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

Timothy Derdenger*
Tepper School of Business
Carnegie Mellon University

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Abstract

Using data from the 128 bit video game industry this paper evaluates the incentives for hardware firms to technologically tie their produced software to their own hardware as well as analyze the impact such an action has on the intensity of console price competition. Tying occurs when a console hardware manufacturer produces software which is incompatible with rival hardware. There are two important trade-offs an integrated firm faces when implementing a technological tie. The first is an effect that increases console market power and forces prices higher. The second, an effect due to the integration of the firm, drives prices lower. A counterfactual exercise determines technological tying of hardware and software increases console price competition and is due to console makers subsidizing consumer hardware purchases in order to increase video games sales, in particular their tied games, where the greatest proportion of industry profits are made. Moreover, I determine technological tying to be a dominant strategy for hardware manufacturers when software development costs are low.

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

Technological tying is when a firm designs or integrates a product so that it only functions with the use of a complementary product also manufactured by the same firm. For instance, such an action is quite prevalent in hardware and software markets where a hardware manufacturer integrates into the software market and ties software to its own hardware. Technological tying is often seen as a way for a hardware manufacturer to eliminate or reduce the probability of a being foreclosed by a software firm who integrates into the hardware market (Church and Gandal 1990) or for a hardware firm to foreclose its rival by degrading its rivals hardware quality by reducing the number of complementary products compatible with its hardware. In doing so, the tying firm subsequently increases its market share by either completely or partially foreclosing its rival from the hardware market (Whinston 1990 and Carlton and Waldman 2002).

My interest in technological tying stems from Nintendo's initial use of exclusive contracts with video game developers during the mid to late 1980's. These contracts forced independent video game developers into exclusive contracts for the first two years of a game's release. Accordingly, a consumer who wished to play any new independent game under such an exclusive contract was required to also purchase or own a Nintendo console resulting in increased market power for Nintendo and the possible foreclosure of Atari, a competing console. Exclusive contracts were one tool in Nintendo's marketing strategy to degrade Atari's console quality and over take the firm as market leader, which was later deemed anticompetitive by the United States government. A second tool was its integration into the software market. By entering the video game market and technologically tying its integrated games it was able to mimic the effect of exclusive contracts on consumer demand for consoles. In this respect technological tying and exclusive contracts were perfect substitutes for Nintendo, yet no government's concerns were raised regarding Nintendo's tying. Which raises the question of what were the effects of Nintendo's technological tying strategy on console price competition and consumer welfare in addition to the incentives for implementing such a marketing strategy. Were they similar to what exclusive contracts would create?

In this paper I attempt to further understand the effects of and a firm's incentive for technological tying. I do so using data from the 128-bit video game industry, which consists of Nintendo GameCube, Sony PlayStation 2 and Microsoft Xbox. Moreover, I also contribute to the marketing 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*[1] , ii) determine the marginal impact an individual game has on console demand and iii) jointly estimate demand and supply for complementary

[1] 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

products.

There are several economic forces that impact the intensity of console price competition when a console manufacturer technologically ties its software to its hardware. In equilibrium, the impact on competition depends upon the relative size of the marginal revenue from games under each regime, a royalty rate or the retail price of the game. If the relative magnitude between these two measures is large then console prices fall. In which case, a rival console manufacturer finds it optimal to compete more fiercely with the tying console maker to retain market share by lowering its price in response to having one less video game. The tying console maker all the while lowers its price from the fact that its marginal revenue from games under technological tying is substantially larger than when software is independent. The tying console thus finds its profitable to lower the price of its console in order to drive sales of its console and in particular its technologically tied game.

When the relative magnitude between the associated marginal revenue of games under the two regimes is small console price competition decreases resulting in higher prices. For the tying console, this is caused by a relatively smaller trade off between console and software profits between the two regimes, which leads to a less intense incentive to lower console price to drive video game sales. Consequently, the incentive to raise console price from having an additional video game dominates. The intuition for why console price increases for the rival is quite different. With a relatively small software valuation the impact on demand from losing a video game to its rival console is not as large as if the software value was high. Consequently, the non-tying console firm does not have to compete as intensely in price to retain market share. Yet, the loss of software profits and the inability to internalize the effect console price has on software profits leads to a higher price.

The economic forces at play can be summarized into three main forces. 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 generates an incentive for the hardware maker to raise its console price from the relative increase in utility given a rival console has one less available game. The second, where software can be thought of as the input or upstream supplier to the production of the downstream hardware (Salop 2005) can produce efficiency effects associated with the pricing of complementary products and create an incentive to decrease console price (Cournot 1838). 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 an additional profit stream which leads to further discounting of the console price by the profit the console producer receives from designing, producing and selling its own video games when one more console is sold. Integration, thus, generates an incentive for a console manufacturer to lower its console price, because a lower price leads to an increase in the demand for its console, which creates greater demand for video games, in particular the console manufacturer's own high margin video games. Or put differently, with integration a console hardware firm can internalize the externality associated with its console price on software profits and vice versa. And lastly, the competitive response of its rival indirectly affects a tying console's incentive to lower or raise its console price.

Given that there is not a 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) as is suggested by Franses (2005) and Bronnenberg, Rossi and Vilcassim (2005). With the use of these simulation 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 its console price in order to increase the demand for its console and in particular their own integrated and tied video games, where the largest proportion of industry profits are made. Moreover, I show the presented static model performs quite well in predicting console and software markups and generating reasonable elasticity estimates.[2] Consequently, 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 rather than dynamics. Given this paper is the first to empirically capture the pricing relationship among complements, consoles and video games, future research should explore the affect of dynamics in predicting markups while simultaneously estimating demand and supply for complementary products and whether doing so adds any significant improvements to model fit.

Lastly, I determine when hardware firms strategically decide to technologically tie software to hardware their actions consist of a dominant strategy Nash equilibrium when software development costs are low, which is quite similar to the classic decision of make versus buy (Williamson, 1971; Coase, 1937). Furthermore, such an action is a dominant strategy since tying allows each hardware firm to recover larger software profits. By tying software and hardware the hardware firm receives the difference between the integrated software price and marginal cost rather than a small royalty rate which it would have received if the game was unintegrated.

The structure of this paper is as follows. First, I review the related literature and follow with an overview of the 128-bit video game industry. Next I present a simple theoretical model of technological tying to explain the effects on console price competition. Sections 5 and 6 present the structural empirical model and data while section 7 and 8 discuss the

[2] 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 cycle and increase over time. One such report is Liu (2009). Moreover, the estimated elasticity estimates are in line with Lee's (2010) results which employs a dynamic demand model.

estimation technique and model results, respectively. Section 9 presents 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 are similarities to tying and raising rival's cost. In addition to these lines of literature this study also builds on other streams related to network externalities, multiproduct pricing and two-sided markets. 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 network effects as a function of the number of users who are in the same "network" (Katz and Shapiro (1985)) and has abstracted away from the fact that quality or differentiation may also play an important role in the formation of the network effect.[3] I build upon the innovative research of Nair, Chintagunta and Dubé (2004); Dubé , Hitsch and Chingtagunta (2007) and Liu (2009), by creating a structural demand model for video game consoles which includes video game quality and variety in the formation of the network effect. In doing so I am able to recover the impact a specific title has on console demand. For instance, the elimination of Microsoft's Halo decreases the market share of Xbox by 4.6290% while increasing Sony's PlayStation 2 by 0.4335% in the first month of Halo's release. Additionally, the two-sided market literature has integrated network effects with complementary pricing to study many relevant applied questions such as optimal pricing structure (Rochet and Tirole (2003) & Armstong (2006)) or the effects of mixed bundling or tying on pricing (Chao and Derdenger (2010) & Choi (2010)).

Other related literature is from Corts and Lederman (2007) and Hu and Preiger (2008) who study exclusive contracting in the video game industry and Nurski and Verboven (2011) who study exclusive dealings as barriers to entry in the Belgium auto market. Corts and Lederman, in particular, focus on software exclusivity in the home video game industry and determine the "increasing prevalence of non-exclusive software gives rise to indirect network effects that exist between users of competing and incompatible hardware platforms." The authors determine the strong prevalence of non-exclusive games and its associated network effects is a leading driver as to why the industry is dominated by three competing consoles rather than one monopolist. Hu and Preiger (2008) also look at exclusivity of software titles. Their interest, however, is in whether such titles create a barrier to entry. The authors determine that such exclusive vertical contracting "in platform markets need not lead to a

[3] 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) .

market structure dominated by one system protected by a hedge of complementary software."

Lastly, the surrounding literature on the topic of technological tying mostly encompasses theoretical works. It is my belief that I am the first to empirically analyze the competitive price effects and the incentives associated with technological tying.

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[4] 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 onetime fee for a software developers kit (SDK).[5,6] The price of the SDK is quite small–for the current PS3 the price is $10,250 per developer. I, thus, ignore this profit stream in the model below.[7] No other transfers occur between software developers and console makers in practice. Figure 1 presents an illustration of the discussed market structure.

[4] 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

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

[6] The price of the software developers kit is a onetime 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.

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

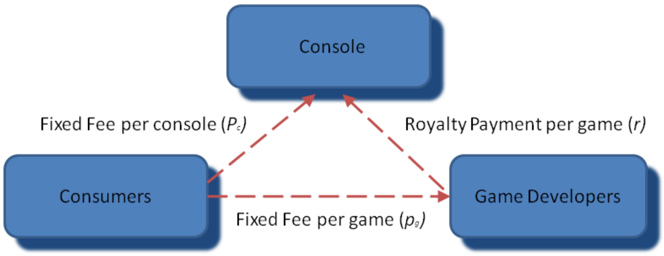

Figure 1: Video Game Market Structure

The above figure describes a much 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 manufacturer's in house design studio. The second type of video game is 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. 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 too many video game developers to produce too many low quality games. Accounting for differentiated video games 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 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, above all 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).

4 Effects of Technological Tying

In this section I present a simple theoretical model to illustrate the effects of technological tying on console price competition and to motivate the need for implementing an empirical model. In order to do so, I first determine prices under a regime in which technological tying is forbidden and follow with the analysis when technological tying occurs.

There are three classes of players in the model: two types of agents and two platforms. The agents are consumers and one content developer. We assume interactions among all three classes of players exist and are illustrated by Figure 1 above.

There are two platforms which are located at the two extreme points of a horizontal line with length one. For simplicity, we assume that each platform's marginal cost of production is constant and equal to mc. The platforms interact with both agents by charging a fixed fee P_c $c = A, B$ to consumers for the access to its respective platform and levying a per unit royalty rate r_c to the independent content developer for the right to produce and sell content compatible with the platform. However, since I lake empirical data on console royalty rates and therefore cannot incorporate the endogeneity of the royalty fee into my empirical model I make the assumption that the fee is not a strategic variable for each platform. Lastly, consumers and content developers interact with consumers purchasing content from developers at their corresponding prices.

I implement a standard Hotelling model to analyze the consumers' console decisions. I assume consumers are distributed uniformly along a unit interval and have linear transportation costs t to purchase a console. The gross utilities a consumer located at location $x \in [0, 1]$ garners from purchasing platform A or B without any software are $\widetilde{U}_A(x) = V - P_A - tx$ and $\widetilde{U}_B(x) = V - P_B - t(1 - x)$, where V is the standalone utility a consumer receives from purchasing either platform. The console utility with software is $U_A(x) = \widetilde{U}_A(x) + S_A$ and $U_B(x) = \widetilde{U}_B(x) + S_B$, where S_A and S_B are the net consumer surplus associated with each compatible game.

In the first regime or the baseline model I assume there is one monopoly video game developer who produces one game, which is compatible with each console, has standalone value v and sells at price p. Moreover, demand for a video game is inelastic. Thus, a consumer who purchases platform c and is located at x will purchase the respective compatible video game if the net utility from software is non-negative i.e.: $S_A = v - p$ or $S_B = v - p$. Since there is only one game developer, the independent software developer prices its video game accordingly.

In the second regime, platform A integrates with the independent game developer and ties its newly acquire game to its console foreclosing platform B from software or put differently technologically ties software to hardware. Consequently, platform B does not have any games available and the utility associated with platform B is the gross utility without any software $U_B(x) = \widetilde{U}_B(x)$ while for A it is $U_A(x) = \widetilde{U}_A(x) + S_A$. Lastly, assume $v \geq r$ to ensure that software price cover software marginal cost, $v \leq 3t$ to keep the market from tipping when software is technologically tied and that r is exogenously determined.

The timing of the game is as follows. First, the platforms and game developer set prices simultaneously. After observing the price offers from the platforms and game developer, consumers make their purchase decisions.

For the first regime in which technological tying is forbidden demands for each console are:

$$
\begin{aligned}
D_A &= \frac{1}{2} + \frac{P_B - P_A}{2t} \\
D_B &= \frac{1}{2} + \frac{P_B - P_A}{2t}.
\end{aligned}
$$

Thus, the platforms' respective profits are:

$$\begin{aligned}\widetilde{\Pi}_A &= D_A(P_A - mc) + r_A D_A \\ \Pi_B &= D_B(P_B - mc) + r_B D_B\end{aligned}$$

where the first term corresponds to profits associated with selling consoles and the second profits from the independent developer paying royalty fees.

Lemma 1 *When technological tying is forbidden and royalty rates are symmetric, the equilibrium is*

$$\begin{aligned}\widetilde{P}_A &= mc + t - r, \qquad \widetilde{P}_B = mc + t - r, \qquad \widetilde{p} = v. \\ D_A &= \frac{1}{2}, \quad D_B = \frac{1}{2}, \qquad \Pi_A = \frac{t}{2}, \quad \Pi_B = \frac{t}{2}\end{aligned}$$

Notice platform prices follow the standard hotelling result but with price lower by the royalty rate, which is from each platforms internalizing the effect its console price has on profits from independent game developers.

The second regime of technological tying is a bit different given the asymmetries among platforms. In this setup the demand for each console is:

$$\begin{aligned}D_A &= \frac{1}{2} + \frac{P_B - P_A + v - p}{2t} \\ D_B &= \frac{1}{2} + \frac{P_A - P_B - v + p}{2t}\end{aligned}$$

while profits are

$$\begin{aligned}\Pi_A &= D_A(P_A - mc) + pD_A \\ \Pi_B &= D_B(P_B - mc).\end{aligned}$$

When technological tying is allowed platform B's profit is only a function of console profits while platform A's profit is now a function of profits associated with selling its integrated game to its console owners.[8]

[8] One might be wondering why video game price is necessary in this regime. I would like to remind the reader that technological tying incorporates the combination of vertical integration and exclusivity and does not follow the usual tying in the bundling literature.

Lemma 2 *When technological tying is implemented, the equilibrium is*

$$\begin{aligned} P_A &= mc + t - \frac{2}{3}v, \qquad P_B = mc + t - \frac{1}{3}v, \qquad p = v. \\ D_A &= \frac{1}{2} + \frac{v}{6t}, \quad D_B = \frac{1}{2} - \frac{v}{6t}, \\ \Pi_A &= \frac{t}{2} + \frac{v}{18t}(15t + v), \quad \Pi_B = \frac{t}{2} - \frac{v}{18t}(21t - v) \end{aligned}$$

Comparing the equilibrium prices associated with the two regimes reveals a stark difference in price structure. When technological tying is implemented by console manufacturer A the console price structure adjusts for both console producing firms. No longer are console prices a function of the royalty rate. Instead they become a function of the tied software standalone valuation. This is a result of console A substituting the collection of a royalty payment for the price of the tied software, which is equal to v. However, given console B has one less software game available to its potential console owners, console manufacturer A does not have to compete as hard as if console B had a technologically tied game of equal value. The tying of the game increases the console manufacturer's market power which generates an incentive to raise its console price. Yet, like the non tying regime, the manufacturer of console A still retains the incentive to lower console price from internalizing the effect console price has on software profits.

The two price effects associated with console A are also present for console B but are of opposing force. For instance, the manufacturer of console B has the incentive to increase its console's price as a result of the complete loss of software profits, which eliminates any internalization of console price on software profits. Moreover, the demand effect or the elimination of a game from console B's game library generates an incentive to lower its price from the fact it has become less valuable in the eyes of consumers. The two opposing effects associated with technological tying on console prices nonetheless lead to an ambiguous result.

Definition 3 *Increase (decrease) in console price competition: An increase (decrease) in console price competition refers to a decline (increase) in prices for each console under two unique regimes* $P_A < \widetilde{P}_A; P_B < \widetilde{P}_B$ $(P_A > \widetilde{P}_A; P_B > \widetilde{P}_B)$

Proposition 4 *When the value of software relative to the royalty rate is i) large* ($\frac{v}{r} > 3$) *technological tying increases console price competition* ($P_A < \widetilde{P}_A; P_B < \widetilde{P}_B$)*, ii) is small* ($\frac{v}{r} < 1.5$) *technological tying decreases console price competition* ($P_A > \widetilde{P}_A; P_B > \widetilde{P}_B$)*, iii) is in an intermediate range* $1.5 \leq \frac{v}{r} \leq 3$ *console price competition is indeterminate* ($P_A < \widetilde{P}_A; P_B > \widetilde{P}_B$)

The effect of a console producer integrating and tying its hardware and software on console price competition is unclear. In equilibrium, the impact on competition depends upon the relative size of the marginal revenue from games under each regime, r and v. If the relative magnitude of v to r is large then console A and B's prices fall. In which case, console manufacturer B finds it optimal to compete more fiercely with console maker A to retain market share by lowering its price in response to having one less video game. Console maker A all the while lowers its price from the fact that its marginal revenue from games under technological tying is substantially larger than when software is independent. Console A thus finds its profitable to lower the price of its console in order to drive sales of its console and in particular its technologically tied game.

When the relative magnitude between v and r is small, less than 1.5, console price competition decreases resulting in higher prices. For console A, this is caused by a relatively smaller tradeoff between console and software profits between the two regimes, which leads to a less intense incentive to lower console price to drive video game sales. Consequently, the incentive to raise console price from having an additional video game dominates. The intuition for why console price increases for B is quite different from A. With a relatively small software valuation the impact on demand from losing its only video game to console A is not as large as if the software value was high. Consequently, firm B does not have to compete as intensely in price to retain market share. Yet, the loss of software profits and the inability to internalize the effect console price has on software profits leads to a higher price.

The purpose of the simple theoretical model is to highlight the two countervailing effects of technological tying on console price competition and that the result boils down to a trade-off between software and hardware profits, or the relative value between the levied royalty rate and possible tied software price. In the next section I construct a more sophisticated and encompassing empirical model to take to data to determine whether technological tying in the home video game market increases or decreases console price competition.

5 The Empirical Model

In this section I discuss the structural model that captures the complementary relationship between consoles and video games, which includes demand and supply models for both hardware and software. The model also incorporates software competition into video game demand and supply.[9] Below I first present the empirical model describing the consumer's decision process and follow with the hardware and software pricing models.

Yet, before I move forward it is important to disclose that in the underlying empirical model and all counterfactual simulations a consumer's choice of video games and console is static and that firms also take a static approach to setting prices of consoles and video

[9] In the Appendix I present the results of several models which help further strengthen my assumption that video games compete and that a dynamic demand model may not be of great concern.

games. Now although the model assumes firm prices are statically set (but with decreasing demand), 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.

5.1 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 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.[10] 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. 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 consumer 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

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

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 the stage in which he elects to purchase a console. Since consumers are static decision makers, the ability to continue to purchase software in subsequent periods does not affect his choice decision. 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

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_{ijt}, 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 $\alpha_{i,hw}$ and $\beta_{i,hw}$ 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 $\theta_{hw} = (\theta_{1,hw}, \theta_{2,hw})$. $\theta_{1,hw}$ contains the linear parameters of the model $(\overline{\alpha}_{hw}, \overline{\beta}_{hw})$ and $\theta_{2,hw} = (\Sigma, \Pi, \phi)$ the nonlinear parameter.

Examples of physical console characteristics are 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 the 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 a console purchase I must examine the utility consumers receive from purchasing software in order to define $\Gamma_{ijt}(\cdot)$, the software index. Consider a consumer who has yet to purchase console j in period t or in some previous period. The indirect utility consumer i receives when purchasing software k compatible with console j in period t takes the random utility 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 compatible with console j in period t is:

$$\begin{aligned}u_{ik_jt} &= \alpha_{i,sw}p_{k_jt} + x'_{k_jt}\beta_{sw} + \psi_{k_jt} + \eta_{ik_jt} \\ u_{ik_jt} &= \delta_{k_jt} + \sigma_{\alpha,sw}\upsilon_i p_{k_jt} + \eta_{ik_jt} \qquad (2)\end{aligned}$$

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, $\sigma_{\alpha,sw}$ 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 $\theta_{1,sw}$ contains the linear parameters of the model $(\overline{\alpha}_{sw}, \beta_{sw})$ and $\theta_{2,sw} = (\sigma_{\alpha,sw})$ the nonlinear parameter. Now although the above model is specific to consumers who have yet to purchase a console it is important to note the above indirect software utility also characterizes the utility for consumers who have purchased 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 of choosing from a set of available and compatible video games for console j in market t:

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

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 the number of 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, parameter estimates are insignificant leading me to conclude the above model 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.

5.2 The Supply Models

5.2.1 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 each acts statically.[11] 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). 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. Additionally, a console exogenously sets its royalty rate at \$10 per game, which deems it a non-strategic variable. I make assumptions two and three from an industry expert's inside knowledge.

[11] 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 immense

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.

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

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

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, s_{dt} is the probability game d, which is produced by the console manufacturer, is purchased by consumers, mc_{dt} is the marginal cost associated with game d, s_{kt} is the probability consumers purchase game k, a third party game, r is the royalty charge by the console firm to independent developers and c is the cost associated with interacting with developers. 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 first party 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. Or otherwise put, the internalization of console price on software profits. 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

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

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 a seasonal variable.

5.2.2 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 a console and there are third party games which are manufactured by independent firms which design, produce and sell games and 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 a console manufacturer which is set at ten dollars per game plus any additional time varying incremental costs

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

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

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

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

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 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*–it only has 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 their profits 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:

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

where the corresponding first order condition for game k compatible on console j in time period t is

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

which differs substantially from that of a traditional independent market via the first term. Since 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, software marginal costs can be estimated. I assume the functional form for marginal cost is

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

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 an integrated and genre indicator variables, month-of-year fixed effects, game age and rating. With the inclusion of the integrated fixed effect, I allow for integrated software manufacturers to have a lower marginal cost since they incur no royalty payment where the month-of-year indicator variables captures differences in costs across 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. 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 rather than dynamics. Given this paper is the first to empirically capture the pricing relationship among complements, consoles and video games, future research should explore the affect of dynamics in predicting markups while simultaneously estimating demand and supply for complementary products and whether doing so adds any significant improvements to model fit.

6 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.

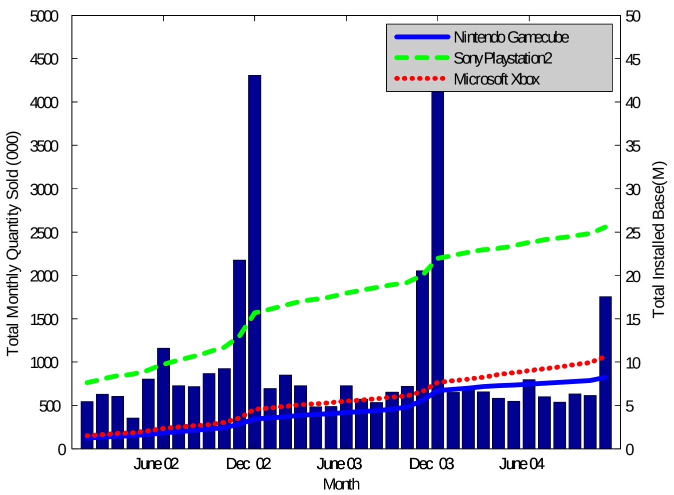

Figure 2: Console Sales and Installed Base

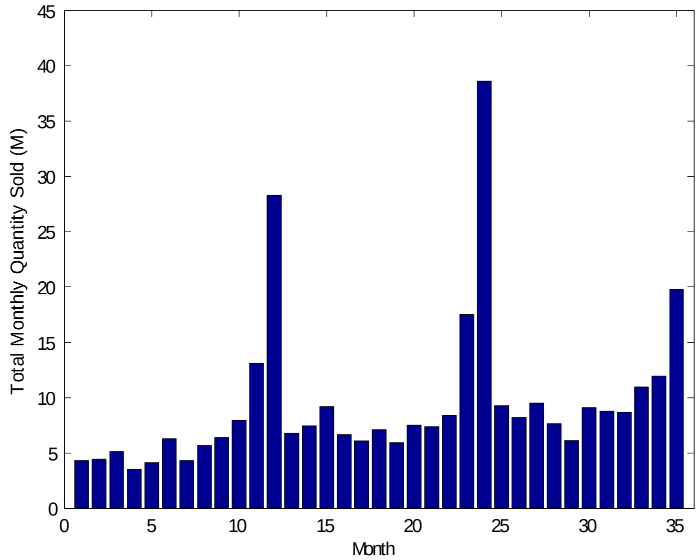

Figure 3: Software Sales per Month

The second fact is that video games are differentiated goods, which is quite evident by walking into any 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 are 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, where the HHI measure is calculated by summing the squared market shares of each integrated game. The HHI index measures the concentration of tied games for each console. A small index indicates technologically tied games have little impact on total video game sales while a large index signifies the opposite. The HHI is a more encompassing measure for technologically tied game importance as compared to the number of games or the total units sold because these two measures do not account for 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, 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.

7 Estimation

The estimation procedure I use to recover the structural model parameters follows that of Berry, Levinsohn and Pakes (1995), henceforth BLP, and Nevo (2001). I jointly estimate console and video game demand and supply models to further aid in the identification of 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. But, 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. As a result, 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 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.[12] I assume the potential market size for video games in these months is 1.25 times the console specific installed base measure.[13] 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 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 bias downward the quality of games over time. To illustrate such bias I present a simple example.[14] 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. In order to introduce competition I consequently must under estimate the quality of games. 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 have sales over 500k and 100k, respectively. This very small bias only affects a limited number of software title observations and therefore, 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. I also present further support of software competition in the Appendix.

7.1 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 these 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

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

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

[14]I thank a referee for a variant of this example

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 to form the corresponding BLP moments.

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

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.[15] However, this does come with a computational cost.

7.2 Instruments & Identification

In order to properly estimate and identify a consumer's price sensitivity for hardware and software I use instrumental variables to correct for their 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. Under this assumption, market specific markups will be 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 instruments with ones 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 affect the retail price of consoles in the US. I employ a one month lag of the exchange rate to allow for the duration between shipping, displaying and purchasing of the console. Lastly, each instrument is interacted with console indicator variables to allow each variable to enter the production function of each console differently. This method is similar to that of Villas Boas (2007). Similarly for video games, I use the software producer

[15] 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 asymptotic covariance matrix.

price index as an instrument for software cost. The producer price index is interacted with additional variables to capture cost differences between game age and rating. The software price instruments are console specific software PPI, console specific software PPI interacted with video game age, software PPI interacted game rating, and lastly software PPI interacted with video game age and rating. The implementation of such instruments captures and proxies for variable software costs among young and old games, across genres and quality levels.

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, $\boldsymbol{\Delta\xi}_{jyt}$, 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 substantial 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, since I suspect ϖ and υ to be correlated with $\boldsymbol{\Delta\xi}_{jyt}$ and ψ_{k_jt}, respectively–a console or piece of 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. As the predicted markup from the demand side is a function of exogenous variables and the instruments for price variable, we are effectively instrumenting for the markup with demand shifters (BLP (2004)).

8 Structural Estimation Results

Parameter estimates for 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 $\theta_1^{hw} = \{\overline{\alpha}, \overline{\beta}, \tau\}$ and the remaining columns provides estimates of unobserved and observed consumer heterogeneity about these means $\theta_{2,hw} = \{\Sigma, \Pi, \phi\}$. 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 level, (-0.0403). Consumers, thus, have significant marginal disutility to console price, as is expected. Furthermore, the associated standard deviation in which consumer taste toward price is distributed is positive yet insignificant indicating there is no unobserved consumer heterogeneity toward console price (0.0046). A consumer's taste for the maximum number of controllers a console has is fully captured by household size (0.3632). This result indicates that larger households gain more utility for consoles which have a larger number of controllers.

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, which 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	-0.0283**	0.0108	0.0046	0.0075		
Controllers			0.8494	0.8423	0.3631**	0.1670
Software Index	0.8994**	0.2992				
Seasonal	1.5575**	0.1882				
Age	-0.0721**	0.0207				
GameCube_2002	-5.5571**	0.1788				
GameCube_2003	-5.1857**	0.4208				
GameCube_2004	-4.8789**	0.6631				
Playstation2_2002	-0.0924	0.4698				
Playstation2_2003	-0.8816	0.9029				
Playstation2_2004	-0.6834	0.9319				
Xbox_2002	-10.2979**	0.2421				
Xbox_2003	-9.9908**	0.4551				
Xbox_2004	-9.1206**	0.6689				
Cost Side Parameters						
Nintendo GameCube	162.4872**	7.5626				
Sony PlayStation2	290.2088**	9.5304				
Microsoft Xbox	214.7020**	13.6175				
Nintendo GameCube*trend	-3.2140**	0.2219				
Sony PlayStation2*trend	-4.6768**	0.2848				
Microsoft Xbox*trend	-3.7509**	0.5351				
Seasonal	6.3820	5.0607				
GMM Objective Function				402.4227		

Notes: **indicates significant at 95%; *indicates significant at 90%;

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 set to $\sigma_{\alpha}^{sw} = 0$ in the model.[16] Additionally, to curb any concerns regarding biased estimates of software price sensitivity due to overcrowding 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 covariate, which has a negative and significant estimate, to capture any decline in popularity or desire to play a particular software title as it moves through its life cycle in addition to indicator variables for Nintendo and Sony's console. These covariates capture any differences

[16] I ran into computational difficulties estimating a model $\sigma_{\alpha}^{sw} \neq 0$ due to the challenge of inverting very small values of shares for nearly 1200 games.

in unexplained video game quality across the three consoles for a particular game. Lastly, from the marginal cost estimates I determine that higher consumer rated games are more expensive to produce while action games are the least costly to produce.

Table 4: Software Model Results

Variable		
Software Utility Parameters	Coefficient	Std. Error
Price	-0.0403**	0.0025
log(number of games)	-1.4688**	0.398
Age	-0.1294**	0.0019
Rating	0.2741**	0.0246
GameCube	-0.4855**	0.0205
PlayStation2	0.4456**	0.0289
Cost Side Parameters		
Age	-0.6759**	0.0053
Rating	2.0857**	0.0437
Action	-4.2970**	0.3730
Family	-4.1776**	0.3576
Fighting	-2.8485**	0.3937
Other	-0.8601**	0.3968
Racing	-3.7014**	0.3657
Shooter	-2.8534**	0.3941
Sports	-3.7998**	0.3671
Integrated	-0.6690**	0.1775

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 not reported in Supply Model

8.1 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 25-34% increase in the *total* number of a given console sold during the time period whereas the cross prices elasticities range from approximately 3-26%. As the table indicates, all the diagonal elements are positive and greater than one, and are consistent with oligopolistic behavior in which firms' price on the elastic portion of the demand curve. Moreover, the off-diagonal elements are negative and the estimated cross-price semi-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	25.9009	-20.5714	-6.8218
PlayStation2	-3.2009	34.7712	-5.8462
Xbox	-4.6925	-25.9425	26.0226

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.

I also gain further insight into firms pricing behavior with the estimation of console marginal cost and 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 roughly -5% 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. The WSJ article titled " Cost Cutting Pays Off at Sony" (2/5/2010) reports Sony's PlayStation3's margin to be roughly negative 6%. Now, although this number corresponds to the current console generation one might expect a similar magnitude for the generation in which this study analyzes.

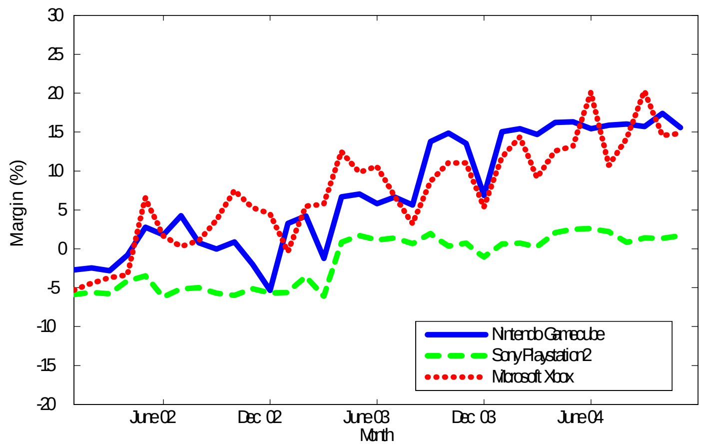

Figure 4: Console Margins

I alternatively estimate a model which only estimates console demand and supply and does not allow console producers to internalize the effect of console price on software profits (one can view these estimates originating from a standard single product firm) and present these measures in Figure 5. I illustrate these estimates to highlight the importance of jointly estimating console and software supply and demand. The figure also underscores the imprecision a model, which does not allow for the internalization of the pricing externalities, has on recovering console margins. From these figures it is evident the alternative model overestimates console margin by two to three times.

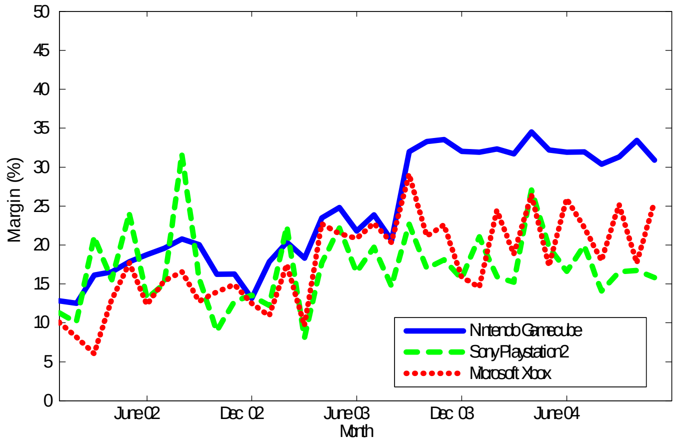

Figure 5: Alternative Model Console Margins

Unlike the alternative model, the preferred model also performs quite well in recovering software margins without imposing any additional model constraints. For instance, the model predicts an average margin of roughly 51 percent for new games priced above $49.00 while Pachter and Woo (2006) reports the average margin to be 57 percent. Ideally, I would be in possession of additional segments but unfortunately I am not. Nonetheless, the data from Pachter and Woo provides a nice check for model fit. I also present a plot of the mean demand residuals for consoles and video games to further illustrate model fit. The figure does not indicate any systematic evidence of serial correlation of the mean errors over time.

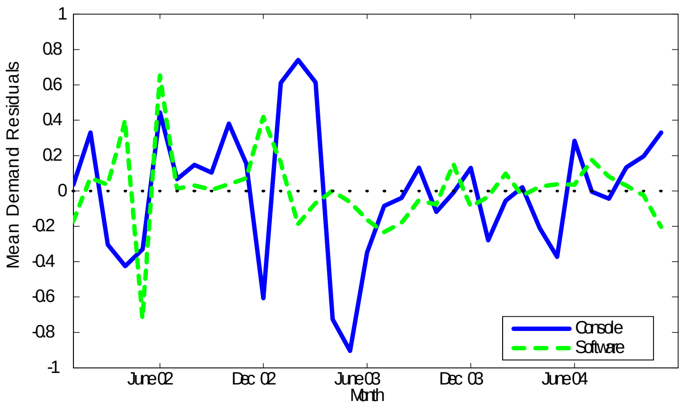

Figure 6: Mean Demand Residuals

9 Counterfactual Simulations

To address the impact technological tying has on market structure and competition I employ the above estimated model primitives in a counterfactual simulation which employs all available data to illustrate the effect on console price competition. I also implement several additional simulations which only use only data on Nintendo's GameCube and Sony's integrated video games to more clearly describe and discuss why hardware makers elect to technologically tie.

It is important to remind the reader that in the empirical model above and the 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. The counterfactual results below consequently capture only partial effects.

9.1 Competitive Price Effects of Technological Tying

The results of the first counterfactual simulation are presented in Table 6. Counterfactual one employs all available data and assumes what were once tied games are now independent and available on all video game consoles. With this counterfactual I determine the efficiency effect dominates the demand effect which leads to an increase in console price competition when console manufacturers integrate and tie their software to their hardware. Moreover, tying games benefit Microsoft and Nintendo more than Sony. The counterfactual predicts a mean increase in the price effect (change in console price) for all three consoles, which leads to a decrease in the total number of consoles sold for the observed time period. Their respected quantities decrease by 23.6265% and 0.6393% while Sony's PlayStation 2 sales increased by 3.0686%. I also determine the price effect is greater for Microsoft and Nintendo than for Sony and 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	2.3072%
	PlayStation 2	0.3385%
	Xbox	0.8203%
% Change in Consoles Sold (Jan02-Nov04)	GameCube	-23.6265%
	PlayStation 2	3.0686%
	Xbox	-0.6393%
	Outside	3.7309%
% Change in Variable Console Profits from Games (Jan02-Nov04)	GameCube	-67.4991%
	PlayStation 2	-16.8064%
	Xbox	-40.4443%
% Change in Variable Console Profits (Jan02-Nov04)	GameCube	-55.0366%
	PlayStation 2	-10.3379%
	Xbox	-24.8023%
Mean % Change in Consumer Surplus		-3.1599%

1. The reader should note that changes in software prices are unreported but are accounted for

When these top selling first party games in addition to all other first party titles are made compatible with competing consoles a console maker's market power deceases because the games in which they used to produce are now available on multiple consoles. The attractiveness of the console also decreases because the indirect network effect is smaller and is a result of greater software congestion leading to smaller software utilities, which drive console prices down. 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 independent developer. I determine this effect is a significantly more important driver of price than the demand effect. Thus, prices rise and in particular raise 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 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 a sizable impact on GameCube's and Xbox's console shares. Now although these results are due to the complete elimination of a specific video game title, they do highlight the importance of tied video games for Nintendo and Microsoft as the results provide some insight into how console shares would change when a game becomes available on multiple consoles.

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

	Mario Kart Double Dash	Grand Theft Auto 3	Halo
GameCube	-6.3638	0.0598	0.3624
PlayStation2	0.5403	-0.7703	0.4335
Xbox	0.7650	0.1655	-4.6290

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 the dominant price factor, I analyze console manufacturer profits and find total profits decrease–video game profits decline substantially. When console makers technologically tie software to hardware they internalize the externality associated with multiproduct pricing of complementary goods, which results in lower console prices and 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.

In summary, the dominate factor affecting the intensity of console price competition is the internalization of software profits on console price. Prices of consoles with a larger degree of concentration in tied games rise more than consoles with less when tying is prohibited, which in conjunction with the increased software competition and congestion leads to lower consumer welfare.

9.2 Incentive to Technologically Tie

With having highlighted the effect of technological tying on console price competition, I move my attention to understand why hardware manufacturers elect to engage in this action- I thus endogenize a console's tying decision. From the above counterfactual results I determined that it is profitable to partake in such an action but this does not indicate that such an action by all firms is an equilibrium. In order to determine this, I must also analyze the alternative scenarios which do not permit all firms to tie simultaneously.

For sake of computational simplicity and clearer intuition I limit my simulations to include only two identical consoles (Nintendo GameCube to be specific) with the production of only software from two firms which produce games identical to Sony. With the use of the estimated model primitives, I run four simulations each for 11 periods and with 10 million potential customers. The four simulations are: i) no technological tying by either hardware firm, ii) allow hardware firm one to tie software firm 1 games, iii) allow hardware firm two to tie software firm 2 games, and iv) allow each hardware firm to tie games from one software firm. The results of the four simulations which report mean percentage change in console price, total number of consoles sold, console profits as a function of software development costs (F_1 and F_2) and consumer welfare are presented in Table 9 below.

Table 9: Simulation Results

		(i)	(ii)	(iii)	(iv)
Mean % Change in Consoles Price $\frac{(p_{new}-p)}{p}$	Console 1		-4.6820%	-0.1270%	-15.4132%
	Console 2		-0.1270%	-4.6820%	-15.4132%
Total Consoles Sold	Console 1	1,010,600	1,464,600	489,400	889,250
	Console 2	1,010,600	489,400	1,464,600	889,250
Console Profits	Console 1	\$62,754,000	\$130,240,000-F_1	\$33,120,000	\$257,710,000-F_1
	Console 2	\$62,754,000	\$33,120,000	\$130,240,000-F_2	\$257,710,000-F_2
Consumer Welfare		\$81,194,000	\$94,586,000	\$94,586,000	\$83,924,000

These results highlight the effect of tying in a competitive environment. First it is important to point attention to the fact that when both firms engage in technological tying console price competition increases, as illustrated in the above counterfactual, and again is a result of the demand effect being dominated by the efficiency effect. Total demand for consoles falls even in the face of greater console price competition. This intriguing result is a consequence of each firm loosing half of its games leading to a sizable decrease in the console indirect network effect. Moreover, the price of the console who engages in tying in a unilateral tying setup also exhibits a decline in price, as one would expect. The console who does not tie, however, also experiences a decline in price and is a result of the firm's decrease in market share from the reduction in the number of compatible software titles. This decline in price is a direct competitive response to lessen the profitability of the firm who elected to technologically tie. Figure 7 presents the prices of console 1 under each of the four scenarios.[17]

[17] Since firms are symmetric I only present firm 1's price paths

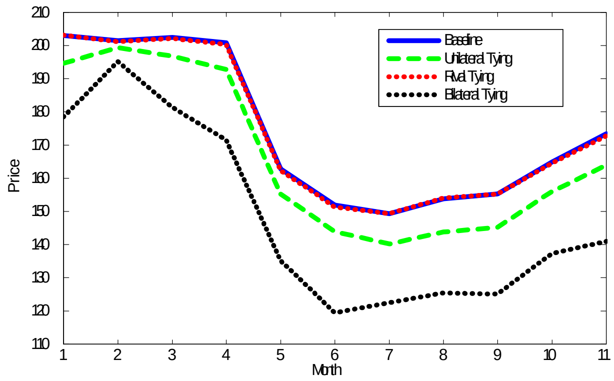

Figure 7: Firm 1 Counterfactual Prices

Technological tying does lead to a substantial increase in variable profits even in the face of lower hardware prices. As I pointed out above, this increase is a result of recovering a larger software margin when software is integrated. Firms are clearly trading off lower hardware profits for greater software profits. Nonetheless, as valuable as tying is in regard to variable profits, the overall profitability is dependent upon software fixed development costs. Below in Table 10, I present the outcomes of each simulation as a function of software development costs while proposition 1 discuss equilibrium outcomes associated with different levels of development costs.

Table 10: Outcomes of Simulations

		Firm 2			
		No Tying		Tying	
Firm 1	No Tying	\$62,754,000	\$62,754,000	\$33,120,000	\$130,240,000-F_2
	Tying	\$130,240,000-F_1	\$33,120,000	\$257,710,000-F_1	\$257,710,000-F_2

In the above game all outcomes can be Nash equilibrium, i) (Technological Tying, Technological Tying) ii) (Technological Tying, No Tying) iii) (No Tying, Technological Tying) and iv) (No Tying, No Tying). Equilibrium depends upon software fixed development costs. All four outcomes can be dominant strategy nash equilibrium (DSNE) while only (No Tying, No Tying) and (Technological Tying, Technological Tying) can be nash equilibrium (NE). (Technological Tying, Technological Tying) is a DSNE if $F_i < 67,486,000$ and a NE if $67,486,000 < F_i < 224,590,000$; or $67,486,000 < F_1 < 224,590,000$ and $F_2 < 67,486,000$; or $F_1 < 67,486,000$ and $67,486,000 < F_2 < 224,590,000$. (No Tying, No Tying) is a DSNE if $F_i > 224,590,000$ and a NE if $67,486,000 < F_i < 224,590,000$; or $67,486,000 < F_1 < 224,590,000$ and $F_2 > 224,590,000$; or $F_1 > 224,590,000$ and

$67,486,000 < F_2 < 224,590,000$. (Technological Tying, No Tying) is a DSNE if $F_1 < 67,486,000$ and $F_2 > 224,590,000$ while (No Tying, Technological Tying) is a DSNE if $F_1 > 224,590,000$ and $F_2 < 67,486,000$.

Proof. From the above simulations and with profits a function of development costs (F), the unique cutoff values of F are derived from the calculated variable profits. ■

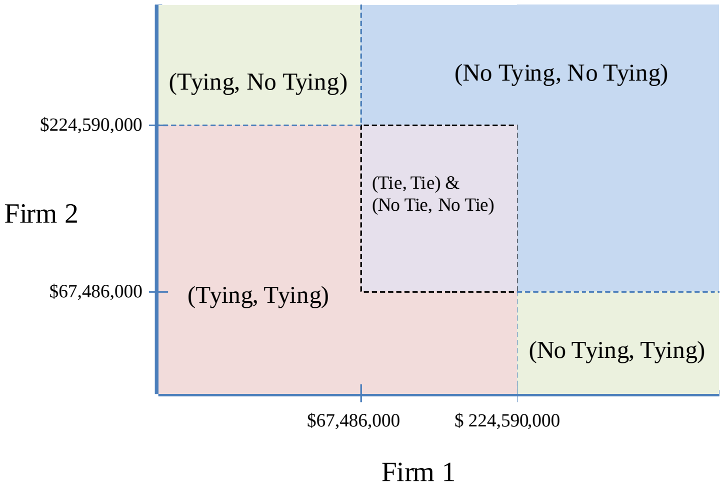

Figure 8: Mapping of Equlibrium

In sum the above proposition states that if fixed software development costs are low the dominant strategy Nash equilibrium is for both hardware providers to integrate and tie. The driving incentive which makes tying a dominant strategy coincides with the above intuition for why console prices fall with tying. Console manufacturers are willing to decrease its console price in order generate greater demand for its console and in particular its technologically tied video games. This increase in demand then allows the firm to recover a video game margin that is larger than the royalty fee levied from what was once an independent game. Thus, each firm finds it profitable to trade-off small, or if not negative, console margins for larger software profits.

If the fixed development cost of software were substantially large then technological tying would not be profitable and would no longer be the dominant strategy. With high development costs, no tying becomes the dominant strategy as the variable profits from a tied game are not enough to cover the fixed cost to develop. Lastly, if fixed development costs fall within a medium range, there exist multiple Nash equilibria. Medium level development costs lead to multiple equilibria since they are not at a level to strictly deter firms from tying.

An alternative explanation is related to the classic "make versus buy" decision of a firm (Williamson, 1971; Coase, 1937). When development costs are high the firm prefers to delegate to independent developers as a way to escape the high fixed costs while when cost are low the firm prefers to produce internally and bear the fixed cost but in return receive a substantial margin.

With the analysis of the above simulations and from observing hardware firms technologically tying video games in the data I infer software development costs must fall within the medium to low range or in the low range to guarantee a tying equilibrium. Although I report development costs as the sum across all tied games in the above simulations, I am able to recover average development costs per month per title. I determine the average development cost per month per game under a dominant strategy Nash equilibrium that leads to a tying equilibrium is $f_i < 176,664$ or \$3.2 *million* per title. This estimate is in line with Pachter and Woo (2006) value of \$2-4 million, where I assume the average length of a game being 18 months.

Its important to note that when both firms technologically tie software to hardware consumer surplus increases relative to the scenarios of no tying. This is a result of the decrease in console price offsetting the impact of less software competition (higher prices and less variety) which results in a smaller software index (a measure of consumer surplus for software on each console in terms of utility). Figure 8 illustrates the software index for firm 1 over the eleven months for each of the four counterfactual simulations. The figure clearly illustrates a smaller index for tying than under the baseline or unilateral tying scenario. However, the firm's index is larger when both firms engage in tying than when only its rival does. Now although in both scenarios software variety is reduced when the firm engages in tying he is able internalize the pricing externality associated with complementary products which results in lower software prices or a larger software index.

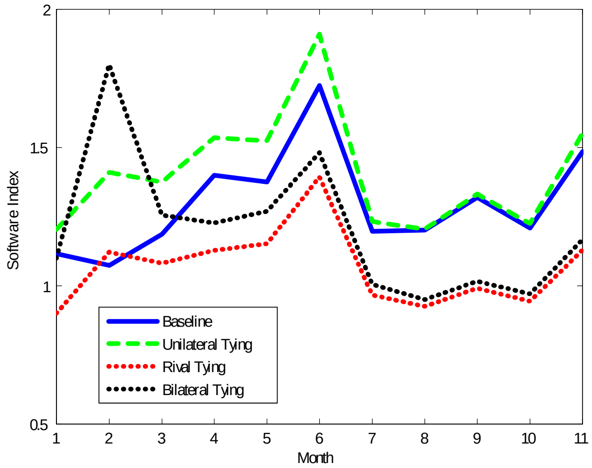

Figure 9: Software Index

In this section I highlight the incentives for a firm to technologically tie in a competitive environment. I determine that if firms face small (large) software development costs firms have a dominant strategy to engage (not engage) in technological tying. Moreover, consumers are better off when bilateral tying is implement. The reduction in console prices offsets the decrease in software index. Consequently, in this partial equilibrium analysis, which holds game quality and variety fixed, technological tying is pro-competitive (increase in consumer welfare and firm profits).

10 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 several 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. Moreover, when software development costs are small hardware manufacturers have a dominant strategy to tie hardware and software. Although I cannot generalize these results to other similar type industries because the question is empirical; my paper does provide the necessary framework to study the competitive price effects of an integrated firm tying its complementary products as well as with the methodology to analyze the impact complementary products have on consumer adoption of an associated platform.

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11 Appendix A-Theoretical Proofs

Proof of Lemma1. Given the above demands, firm profit functions and that firms compete

in price each firm maximizes its profit with respect to price. Firm $A's$ and Firm $B's$ first order conditions are

$$\begin{aligned}\frac{\partial\widetilde{\Pi}_A(\widetilde{P}_B,\widetilde{P}_A)}{\partial\widetilde{P}_A} &= \left(\frac{t+\widetilde{P}_B-\widetilde{P}_A}{2t}\right)-\frac{1}{2t}(\widetilde{P}_A-mc+r)=0\\ \frac{\partial\widetilde{\Pi}_B(\widetilde{P}_B,\widetilde{P}_A)}{\partial\widetilde{P}_B} &= \left(\frac{t+\widetilde{P}_A-\widetilde{P}_B}{2t}\right)-\frac{1}{2t}(\widetilde{P}_B-mc+r)=0\end{aligned}$$

with reaction functions of

$$\begin{aligned}2\widetilde{P}_A &= mc+t-r+\widetilde{P}_B\\ 2\widetilde{P}_B &= mc+t-r+\widetilde{P}_A\end{aligned}$$

Given the firms are symmetric $\widetilde{P}_A=\widetilde{P}_B=\widetilde{P}=c+t-r$. Equilibrium demand and profits follow accordingly. ■

Proof of Lemma 2. Given the above demands, firm profit functions and that firms compete in price each firm maximizes its profit with respect to price. Firm $A's$ and Firm $B's$ first order conditions are

$$\begin{aligned}\frac{\partial\widetilde{\Pi}_A(P_B,P_A)}{\partial P_A} &= \left(\frac{P_B-P_A+v-p+t}{2t}\right)-\frac{1}{2t}(P_A-mc+p)=0\\ \frac{\partial\widetilde{\Pi}_B(P_B,P_A)}{\partial P_B} &= \left(\frac{P_A-P_B-v+p+t}{2t}\right)-\frac{1}{2t}(P_B-mc)=0\end{aligned}$$

with reaction functions of

$$\begin{aligned}2P_A &= mc+t-2p+v+P_B\\ 2P_B &= mc+t+p-v+P_A.\end{aligned}$$

In equilibrium video game price equals v. Thus, console prices are $P_A=mc+t-\frac{2}{3}v$, $P_B=mc+t-\frac{1}{3}v$. Equilibrium demand and profits follow accordingly. ■

Proof of Proposition 1. i) $P_A<\widetilde{P}_A; P_B<\widetilde{P}_B$ implies that $mc+t-\frac{2}{3}v<mc+t-r$ & $mc+t-\frac{1}{3}v<mc+t-r\Rightarrow\frac{v}{r}>1.5$ & $\frac{v}{r}>3$. For each price to fall $\frac{v}{r}>3$

ii)$P_A>\widetilde{P}_A; P_B>\widetilde{P}_B$ implies that $mc+t-\frac{2}{3}v>mc+t-r$ & $c+t-\frac{1}{3}v>mc+t-r\Rightarrow\frac{v}{r}<1.5$ & $\frac{v}{r}<3$. For each price to rise $\frac{v}{r}<1.5$

iii)$P_A<\widetilde{P}_A; P_B>\widetilde{P}_B$ implies that $mc+t-\frac{2}{3}v<mc+t-r$ & $mc+t-\frac{1}{3}v>mc+t-r\Rightarrow\frac{v}{r}>1.5$ & $\frac{v}{r}<3$ ■

Appendix B-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[18], 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:

$$k_t = a + bK_t + cK_t^2 + \upsilon_t.$$

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 $M_t = \bar{M} - \textit{cumulative console sales till month } t$[19].

Appendix C-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 (2010). 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 whether 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 with a nested logit model with nests corresponding to the video game genre. I also include a covariate which 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 $ln(Num^{SW})$ 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

[18] See Lee (2010)

[19] 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.

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 without 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 11: 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 due to 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 12: Competitive Software Test 2

Price	GameCube		PlayStation 2		Xbox	
	Coeff	Std Err.	Coeff	Std Err.	Coeff	Std Err.
Age*Jan 02	-5.4529	1.0222	-1.6653	0.0547	-3.0832	0.7258
Age*Feb 02	-3.6220	0.5786	-1.4666	0.0501	-1.6532	0.4230
Age*Mar 02	-3.1827	0.4097	-1.4273	0.0464	-1.4513	0.3029
Age*Apr 02	-3.5630	0.3034	-1.5153	0.0428	-1.8278	0.2268
Age*May 02	-3.5875	0.2373	-1.4950	0.0398	-2.2919	0.1797
Age*Jun 02	-2.6575	0.1911	-1.1600	0.0371	-1.7465	0.1465
Age*Jul 02	-2.1446	0.1594	-1.0911	0.0347	-1.6151	0.1234
Age*Aug 02	-1.9688	0.1351	-1.1288	0.0326	-1.5409	0.1057
Age*Sep 02	-1.6433	0.1166	-1.0795	0.0308	-1.4478	0.0920
Age*Oct 02	-1.5569	0.1025	-0.9048	0.0292	-1.6418	0.0814
Age*Nov 02	-1.5079	0.0904	-0.8429	0.0277	-1.4118	0.0724
Age*Dec 02	-1.2210	0.0805	-0.6623	0.0264	-1.1323	0.0650

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

Table 13: Competitive Software Test 3

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

Appendix D-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 maybe unnecessary. The logit demand models below assume consumers have perfect foresight of next period's prices and video game availability and are 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 14: 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