is empirical; my paper does provide the necessary framework for product managers to study the competitive price effects of an integrated firm tying its complementary products as well as provide them with the methodology to analyze the impact complementary products have on consumer adoption of an associated platform.

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Appendix A-Console Market Size

The determination of a potential market size for consoles is an important step in properly estimating console demand. One useful measure which is often used is the number of households with a TV in 2000[30], since the introduction of the Sony Playstation 2 occurred in 2000. Yet, I use an approach from Bass (1969) that illustrates how to infer the initial potential market size of a product from its sales data. "An approximation to the discrete-time version of the model implies an estimation equation in which current sales are related linearly to cumulative sales and (cumulative sales)^2" (Nair 2004). Let k_t and K_t denote the aggregate sales of all consoles in month t and cumulative sales up to and including month t respectively. Let the below equation be the regression I estimate:

$$k_t = a + bK_t + cK_t^2 + v_t.$$

Given the estimates, the Bass model implies the initial potential market size for all consoles is $\bar{M} = \frac{a}{f}$, where f is the positive root of the equation $f^2 + fb + ac = 0$ and a is from the regression above. The predicted initial market size is 78,354,700 households with the potential market in period t as $M_t = \bar{M} - \textit{cumulative console sales till month } t$[31].

9 Appendix B-Software Competition

In the model above one of the main assumptions I implement is in regard to software competition. I make the assumption that video games do compete with one another rather than assume games are monopolists like the previous works of Nair (2007) and Lee (2010a,b). In order to validate this assumption I present the results of two tests below. The first determines whether cross price effects are present with the implementation of a nested logit model while the second, tests if falling prices are a consequence of competitive conditions with a simple price regression.

In determining whether there are cross price effects among software titles I implement a nested logit model for software demand. However, under such model there are several concerns. One concern is that cross-price substitution might be under estimated if game developers strategically release video games as to minimize the cannibalization of similar games currently in the market. I follow a similar specification to that of Einav (2006) and Nair (2007) which tries to account for this endogeneity. This model is a nested logit model with nests corresponding the video game genre and the inclusion of a covariate which

[30] See Lee (2010a) and Lee (2010b)

[31] The construction of the potential market size reflects the idea that a consumer is a first time buyer and does not re-enter the market to purchase additional goods. Consequently, I do not account for multihoming consumers.

captures video game age. The video game demand specification is:

$$\ln(s_{k_jt}/s_{0_jt}) = \alpha_j + \lambda(t - r_{k_j}) + \beta p_{k_jt} + \sigma \ln(s_{k_jt|g}) + \eta \ln(Num_t^{SW}) + \psi_{k_jt}$$

where t indexes month, r_{k_j} is the release date of game k_j, p_{k_jt} is the price, s_{k_jt} is the market share, s_{0_jt} is the outside good's share, $s_{k_jt|g}$ is the within genre share of game k_j in period t and $\ln(\text{Num}^{SW})$ is the log of the total number of available games on platform j. Moreover, the parameter σ captures the degree of correlation of utilities among games in a given genre. A small σ near zero infers little correlation among genre games while a larger value indicates larger cross-price effects. Thus, a test of competition among software titles would be to determine if σ is statistically different from zero. Nonetheless, to properly test whether σ is statistically different from zero we need to account for the endogeneity of price, release timing and within genre share. To correct for software price I employ the same price instruments as the main model. The endogeneity of release time is addressed with the inclusion of software fixed effects. "With the inclusion of such all variation in demand arising from aspects of game-quality is controlled for." (Nair 2007) Lastly, the number of video games in a given genre in a given period instruments for within genre share. The results of several models are presented below including OLS and 2SLS with and with out including instruments for price. I additionally include specifications with quadratic and cubic software age covariates. From the results it is clearly evident that video games compete against one another and are not monopolists.

Table 10: Competitive Software Tests

	OLS						2SLS w/ Instruments for price & within share					
	Coeff	Std Err.	Coeff	Std Err.	Coeff	Std Err.	Coeff	Std Err.	Coeff	Std Err.	Coeff	Std Err.
Price	-0.0033	0.0003	-0.0059	0.0003	-0.0073	0.0004	-0.0118	0.0024	-0.0406	0.0052	-0.0446	0.0046
σ	0.8461	0.0024	0.8384	0.0025	0.8345	0.0025	0.4295	0.0180	0.5476	0.0168	0.5392	0.0165
Age	-0.0363	0.0007	-0.0506	0.0012	-0.0669	0.0019	-0.0777	0.0022	-0.1408	0.0075	-0.2045	0.0108
Age^2			0.0003	2.155e-05	0.0012	8.841e-05			0.0014	0.0001	0.0053	0.0003
Age^3					-1.503e-05	1.364e-06					-6.168e-05	4.714e-06

If the results from the first test are not conclusive enough I present a second test to illustrate that software video game prices largely decline to do increased video game competition. For this test I pool all game data across each console and regress software price on age, game fixed effects and the interaction of age and console specific month fixed effects. I hence measure the rate at which prices fall after controlling for game quality via game fixed effects. Negative and statistically significant estimates of the interaction terms therefore indicate that prices fall due to the competitive interaction of software titles. In addition to this test I also employ a regression which implements the change in software prices each period as the dependent variable–positive and significant estimates of the interaction terms will indicate competition impacts the rate of decline in software prices. The table below presents these results but only report the coefficients of the interaction term for the first twelve months for space concerns.

Table 11: Competitive Software Test 2

Dependent variable:					
Price	GameCube		PlayStation 2		Xbox
	Coeff	Std Err.	Coeff	Std Err.	Coeff
Age*Jan 02	-5.4529	1.0222	-1.6653	0.0547	-3.083
Age*Feb 02	-3.6220	0.5786	-1.4666	0.0501	-1.653
Age*Mar 02	-3.1827	0.4097	-1.4273	0.0464	-1.451
Age*Apr 02	-3.5630	0.3034	-1.5153	0.0428	-1.827
Age*May 02	-3.5875	0.2373	-1.4950	0.0398	-2.291
Age*Jun 02	-2.6575	0.1911	-1.1600	0.0371	-1.746
Age*Jul 02	-2.1446	0.1594	-1.0911	0.0347	-1.615
Age*Aug 02	-1.9688	0.1351	-1.1288	0.0326	-1.540
Age*Sep 02	-1.6433	0.1166	-1.0795	0.0308	-1.447
Age*Oct 02	-1.5569	0.1025	-0.9048	0.0292	-1.641
Age*Nov 02	-1.5079	0.0904	-0.8429	0.0277	-1.411
Age*Dec 02	-1.2210	0.0805	-0.6623	0.0264	-1.132

Not all console specific month effects reported. All models include video game FE and age regressor

Table 12: Competitive Software Test 3

Dependent variable:						
Price(t)-Price(t-1)	GameCube		PlayStation 2		Xbox	
	Coeff	Std Err.	Coeff	Std Err.	Coeff	Std Err.
Jan 02	18.2743	1.6538	6.3078	0.6974	12.9534	1.3020
Feb 02	18.3980	1.4124	7.0973	0.6753	10.7646	1.1809
Mar 02	5.90143	1.3544	2.1637	0.6701	4.52948	1.1329
Apr 02	4.82065	1.3163	3.4901	0.6621	3.38067	1.0913
May 02	12.3789	1.2299	8.2340	0.6449	7.36131	1.0491
Jun 02	7.09365	1.2017	3.6686	0.6423	5.75972	1.0174
Jul 02	10.2785	1.1298	4.0700	0.6338	8.12465	0.9548
Aug 02	15.9875	0.9978	7.5615	0.6095	9.79995	0.8742
Sep 02	13.1178	0.9029	6.5795	0.5946	6.44177	0.8174
Oct 02	13.6205	0.8121	6.7212	0.5748	9.78922	0.7537
Nov 02	6.75487	0.7837	4.8303	0.5726	4.60650	0.7376
Dec 02	2.52066	0.7755	3.3785	0.5693	2.10120	0.7322

10 Appendix C-Test of Dynamic Demand for Hardware

In the Table below I present four OLS console logit models to alleviate any concerns readers might have over their beliefs that there is a disconnect between the software and hardware model given the assumption that consumers remain in the video game market after purchasing a console but only make a console purchase decision from the current periods software index. The models below illustrate such concerns are unnecessary. The results of a logit demand models assumes consumers have perfect foresight of next period's prices and video game availability and is accomplished by simply including such measures as additional covariates in the consumer's utility function. If consumers are forward looking, in at least one period ahead, there should be a positive and significant coefficient associated with the t+1 period's software index and/or price. Yet, what I find are insignificant parameter estimates. The above model, therefore, performs quite well in capturing the main drivers of a consumer's console purchase and does not exhibit a disconnect between software and hardware purchase decisions.

Table 13: Model Results- Without Supply

	Model 1		Model 2		Model 3		Model 4	
Utility Parameters	Coefficient	Std.Error	Coefficient	Std.Error	Coefficient	Std.Error	Coefficient	Std.Error
Price	-0.0043**	0.0011	-0.0043**	0.0011	-0.0057**	0.0019	-0.0057**	0.0019
Price$_{t+1}$					0.0019	0.0020	0.0019	0.0021
Software Index	0.4276**	0.0728	0.4209**	0.0794	0.4264**	0.0729	0.4189**	0.0795
Software Index$_{t+1}$			-0.0003	0.0013			-0.0003	0.0013

Notes: ** indicates significant at 95%; * indicates significant at 90%; All models include a seasonal FEs, console specific year FEs and age covariate