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ESSAYS ON QUALITY IMPROVEMENT AND SECOND HAND MARKET IN THE VIDEO GAME INDUSTRY

A DISSERTATION APPROVED FOR THE DEPARTMENT OF ECONOMICS

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DEDICATION

to

My parents

Yong Ding and

Yunbei Wu, and

My wife

Huimin Zhang

For

Providing constant support on my path towards academic achievements

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Chapter 1

Video Game Industry Overview and Data Introduction

1.1 Video Game Industry

1.1.1 Industry Overview and Demographics

The video game market has been a fast-growing market in the past 20 years. The total population of video gamers has increased by four times since seven years ago and has reached almost one billion according to a presentation given by the chief financial officer at Electronic Arts. According to the same source, the total size of the video game software market was larger than video rental, recorded music, and box office in the year of 2008. The video game market is able to expand at a relatively fast pace because it is able to attract more and more consumers into the market and does not have to suffer a huge loss of existing consumers. Consumers who play video games at a young age tend to stay in the market as they grow older. The annual report by Nintendo for 2010 concludes that "the public perception towards video games has significantly improved over the past years".

Traditionally, people think the video game market is for young people. This has been changing during the past years. When the young kids grow up, they do not simply give up playing video games. According to a report released by the Entertainment Software Association in 2009, the current demographics of video game players show a lot of diversity. Only 25% of game players are 18 or younger. Almost half of the players are between 18 and 49 years old. Impressively, 26% of these players are over 50 years old. The average age of the most frequent game purchaser is 39 years old. Among all video game players, 40% of them are female. This shows the gender diversity is not negligible either.

1.1.2 Strategic Competition

In the video game market, several large firms compete for market share. According to the annual report of Take-Two Interactive Software, Inc., the competitors in the video game software market are: Activision Blizzard, Electronic Arts, THQ, Capcom, Square Enix, Konami, Namco-Bandai, SEGA, Ubisoft and itself. Sony, Microsoft and Nintendo produce both software and hardware for video games.

The video game industry requires a lot of input in research and development. All the firms invest a large amount of resources in their R&D as stated in their annual reports. For instance, the annual report by Nintendo for 2010 shows that Nintendo paid ¥42,211 million in research and development expenses, which is the second highest among all operating expenses. During the same year, R&D expenses were the highest among all the operating expenses for Electronic Arts, Inc. R&D expenses consist of expenses spent on direct development and related overhead costs in connection with the development and production of their products at Electronic Arts, Inc. As pointed out by many economic studies, durable good manufacturers adopt planned obsolescence to kill off the competition from the used good market. In order to have planned obsolescence, these firms have to invest a fortune to develop new features for their products.

The outcomes of the R&D departments of the video game companies are not necessarily profitable. With the fast developing technology, a company may not be able to equip their new generation products with technologies required for or suited to entertainment. With changing consumer preferences, newly developed features that require high development costs may not be favored by the consumers at the end. Timing for the hit titles' releases is critical for the overall profitability. Competition from other companies forces all the companies in this industry to pay intensive attention to the development of their own products. All the reasons listed here explain the large investment costs for the video game companies.

Overall economic fluctuations have effects on video game sales as well. Many of the major players from the video game market have suffered losses in the most recent economic crisis. Their balance sheets all state that they have been able to cover the variable costs but not the total costs. This fact shows that the sunk costs play an extremely important role in this market.

1.2 Data Introduction

The focus of this project is video game software. The main goal of this investigation is to show the effects on secondary market activities when a new generation game has improved quality. As stated before, a considerable portion of video game consumers will stay in the market over time. In this case, before the release of the newest generation game, the older generations of the respective game will face a high demand. This abnormally high demand can be explained by two reasons. The first reason is that the consumers who have already played the vintage generation want to play it again due to memories recalled by the advertisement of the new generation. The second reason is because some gamers, who want to prepare themselves for the forth-coming game by warming up or getting familiar with the story line of the game, want to play the older generations of the given game. This high demand pushes up the used good price of the older generations. In order to avoid this problem, I only include sports games and vehicle simulation games. These two genres of games do not have story lines and do not have stable characters. Since these two types of games have counter parts in real life, the most up-to-date features will only be found in the newest generation games. This fact makes it less likely that consumers want to play the older generation when a newer generation is coming out.

Video game sales decline dramatically as a game ages. Therefore, it is not worthwhile to include all the games that have ever been in the market. I include all the sports games and vehicle simulation games that are relatively new; more specifically, a game title will be included if the game title was released later than January 1st, 2006. Since my data collection was almost done at the end of May 2010, any game title that has been released afterwards will not be in my data set either. The inclusion of game titles depends on data availability as well.

The game data are organized into a three-tier hierarchy: (1) game series, (2) game generation, and (3) game title. Specifically, a game series includes all games that are a part of a product line. For example, NFL Madden 2009 for Xbox360 and NFL Madden 2008 for PS2 will both be in the NFL Madden game series. A game generation includes all game titles that share the same name and are

# of Generations	Frequency	Percent
2	34	54.84
3	9	14.52
4	14	22.58
5	4	6.45
6	1	1.61
Total	62	100

Table 1.1: Generation Summaries

normally introduced in a relatively short time span. For instance, NFL Madden 2009 for Xbox360 and NFL Madden 2009 for PS3 are both game titles in the NFL Madden 2009 game generation. A game title is specified for both game generation and platform. NFL Madden 2009 for Xbox 360 and NFL Madden 2009 for PS3 are different game titles but both belong to the same game generation and game series. The data set has in total 62 game series, with 325 different game titles. The longest game series has 6 generations.[1] Table 1.1 shows the frequencies of the game series with different numbers of generations. More than half of all game lines have two generations. I rarely have game series wth very long product lines, 5 or 6 generations. This is due to limited availability of the price and quantity data.

A key feature of the video games market is that there are distinct platforms to play games. A purchased game title is not compatible across different platforms, though a game is often released on multiple platforms. That is, an Xbox360 game will not work on a SONY PlayStation 3 console. However, it is quite common for a game to be available across a wide range of platforms. There have been seven generations of gaming consoles developed by related companies. and my data

[1]The missing data problem is more significant for weekly quantities. I have to drop the game titles where there is no observations for quantities or prices. In most cases, these game titles are not popular ones or not released in the United States.

Platform	Abbrev.	Console Manufacture	Frequency	Percent
Nintendo DS	DS	Nintendo	30	9.23
Game Boy Advance	GBA	Nintendo	2	0.62
Game Cube	GC	Nintendo	1	0.31
PlayStation 2	PS2	SONY	61	18.77
PlayStation 3	PS3	SONY	56	17.23
PlayStation Portable	PSP	SONY	50	15.38
Nintendo WII	WII	Nintendo	49	15.08
XBOX 360	X360	Microsoft	66	20.31
XBOX	XBOX	Microsoft	10	3.08
Total			325	100

Table 1.2: Platform Summaries

include game titles that are compatible to nine platforms: Nintendo DS (DS), Gameboy Advance (GBA), Gamecube (GC), Playstation 2 (PS2), Playstation 3 (PS3), Playstation Portable (PSP), Wii (Wii), Xbox360 (X360), and Xbox (Xbox). Table 1.2 summarizes the proportion of observations for each platform in the dataset. Portable consoles have less of a share in the data set, and all the mainstream consoles, PS2, PS3, Wii, X360, and Xbox, have similar shares in the data.

Video game developers will develop their games for variable consoles based on their strategic decisions. Most of the big games will be compatible with and only with the newest generation consoles. However, some newly developed games are compatible with older generation consoles as well. It is quite common that one video game will have multiple developers corresponding to different consoles. Otherwise, a game developing company will have different studios owned by this company to develop the same game for different platforms. Sometimes a game developing company outsources the development of their products for certain platforms to other developers, although this happens more for less popular platforms. For instance, Madden NFL 2011 for Wii is a different game than Madden

NFL 2011 for Playstation 3. In this investigation, a game title actually means a game on only one platform. Games that are compatible with multiple consoles show up as more than one game title in the data.

In my data set, I have three groups of variables: weekly prices of each game title, weekly sales of each game title, and both time-variant and time-invariant characteristics of each game title. Weekly prices are obtained from Cosmic Shovel, Inc., weekly sales data is provided by the VGChartz group, and the characteristics observations are collected by myself manually[2].

1.2.1 Weekly Prices

Cosmic Shovel, Inc. has established websites where users can request price tracking for specific items sold on Amazon.com. On Amazon.com, almost all products have new and used products on sale at the same time. For most items, Amazon.com itself sells brand new products. There are third-party users who sell new and used products. This makes every product sold on Amazon have three types of prices: Amazon new good price, third-party new good price, and used good price. In order to "track" a product, users only need to input the ASIN (Amazon Standard Identification Number) for that product on CamelCamelCamel.com, which is website administrated by Cosmic Shovel, Inc. Users are able to see a plot of all three price trends and receive alerts regarding price changes after they have a product "tracked". The methodology that Cosmic Shovel, Inc. employs to record historical prices is as follows:

- Put all products into two queues, one for products people have "tracked" and one for all other products.

[2] Refer to further discussions in later subsections of the chapter

- Collect the lowest available price for each price type of each product.
- The length of time queue processing takes has grown along with their product coverage, such that right now the "tracked" queue gets about 2-3 updates per day and the other queue receives 1-2 updates per week.
- When queues are empty, they will be re-populated and begin again.

According to the methodology, the prices of any item are updated at least once per week. Using related information, I am able to construct the weekly prices for products, where these weekly prices are the last updated price in each week.

Cosmic Shovel, Inc. does not only track product prices on Amazon.com for the United States. It does the similar tracking job for Amazon.com for other countries as well, such as Japan, United Kingdom, etc. Thus, every item sold on the corresponding website has three historical price series. With price data for the United States, Japan, and UK, I have in total nine price series for a certain product. The data availability is best for the United States and not as good for the other two countries. The units of each variable is the smallest currency unit in the corresponding country. For instance, for the used good price in the United States, the unit of the price will be in pennies.

Cosmic Shovel, Inc. started to track the prices of all items around mid-2008. So if a product was released before that, I will not have the complete historical price series for this product. Different game titles have different starting times after which the historical price data became available. Some game titles were introduced after the later half of 2008. So the availability levels of different game titles vary across the panel.

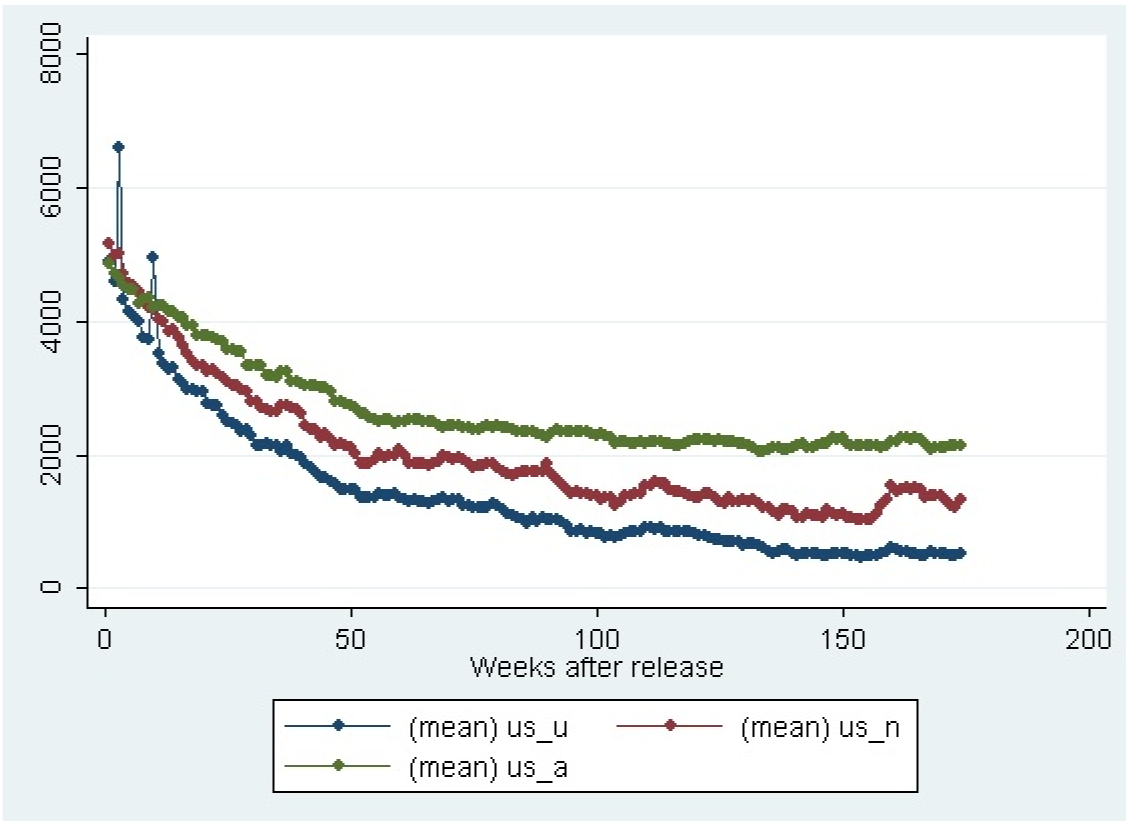

Figure 1.1: Trends for Three Price Series for All Games

Since I concentrate my investigation in the American market, I only include price data from the main Amazon website, Amazon.com. Every product sold on Amazon has three types of prices: an Amazon new good price (us^a), a third-party new good price (us^n), and a used good price (us^u). The data availability for these three price series are almost the same. The used good price and third-party new good price each have slightly better coverage than the Amazon new good price. Prices are measured in cents per unit. I can clearly see the decreasing trends in Figure 1.1. All three price series start at around 5000 cents or 50 dollars. Overall, the average for all three price series decreases over time as game titles age. The Amazon new good price has the highest average and the average used good price is the lowest among the series. This is because people tend to trust Amazon.com better than a random third party seller on the internet. I see that over the weeks after release, the mean of all three price series decline.

The third party prices seem more fluctuated than the Amazon official price after the game has been released for a year. Amazon carries a much larger amount of products than most third party sellers. After a game title has been out for a while, the weekly sales decline significantly. This makes Amazon.com less interested in making a strategically competitive price for the game title. However, this is not true for each individual seller who may be only selling a few game titles.

The presence of strong seasonal effects is not very apparent in Fig 1.1 because the x-axis plots time as weeks since introduction of a game and different game genres (i.e., football, baseball, hockey) have different introduction points during a year. However, if I focus on a single game type I can observe a clear seasonal pattern. Figure 1.2 shows the changing trends of used and new good prices for football games. These three price trends are drawn taking the mean of the

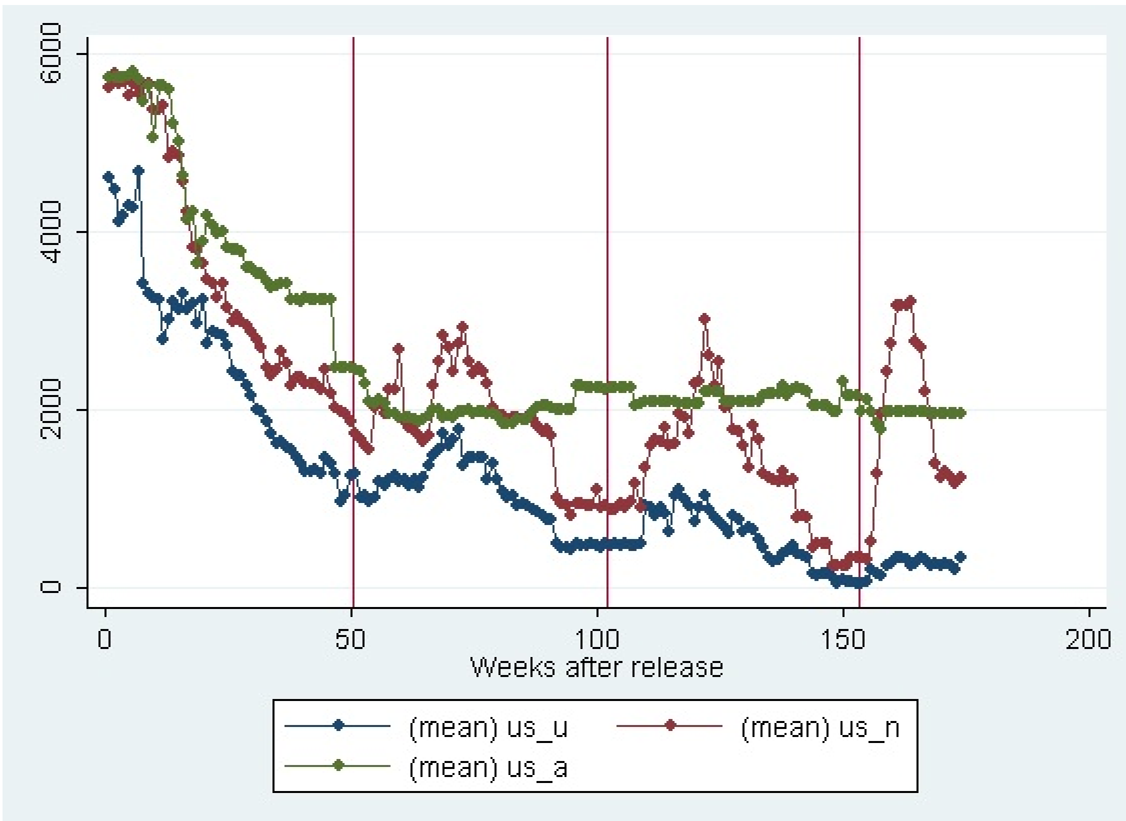

Figure 1.2: Trends for Three Price Series for Football Games

all the observations of each series in one week. The three dotted lines indicate when a new generation of games is introduced. According to my data set, after a football game is introduced, it takes about 51 weeks to introduce the next generation game title. The second and third generation release dates are shown as well – each separated by roughly a year. The red vertical lines indicate the average releasing week for the next 3 generations. It is quite natural that a new football game generation will be introduced to the market every 50 weeks or so, as this follows an annual release schedule. Figure 1.2 clearly shows that before the new generation introduction, all three prices go down. They bounce back after the new generation has been released due largely to the Christmas shopping season. The exception is the Amazon new price, where there is less seasonality and less of a trend after the first year. For football games, the average new video game price starts at about 60 dollars and the average used good price starts at about 40 dollars. When a game title has been out in the market for more than 150 weeks and it becomes the third newest generation of its series, the used good price drops to a level that is close to zero. However, the new good price of the old generation products remain somewhat elevated at 20 dollars per copy.

1.2.2 Weekly Sales

VG Chartz describes itself as follows: "VG Chartz is a video game sales tracking website that provides weekly sales figures of console software and hardware by region. VG Chartz is ranked amongst the top 5,000 websites in the United States and serves over 8 million page impressions per month. VG Chartz tracks the sales data of video game consoles sold by Nintendo, Sony, and Microsoft, as well as software for those consoles." Thus, I have reasons to believe that VG Chartz is a credible source of video game weekly sales and the weekly sales estimates it provides are among the best available estimates in the world. Plus, "VG Chartz has been cited and featured by a number of leading worldwide publications such as Reuters TV, The BBC, CNN Money, The New York Times, Fortune, Business 2.0, Forbes, The New York Post, The Telegraph, The Guardian, The Times, Sddeutsche Zeitung, The Birmingham News, The Toronto Star, The Indianapolis Star, The Inquirer, NU.nl, CNet, Seeking Alpha, OReilly Radar, Yahoo Games and The Guinness Book of World Records."

The VGChartz website states that all the weekly sales estimated by VG Chartz are obtained through channels as follows:

- "Polling end users to find out what games they are currently purchasing and playing"
- "Polling retail partners to find out what games and hardware they are selling"
- "Using statistical trend fitting and historical data for similar games"
- "Studying resell prices to determine consumer demand and inventory levels"
- "Consulting with publishers and manufacturers to find out how many units they are introducing into the channel"

For the best selling titles in each week, at least 3 of the 5 channels above will be used to ensure the accuracy of their estimates. For other titles, either one or two channels will be used to estimate the weekly sales.

VGChartz group estimates the weekly sales data for different regions of the world. On their website, they have estimates for three regions: Americas (The entire North and South American Continent), Japan, and EMEAA(Europe, Middle East, Asia and Africa - every region not covered by the first two options essentially). Similar to the price data, the data availability is the best for the Americas and not as good for the other two regions. For a given game, I will have three weekly sales observation series starting from the week when the game was originally released. The three series are as follows:

- *Americas*: weekly sales for the North and South American countries[3]
- *Japan*: weekly sales for Japan
- *EMEAA*: weekly sales for every region not covered by the previous two.

Due to better data availability and the main purpose of this project, the weekly sales for the North and South American countries are used. Figure 1.3 shows the mean weekly sales for all video game titles and all football game titles with respect to the number of weeks after release. Football game titles have better weekly sales on average than all game titles. A seasonal pattern is captured from the football game sales trend. This trend is caused by the Thanksgiving and Christmas shopping season. Football games are normally released at the beginning of each football season (some time in August). The mean weekly sales for football games reach the peak at around fifteen weeks after release. The weekly sales for football game titles hardly have large increases after they have been introduced for longer than a year. For the overall average weekly sales, the dotted line has a seasonal trend and the seasonal effect is much more amplified. This shows that football consumers are more likely to consume the newest generation game titles and not interested in older generations of game

[3]According to the email conversations I had with the website administrator, the quantity for Americas is the quantity for the United States multiplied by ten ninth.

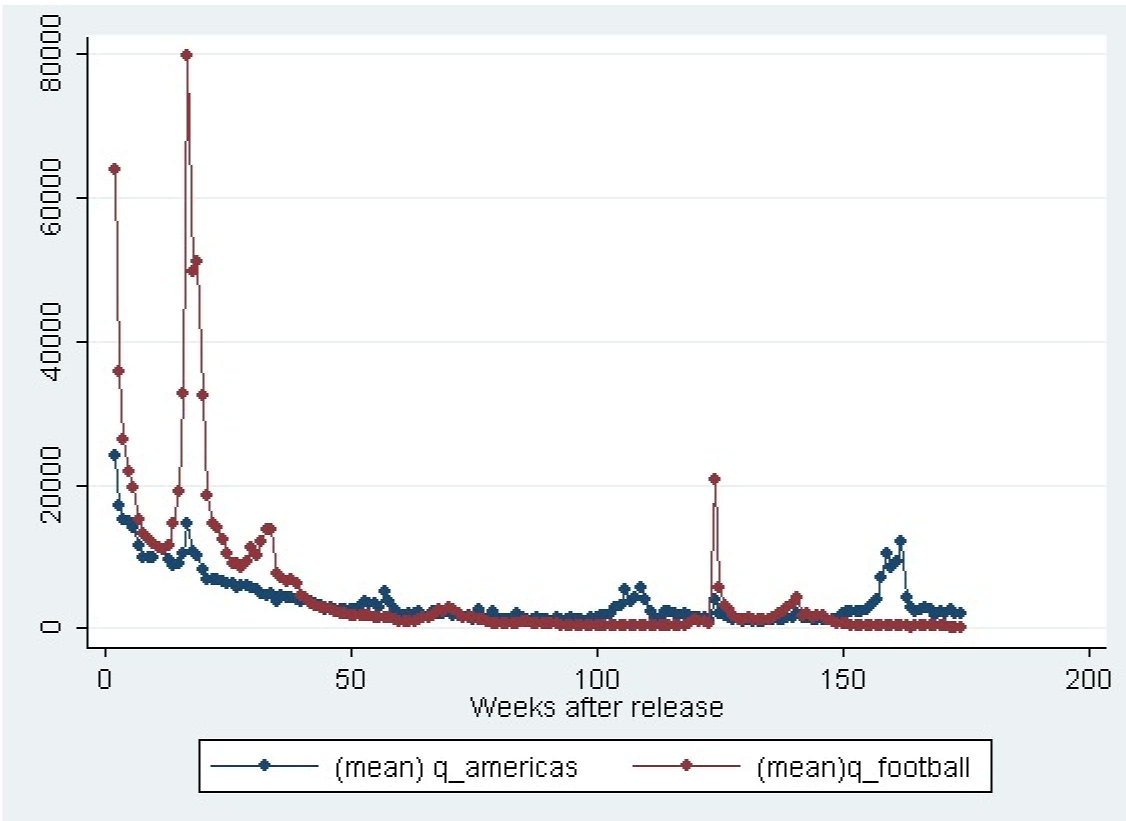

Figure 1.3: Quantity Chart: mean weekly sales for all games and football games

titles. Other sports games have similar features. Vehicle simulation games do not have certain release dates. However, they do not suffer from problems like a spike in used good price right before the release of a new generation.

1.2.3 Product Characteristics

I collect product characteristics variables from multiple sources manually by myself. Some product characteristics are time-invariant. These variables will not change after the game has been released. Others are time-variant. Some of the observations of these variables will be used as game title quality measures. Some will be used as instrumental variables. Some will be used as control variables. Due to the data quality of each variable, certain variables are used more frequently than others.

The time-invariant variables are the stable ones. They include game scores, physical appearances of the gaming discs, game content ratings ,publishers and developers for all games, cover stars for available games, and PC system requirements for games that are compatible with personal computers. Release dates for each game title are obviously a part of my data set.

Game Scores

Many video gaming websites and publications have their own ratings for a large number of games. Although these ratings are not identical across websites, they are highly correlated. I include ratings from Gamespot.com (owned by CBS interactive) and IGN entertainment. These are both leading platforms that release information and reviews about video games. The structure of game reviews generally takes two forms – a professional game review and user reviews. While reviews, and especially user reviews, change over time during the lifetime of the game. The early professional reviews change little after a game has been released. Hence, these types of reviews can be treated as time-invariant quality differences. For example, on Gamespot.com, every game has a "Critic Score" and a "User Score". The former is rated by game critics and it becomes stable soon after the game has been released. The latter is rated by users of the website, and it is constantly updated since users submit their own scores at random times. On IGN.com, every game has a "Press Score" and a "Reader Score". They work similarly as the two scores given by gamesopt.com. In this case, the "Critic Score" and the "Press Score" can be treated as measures of the initial quality of a game. The other two can be treated as measures of the up-to-date game qualities, though data availability is much more limited for these kinds of reviews. The corresponding variables I created in the data set are as follows:

- $GSCritics$: the "Press Score" from gamespot.com
- $GSConsumers$: the "User Score" from gamespot.com
- $IGNPress$: the "Press Score" from ign.com
- $IGNReaders$: the "Reader Score" from ign.com

Physical Appearances

Every game sold on Amazon.com will show the physical size of the game disc. The size variables include the length, the width, and the height of the item. Since the item will be shipped at the end, the weight is listed for each product as well. All these variables are time-invariant. I am able to include the physical appearance variables as follows:

- *length*: the length of a game title disc, unit: inch
- *width*: the width of a game title disc, unit: inch
- *height*: the height of a game title disc, unit: inch
- *weight*: the weight of a game title disc, unit: ounce

Game Content Rating

Since games have different target consumers and different content, every game sold in the United States is rated by the Entertainment Software Rating Board (ESRB). The corresponding ESRB ratings of all games sold on Amazon.com are available. For games that are released in Europe, Pan European Game Information (PEGI) has another content rating for each game. This type of information is publicly available as well. Both of these rating systems have different ratings for different game titles, which means the same game for different consoles may have different ESRB ratings or different PEGI ratings.

ESRB ratings have these ratings: EC (early childhood), E (everyone), E10+ (everyone 10 and older), T (teen), M (mature), AO (adults only), and RP (rating pending). As explained by ESRB, EC means a game is suitable for ages 3 or older; E means a game is suitable for ages 6 and older, E10+ means a title is for ages 10 or older; T means a title is for ages 13 or older; M is only for ages 17 or older; AO is for ages 18 or older. If a game title receives an ESRB rating, the youngest age permissible will be the value of the ESRB rating variable.

PEGI ratings include 3, 7,12, 16 and 18. These numbers stand for the youngest age allowed to play each game. These numbers naturally become the observations for the PEGI ratings. However, PEGI ratings have limited availability compared to the ESRB ratings.

The game content rating variables are as follows:

- *ESRB*: the value of the ESRB rating of each game title
- *PEGI*: the value of the PEGI rating of each game title

Publishers and Developers

A game title will have one or more developers, which are studios that are in charge of making this game. In many cases, the developers will be studios that are owned by the publisher of the game. In other cases, the development work can be outsourced by the publisher to individual developers. The same game designed for different platforms can be developed by one or more studios. The sequential games can be developed by different developers as well. Sometimes, the publisher of a game's successor can be different from the publisher of its earlier generations. It is reasonable to believe that the developers' and publishers' capabilities will have significant influences on the game qualities. The identities of the developers and the publishers of a certain game are public information.

Since the developer's ability to develop game features does have effects on gaming experiences, my empirical investigation derives developer rankings in order to create a measure of developer ability. "Game Developer" is a magazine that specializes in the video game market. It ranks the top one hundred among all video game studios every year. I was able to get the game developer rankings for 2007, 2008, 2009 and 2010. A measure of the developer is created as the developer value for each game title using the corresponding developer's ranking in the year the game title was introduced.

The editors of "Game Developer" magazine formed Game Developer Research, which publishes the game publishers' annual ranking. The publishers' rankings are developed using information from various aspects, such as total game sales, publishers' employee salaries, acknowledged experts at video games, and the final end consumers etc. The top 20 video game publishers will be ranked every year. This allows me to create a measure of the publisher of each game similar as the developer values.

These two variables are as follows:

- *developer*: According to the developers' ranking in the game release year, the No. 1 ranked developer will be given 100, the No. 2 ranked developer will be given 99, and so on. The unranked developers will be assigned 0 as the developer value for a game.

- *publisher*: Similarly, if the game is published by the No. 1 publisher in the game introduction year, the publisher value will be 20, and others will decrease accordingly. If the publisher is not ranked in that year, a zero will be used as the publisher value.

Cover Star

A lot of sports and vehicle games employ sports stars to do advertisements for the game titles. It is quite normal to see that the same game will have different stars for different console versions. The cover stars are normally different across different generations. It is not at all common to see a star being chosen by a game series constantly except for game series that are designed specifically for one athlete. The cover stars are seen by the public and the econometrician at no cost.

To construct a measure of the cover star, the popularity of this athlete in the year when the game title is introduced has to play a dominant role. For different sports, popularity levels are measured by different standards. For NCAA sports, whether the athlete makes it to the All-American team will be a good measure of the cover star popularity. For sports like tennis and golf where a year-end standing for all professionals is available, it is natural to use this ranking as a measure. The salaries of all athletes reflect how much the players are appreciated. Major awards one athlete wins in a year suggest the popularity of the player in the respective year.[4]

PC Requirements

For games that are compatible with personal computers, the system requirements are good indicators of how complicated or sophisticated a game is. If a game has PC requirements, it will be constant across different platforms. Since a PC game will have two groups of system requirements, the minimum system requirements and suggested system requirements, both groups are included. The variables I developed for system requirements are as follows:

- *min_prcsr*: the minimum standard for the processor; unit: GHz
- *min_memo*: the minimum standard for the memory space; unit: GB
- *min_hard*: the minimum standard for the hard drive; unit: GB
- *min_video*: the minimum standard for the video card; unit: MB
- *rcmd_prcsr*: the recommended standard for the processor; unit: GHz
- *rcmd_memo*: the recommended standard for the memory space; unit: GB
- *rcmd_hard*: the recommended standard for the hard drive; unit: GB

[4] A detailed explanation of how this variable is created can be found in the Appendix.

- *rcmd_video*: the recommended standard for the video card; unit: MB

The only time-variant variable I have in this investigation for each game title is the number of compatible platforms (*compatibility*). Since a certain game generation will not necessarily release all game titles for all consoles at the same time, the number of compatible platforms can change. This variable will increase when the same game is released for another console.

1.2.4 Conclusions

The video game market has been a fast growing industry in the last few decades. However, the research that is focused on this industry has not been as popular. I will further explore this industry in the later part of my dissertation. As mentioned before, video game producers constantly introduce new generations of video games to the market. Chapter 2 of my dissertation investigates such behavior by the video game producers. A theoretical model is developed to investigate the relationship between producer's choices related to new generation releases and the activities in the second hand market. A simple reduced form regression will be used to test the main hypothesis from the theoretical model as well.

Due to the uniqueness and richness of my data set, I am able to do a wide range of empirical tests and applications in the video game market. The third chapter of my dissertation employs this data set to show a potential improvement of the traditional differentiated product models. The results show that the inclusion of rental prices instead of retail prices in differentiated product models are critical. I am able to obtain more accurate and reasonable empirical estimates by including both the new good retail price and the future resale price for each game title. I do not use all variables that are complied in the data set. This leaves room for more empirical investigation ideas for future research.

Chapter 2

Competing with your own products: Endogenous planned obsolescence behavior in the video game industry

2.1 Introduction

Durable goods producers often release new generations of their products in a relatively frequent manner. It is well known that automobile manufacturers regularly introduce new versions of their models, and so do producers in many other industries. Textbook publishers upgrade versions of their books through the introduction of new editions and cell phone manufacturers are continually bringing to market new products with new features. A key aspect of these types of durable markets is that the durable goods producer faces potential competition from its existing stock of used goods. This raises a number of issues in modeling the behavior of durable goods producers including the role of planned obsolescence and the timing of new model introductions. In this chapter, I focus on the former issue and examine how quality upgrading by a durable goods producer affects pricing in the second-hand market.

This chapter develops a model that incorporates dynamic pricing and quality upgrading decisions in a durable-goods monopoly setting and then tests predictions of that model using data from the video-game market. The video-game industry is a nice setting in that the product is generally quite durable, there is a well-developed second-hand market for games, and software producers upgrade specific game titles over time. Most video game producers release new generations of their products often, especially for the popular and successful games. For instance, one of the major sports game producer, EA sports, releases a Madden NFL game at the beginning of each football season. This is common in the industry and allows me to focus on a set of games where the timing of the game release will not generally be a strategic consideration. Moreover, by using information on publicly available game reviews, proxy measures of quality improvements can be constructed.

My theoretical strategy is to build a two-period model with heterogeneous consumers that have different preferences over product features and prices. In the video game market, I observe that there are some consumers who buy a game immediately after the game is released in the market. Other consumers may choose to wait and purchase in the used good market. The different choices made by these consumers result from consumer heterogeneity, as well as the menu of products available to consumers in the new- and used-goods markets. If a consumer places great weight on having the most up-to-date and sophisticated version of a game series, she will likely choose the newest generation of this game. This is because manufacturers generally expand and improve product features in their latest offerings. This behavior by durable-goods producers is a form of planned obsolescence, decreasing the value of used products.

A good example that illustrates this incentive is the introduction of textbook editions. Textbook publishers make minor changes to their existing textbook edition, mainly by adding real time tables and new examples into their latest edition. Bond and Iizuka (2004) show the competition from the used book market indeed lowers the price of new books. This result is consistent with the findings of Chevalier and Goolsbee (2009). If a firm wants to reduce the competition from the secondary market, it has to make the new generation of their products more appealing. The firm can improve the quality of the new generation or lower the price of the new generation, or do both. However, quality improvements require investments in R&D spending. Higher R&D costs will restrict the firm's ability to lower the price of its products.

In this chapter, a two-period model is developed in order to investigate a monopolist's equilibrium choice of quality improvement and product price. The impact on the secondary market is shown as well. Both consumers and the firm are assumed to be forward looking. The model shows that a firm with lower R&D costs will increase quality improvements, resulting in lower resale price of the older-generation products. The model shows that a more R&D efficient firm will bring to market higher quality goods in the second period, allowing the firm higher prices and margins of the new good in the second period and lowering the price in the second-hand market.

The main empirical test is to examine whether an inverse relationship between quality improvement in the new generation good and prices in the used-good market exists. As mentioned above, my analysis looks at data from the video game industry. This industry has been growing very quickly over the past 30 years. My focus is on games that have regularly updated new generations including sports games and vehicle simulation games. As introduced in Chapter 1, Data on new good prices and quantities sold are collected, along with price data for each game title from the used good market. A number of different sources provide information on game reviews and compatibility levels, my main gauge of product quality improvement, and data on game characteristics are constructed. The key finding is that used video game prices are increasing in new generation video games prices and decreasing in compatibility levels. However, the game rating differences do not seem to follow the pattern my theory indicates. My results support the idea that the used good prices are endogenously decided by the firm's choices concerning the next generation products.

The main structure of this chapter is as follows. Section 2 provides a literature review on planned obsolescence and quality improvement of durable goods. Section 3 of this chapter introduces the two-period model and its implications. The section after the model consists of an empirical test that is employed to show the main prediction of the theoretical model. Section 5 shows future extensions and conclusions.

2.2 Literature Review

The theoretical literature on planned obsolescence and durable goods recognizes that producers of a durable good choose durability as a fundamental characteristic of the product. Swan (1970, 1971) shows that a producer of a durable good will design their products with the socially optimal durability level, so the quality of the products are not artificially lowered by the manufacturers. Swan's results were shown to be quite sensitive to assumptions about cost structures and substitutability between new and used goods. Indeed, Rust (1986) derives the opposite result by changing a basic assumption in Swan (1970)'s work. Rust assumes the lifetime distribution of a durable good is endogenous. His main conclusion is that a monopolist firm has an incentive to kill off the secondary market by introducing products with short durability, basically incorporating the idea of "planned obsolescence". Waldman (1996) continues this line of inquiry but assumes that new and used goods are not perfect substitutes. In this paper, the model shows that competition from the secondary market lowers the firm's total profit and the firm has an incentive to produce less durable goods in order to reduce competition from the used good market.

The time inconsistency problem faced by a durable good monopolist is the driving force behind the model in Bulow (1982). When the game is set up with a finite number of stages, the monopolist will always over-supply in the last period. Bulow develops a model to show that a monopolist producer will always have a strong incentive to make the durability of the product shorter when consumers are forward-looking and renting is not feasible. Later, both Waldman (1993) and Choi (1994) develop multi-stage models to investigate planned obsolescence. Waldman (1993) compares the circumstances where the monopolist can or cannot commit to second period production. The monopolist who cannot commit to second period production levels always lowers the price and produces more in the second period in order to make a higher profit. In so doing, the monopolist will lower the total social surplus while lowering its own profit in the mean time compared to the commitment case. In Choi (1994), the monopolist's choice of compatibility is considered instead of the choice of product type. The model shows that the monopolist seller will choose to make the second period product incompatible with the first period product. Although offering full compatibility is the socially optimal choice, it will not be achieved. Bond and Iizkua (2004) develop a similar model to describe behavior in the textbook market. They show that textbook producers are more likely to introduce a new textbook edition, decreasing the value of the old edition, when the competition from the used book market grows too strong. An empirical application by Chevalier and Goolsbee (2005) looked at the textbook market and showed that durable good consumers are indeed forward looking, suggesting that the time inconsistency problem, and hence planned obsolescence, may be an important feature of durable goods markets.

Most of the papers discussed above deal with the introduction of a new product by assuming the firm is able to put out a new generation of goods without any difficulties. Waldman (1996) introduces endogenous R&D decision-making into a durable goods model using a two period game. In the first period, the firm faces a problem of deciding the level of R&D investment to undertake in order to improve the quality of the goods in the second period. The model shows that the monopolist firm will have an incentive to over-improve the quality of the second period product. The social welfare level increases as long as the firm in crease the quality in the second period but will not be maximized from a social planner's standpoint. This conclusion follows the main ideas in the previous work on planned obsolescence. By including endogenous R&D decisions into the firm's profit maximizing function, the firm still engages in planned obsolescence. Dhebar(1994) develops a model to investigate product improvement where the consumer population is distributed continuously. The firm chooses both the quality and the price of its products each period in the model. Due to the time-inconsistency problem discussed above, when consumers expect the product to improve in present-value terms, the subgame-perfect equilibrium does not exist.

The existing literature on planned obsolescence provides some interesting results regarding a durable good monopolist's equilibrium behavior. When new products and old products are not perfect substitutes, the monopolist producer will engage in planned obsolescence. If the consumers are forward-looking, the monopolist producer of durable goods will face a time inconsistency problem. A durable goods monopolist has a strong incentive to kill off the second-hand market by introducing new good features or incompatibility; forms of planned obsolescence. However, while other papers on planned obsolescence adopt discretely distributed consumers, Dhebar(1994) assumes continuously distributed consumers but fails to derive a subgame-perfect equilibrium due to the lack of an active second-hand market. Kornish (2001) changes the model introduced by Dhebar (1994) by assuming away the special upgrade offer provided by the firm. Although Kornish (2001) proves the subgame-perfect equilibrium exist, her model also does not include a second-hand market. While affirming the important role of the second-hand market, none of authors attempt to intensively analyze the impact on the second-hand market activities.

It is clear that the second hand market activities will be affected by product innovation strategies. However, it is not quite clear how large this impact is. This chapter shows the effect of quality improvement on second-hand market activities from both theoretical and empirical stand points.

2.3 A Two-Period Model

This model follows Dhebar (1994) and Kornish (2001). I assume only one set of consumers exist in both periods. If consumers are only allowed to buy new products in each period, the model results are relatively clean. In my approach, the same set of consumers exist in both periods but they are now allowed to buy and sell in a used good market in the second period. My model shows that by adding a second-hand market into the model, I am able to obtain subgame perfect equilibrium results.

2.3.1 Model Introduction

The Product

The product of interest is a durable good that does not suffer any physical wear and tear. A monopolist producer is the only producer of this product. This firm chooses prices and qualities of its products in two periods and only produce and sell the most up-to-date products in each period. The quality of the products is measured on a cardinal scale. In the first period, the firm announces the quality of their product version 1, q_1, and the price of version 1, p_1. In the second period, the firm announces their choices of product quality for version 2, q_2, and price, p_2. The products with q_1 quality are not produced any more. After the quality levels of the products are announced, the firm need to pay zero marginal cost to produce the products.

The Consumers

I assume that in each period, a consumer can observe the price and quality of the products at zero cost. The same set of consumers exist in both periods of the game. Consumer hetergeneity is represented by an index number between 0 and 1. All consumer indexes are uniformly distributed over the interval $[0, 1]$.

In the first period, consumers decide whether they want to purchase a unit of product version 1 given the quality level q_1 and price level p_1. In the second period, the firm announces its choices of q_2 and p_2. A consumer who owns a unit of version 1 can choose whether to sell the product in the used good market. If she wants to buy the new product in the second period, she will sell the used good she owns and purchase a unit of product version 2. If she chooses not to participate in the second-hand market, she holds the good she purchased before in the second period. She is also allowed to sell her version 1 product without purchasing the new generation. For a consumer who did not purchase in the first period, she can choose among three options: no purchase, purchase in the second-hand market, and purchase a new product version 2.

For a consumer with consumer index x, the present value of the benefits that she derives if the product has quality q as follows:

$$W(q, x) = f(q)g(x), \tag{2.1}$$

where both $f(\cdot)$ and $g(\cdot)$ are monotonically increasing functions.Consumers share the same discount factor as the firm. The discount factor is indicated by $\delta \in (0, 1)$. In the first period, a consumer makes the consumption choice based on the expectation of the second period firm decisions. In the second period, all first period firm decisions and consumption choices are given, and consumers decide whether they want to participate in the second-hand market or the new good market. I assume that the agents in the model have rational expectations. With this assumption, I will not need to include the expectation symbol when I write down the utility function of each consumer at the beginning of the first period. A consumer with consumer index x will be able to obtain $V_{ij}(x)$ as her utility if she owns product version i at the end of the first period and owns product version j at the end of the second period. $i = 0$ or $j = 0$ indicates the outside option.

To summarize the consumers' consumption choices, they have six choices over two periods. If they stay out of the market and never purchase in either period, their utility function will be:

$$V_{00} = 0. \tag{2.2}$$

Consumers may choose only to purchase a unit of used product in the second period. Their utility will be:

$$\begin{aligned} V_{01} &= 0 + \delta[f(q_1)g(x) - s_2] \\ &= \delta[f(q_1)g(x) - s_2], \end{aligned} \tag{2.3}$$

where s_2 is the used good price. Consumers who only purchase a unit of new product version 2 in period 2 will have utility as follows:

$$\begin{aligned} V_{02} &= 0 + \delta[f(q_2)g(x) - p_2] \\ &= \delta[f(q_2)g(x) - p_2]. \end{aligned} \tag{2.4}$$

For consumers who decide to purchase in the first period, they are allowed to sell the used good and do not buy any products in the second period. If this is the actual consumption choice, the utility will be:

$$\begin{aligned} V_{10} &= [f(q_1)g(x) - p_1] + \delta s_2 \\ &= f(q_1)g(x) - (p_1 - \delta s_2). \end{aligned} \tag{2.5}$$

If a first period buyer decides to keep the used product in the second period, she will obtain a utility level as follows:

$$\begin{aligned} V_{11} &= [f(q_1)g(x) - p_1] + \delta f(q_1)g(x) \\ &= (1+\delta)f(q_1)g(x) - p_1. \end{aligned} \tag{2.6}$$

If a consumer decides to sell her used product in the second period and purchase a unit of product version 2, her utility function will be:

$$\begin{aligned} V_{12} &= [f(q_1)g(x) - p_1] + \delta[f(q_2)g(x) - p_2 + s_2] \\ &= [f(q_1) + \delta f(q_2)]g(x) - [p_1 + \delta(p2 - s_2)]. \end{aligned} \tag{2.7}$$

In a subgame perfect equilibrium, a consumer with index x will choose the consumption choice that generates the highest utility among all V functions in the first period and accordingly in the second period. This is due to both rational expectations and firms not deviating from the equilibrium strategies. s_2 is the market clearing price in the used good market in the second period. p's and q's are the monopolist producer's equilibrium choices. Since the quality improvement is restricted to be non-negative, s_2 has to be smaller than p_2 since no buyers will be willing to purchase a used product version 1 if $s_2 \geq p_2$.

The Producer

The producer chooses p_1 and q_1 at the beginning of the first period. At the beginning of the second period, everything happened in the first period is given. The firm chooses p_2 and q_2 in order to maximize the second period profit. Since the firm does not benefit from the transactions in the second-hand market, the producer has an incentive to introduce a high q_2 so that it can make its product version 2 more attractive to the consumers. However, I assume that the firm has to pay a fixed cost in order to develop a certain level of quality in the first period and some fixed cost again in the second period in order to develop a given level of quality improvement. The size of the fixed cost takes a quadratic form so that the marginal cost of developing quality is increasing. For the firm, the second period profit function will be:

$$\Pi_2 = p_2 \cdot Q_2(p_2, q_2) - \alpha_2(q_2 - q_1)^2, \tag{2.8}$$

where α_2 indicates the fixed cost parameter and Q_2 is the quantity of product version 2 sold in the second period. Since the firm's choices of p_2 and q_2 are made based on the realizations of p_1 and q_1, the second period profit is eventually a function of the first period firm choice variables.

In the first period, the firm has to develop a certain level of quality. They pay a fixed cost to do the R&D. The firm's first period profit is as follows:

$$\Pi_1 = p_1 \cdot Q_1(p_1, q_1) - \alpha_1 q_1^2, \tag{2.9}$$

where α_1 is the fixed cost parameter for the first period and Q_1 is the quantity of product version 1 sold in the first period. I assume that the monopolist producer shares the same discount factor, δ, as the consumers. By combining the two periods' profits, I can derive the firm's total profit function as follows:

$$\Pi = \Pi_1 + \delta\Pi_2 = p_1 \cdot Q_1 + \delta p_2 \cdot Q_2 - \alpha_1 q_1^2 - \alpha_2\delta(q_2 - q_1)^2. \tag{2.10}$$

This is a function of p_1 and q_1. This shows that the firm chooses the quality level and price level in the first period in order to maximize the total profit over two periods. After the first period firm strategies are revealed, the firm announces the second period strategies as planned and the consumers behave accordingly to the firm's choices. The main results of the model show that the monopolist producer will develop different pricing and quality choices in the second period for different exogenous variables.

2.3.2 Backward Induction and Candidates for Equilibria

Assume that the present value function takes a simple functional form:

$$W(q,x) = qx, \tag{2.11}$$

This will simplify the value functions significantly.

$$V_{00} = 0. \tag{2.12}$$

$$V_{01} = \delta q_1 x - \delta s_2. \tag{2.13}$$

$$V_{02} = \delta q_2 x - \delta p_2. \tag{2.14}$$

$$V_{10} = q_1 x - (p_1 - \delta s_2). \tag{2.15}$$

$$V_{11} = (1+\delta) q_1 x - p_1. \tag{2.16}$$

$$V_{12} = (q_1 + \delta q_2)x - [p_1 + \delta(p_2 - s_2)]. \tag{2.17}$$

The index orders consumers according to how much they care about quality. I can prove that in the first period, the consumers who purchase will have higher indexes than the consumers who do not purchase.

Lemma 2.1. *If a consumer with consumer index* $x^* \in [0,1]$ *purchases in the first* *period, all consumers with consumer indexes greater than x^* will be purchasing in the first period.*

Proof. I just need to show that there is a unique cut-off point in the first period. I can solve the equation:

$$V_{10}(x) = V_{00}(x).$$

The root of the equation above is

$$x_1 = \frac{p_1 - \delta s_2}{q_1}.$$

So,

$$\forall x > x_1, V_{10}(x) > V_{00}(x); \forall x < x_1, V_{10}(x) < V_{00}(x). \qquad (2.18)$$

I can show that x_1 is the root of the following two equations as well.

$$V_{11}(x) = V_{01}(x).$$

$$V_{12}(x) = V_{02}(x).$$

I have

$$\forall x > x_1, V_{11}(x) > V_{01}(x); \forall x < x_1, V_{11}(x) < V_{01}(x). \qquad (2.19)$$

$$\forall x > x_1, V_{12}(x) > V_{02}(x); \forall x < x_1, V_{12}(x) < V_{02}(x). \qquad (2.20)$$

If I combine (2.18), (2.19), and (2.20), I find that

$$\forall x > x_1, \max\{V_{10}, V_{11}, V_{12}\} > \max\{V_{00}, V_{01}, V_{02}\};$$

$$\forall x < x_1, \max\{V_{10}, V_{11}, V_{12}\} < \max\{V_{00}, V_{01}, V_{02}\}.$$

This shows that x_1 is the unique cut-off point that divides all consumers into two groups: the buyers and non-buyers in the first period.

□

In order to solve for the subgame perfect equilibrium, backward induction will be employed to solve the model. At the beginning of the second period, the firm announces the price and quality of its product version 2. Consumers who have a unit of used good will consider whether they want to participate in the used good market and whether they want to purchase a unit of the new product. Consumers who have not purchased yet will need to consider whether they will buy a unit of the used product version 1 or buy a unit of the new product version 2 or stay out of the market. Assume the lowest consumer index of the ones who purchase in the first period is $x_1 \in [0, 1]$. Lemma 1 shows that this x_1 exists and it is unique. Furthermore, the value of x_1 will be $(p_1 - \delta s_2)/q_1$ if $(p_1 - \delta s_2)/q_1 \in [0, 1]$. $\forall x \geq x_1$, the consumer with index x will purchase in the first period. $\forall x < x_1$, the consumer with index x will not purchase in the second period.

After the firm announces p_2 and q_2 at the beginning of the second period, for consumers with index $x > x_1$, they need to consider their second period utility. They can either sell their product and stay out of the market in order to obtain $U_{10}(x)$, or keep their used first period good and obtain $U_{11}(x)$ as the second period utility level, or sell the used good and purchase a new product version 2 and obtain $U_{12}(x)$ as the second period utility level, I can derive the functional forms for U_{10}, U_{11}, and U_{12} as follows:

$$U_{10} = s_2 \tag{2.21}$$

$$U_{11} = q_1 x \tag{2.22}$$

$$U_{12} = q_2 x + s_2 - p_2 \tag{2.23}$$

I have to compare the values of these three second period utility functions in order to obtain the second period choices made by these consumers.

$$U_{10}(x) > U_{11}(x), \forall x < \frac{s_2}{q_1}; U_{11}(x) \geq U_{10}(x), \forall x \geq \frac{s_2}{q_1}. \tag{2.24}$$

$$U_{10}(x) > U_{12}(x), \forall x < \frac{p_2}{q_2}; U_{12}(x) \geq U_{10}(x), \forall x \geq \frac{p_2}{q_2}. \tag{2.25}$$

$$U_{11}(x) > U_{12}(x), \forall x < \frac{p_2 - s_2}{q_2 - q_1}; U_{12}(x) \geq U_{11}(x), \forall x \geq \frac{p_2 - s_2}{q_2 - q_1}. \tag{2.26}$$

For consumers who did not purchase in the first period, they have three options in the second period as well. They obtain $U_{00}(x)$ utility if they stay out of the market. They will have $U_{01}(x)$ as their utility level for the second period if they purchase a used product version 1. They will obtain $U_{02}(x)$ as their second period utility level if they purchase a new product version 2. I can write down the functional forms for these utility functions:

$$U_{00} = 0 \tag{2.27}$$

$$U_{01} = q_1 x - s_2 \tag{2.28}$$

$$U_{02} = q_2 x - p_2 \tag{2.29}$$

Simply, I can derive that

$$U_{00}(x) > U_{01}(x), \forall x < \frac{s_2}{q_1}; U_{01}(x) \geq U_{00}(x), \forall x \geq \frac{s_2}{q_1}. \tag{2.30}$$

$$U_{00}(x) > U_{02}(x), \forall x < \frac{p_2}{q_2}; U_{01}(x) \geq U_{00}(x), \forall x \geq \frac{p_2}{q_2}. \tag{2.31}$$

$$U_{01}(x) > U_{02}(x), \forall x < \frac{p_2 - s_2}{q_2 - q_1}; U_{01}(x) \geq U_{00}(x), \forall x \geq \frac{p_2 - s_2}{q_2 - q_1}. \qquad (2.32)$$

When $s_2/q_1 > p_2/q_2$, I have $s_2/q_1 > p_2/q_2 > (p_2 - s_2)/(q_2 - q_1) > 0$; when $s_2/q_1 < p_2/q_2$, I have $0 < (p_2 - s_2)/(q_2 - q_1) < s_2/q_1 < p_2/q_2$. I can show that both s_2/q_1 and p_2/q_2 are less than 1 if the firm maximizes their second period utility.

Lemma 2.2. *In the second period, the monopolist's equilibrium strategy will generate $p_2/q_2 < 1$ and $s_2/q_1 < 1$.*

Proof. If $p_2/q_2 > 1$, according to Eq (2.25), U_{12} will be dominated by U_{10} for all consumers. According to Eq (2.31), U_{02} will be dominated by U_{00}. If none of the consumers have either U_{02} or U_{12} as their highest possible utility level in the second period, the monopolist will have zero sales in the second period. However, the monopolist will never have zero sales in the second period at subgame perfect equilibrium. At the beginning of the second period, all first period strategies have been revealed. As long as the firm keeps the quality level fixed and charges a sufficiently low price, it has positive sales.

If $s_2/q_1 > 1$, according to Eq (2.24) and Eq(2.30), U_{11} and U_{01} will be both dominated. When U_{11} is dominated, consumers who have purchased in the first period will not want to hold on to their used products in the second period. Instead, these consumers will want to supply their products in the used good market. When U_{01} is dominated, consumers who did not purchase in the first period will not purchase in the used good market. In this case, the demand for the used good is zero. This will not be an equilibrium outcome in the used good market, as s_2 will be driven down by the secondary market activities. □

Since I am not able to figure out the comparison between s_2/q_1 and p_2/q_2 at this point, I will have to analyze all possible cases in order to find out candidates for subgame perfect equilibrium. I have three cases: $\frac{s_2}{q_1} < \frac{p_2}{q_2} < \frac{p_2-s_2}{q_2-q_1} < 1$, $\frac{p_2-s_2}{q_2-q_1} < \frac{p_2}{q_2} < \frac{s_2}{q_1} \leq 1$, and $\frac{s_2}{q_1} < \frac{p_2}{q_2} < 1 < \frac{p_2-s_2}{q_2-q_1}$. I next consider possible scenarios for subgame perfect equilibria.

2.3.3 Case I: $\frac{p_2-s_2}{q_2-q_1} < \frac{p_2}{q_2} < \frac{s_2}{q_1} \leq 1$

I only need to know the location of x_1 in order to figure out which consumers are making each specific consumption choice. In this case, I have four possible intervals between 0 and 1 that may contain x_1, the cutoff point in the first period. Since the supply in the secondary market is always positive and the demand for used good is zero, I am able to show that Case I will not be a candidate for subgame perfect equilibrium. Detailed explanations are included in the Appendix.

2.3.4 Case II: $\frac{s_2}{q_1} < \frac{p_2}{q_2} < 1 < \frac{p_2-s_2}{q_2-q_1}$

The same idea applies to Case II. I have to locate the indifferent consumer with x_1 consumer index in the first period. In this case, x_1 can only show up in three different intervals since x_1 cannot be greater than 1. Case II cannot be a subgame perfect equilibrium for the same reason as Case I: the used good supply is positive, and the demand for the used products is zero. Detailed derivations are included in the Appendix as well.

2.3.5 Case III: $\frac{s_2}{q_1} < \frac{p_2}{q_2} < \frac{p_2-s_2}{q_2-q_1} < 1$

There are four possible intervals that x_1 may belong to. In the following part of this subsection, I will analyze different cases in which x_1 belongs to each of the four intervals and show possible subgame perfect equilibrium results.

Case III-I: $x_1 < \frac{s_2}{q_1} < \frac{p_2}{q_2} < \frac{p_2 - s_2}{q_2 - q_1} < 1$

In this case, any consumers who do not purchase in the first period will still stay out of the market in the second period. Consumers who purchase in the first period will sell their used product and not buy again if their consumer index is smaller than $\frac{s_2}{q_1}$. Consumers keep their purchase if their consumer index is between $\frac{s_2}{q_1}$ and $\frac{p_2 - s_2}{q_2 - q_1}$. For consumers with indexes greater than $\frac{p_2 - s_2}{q_2 - q_1}$, they will sell their first period purchase and buy a new product version 2.

$$\forall x \leq x_1, U_{00} > \max\{U_{01}, U_{02}\}; \forall x \in (x_1, \frac{s_2}{q_1}), U_{10} > \max\{U_{11}, U_{12}\};$$

$$\forall x \in [\frac{s_2}{q_1}, \frac{p_2 - s_2}{q_2 - q_1}], U_{11} \geq \max\{U_{10}, U_{12}\}; \forall x \in (\frac{p_2 - s_2}{q_2 - q_1}, 1], U_{12} > \max\{U_{10}, U_{11}\}.$$

As in Case I, the used good supply is positive and there is no used good demand, so there is no subgame perfect equilibrium.

Case III-II: $\frac{s_2}{q_1} \leq x_1 < \frac{p_2}{q_2} < \frac{p_2 - s_2}{q_2 - q_1} < 1$

For consumers whose consumer indexes are smaller than $\frac{s_2}{q_1}$, they will not purchase in either period 1 or period 2. For consumers with indexes between $\frac{s_2}{q_1}$ and x_1, they will choose to purchase a unit of used product version 1 in the second period. For consumers whose indexes are between x_1 and $\frac{p_2 - s_2}{q_2 - q_1}$, they will purchase in the first period and keep their product in the second period. for consumers with relatively high indexes, higher than $\frac{p_2 - s_2}{q_2 - q_1}$, they will purchase in the first period and supply their products in the used good market in the second period.

$$\forall x \in [0, \frac{s_2}{q_1}], U_{00} > \max\{U_{01}, U_{02}\}; \forall x \in [\frac{s_2}{q_1}, x_1], U_{01} \geq \max\{U_{00}, U_{02}\};$$

$$\forall x \in (x_1, \frac{p_2 - s_2}{q_2 - q_1}], U_{11} \geq \max\{U_{10}, U_{12}\}; \forall x \in (\frac{p_2 - s_2}{q_2 - q_1}, 1], U_{12} \geq \max\{U_{10}, U_{11}\}.$$

So the used good supply is

$$S^u = 1 - \frac{p_2 - s_2}{q_2 - q_1}, \tag{2.33}$$

and the used good demand is

$$D^u = x_1 - \frac{s_2}{q_1}. \tag{2.34}$$

I will be able to derive the equilibrium market clearing used good price by equalizing the supply and demand of the used products.

$$1 - \frac{p_2 - s_2}{q_2 - q_1} = x_1 - \frac{s_2}{q_1} \tag{2.35}$$

Case III-II is a candidate for a subgame perfect equilibrium. Consumers' consumption choices will be illustrated in Figure 2.1 in this case. Figure 2.1 shows that consumers with highest consumer indexes will choose to purchase in both period since they have the highest utility levels generated from purchases. Consumers with indexes not as high will choose to purchase in the first period and then keep their purchases in the second period. Consumers with relatively lower indexes will only choose to purchase a unit of used product in the second period. Consumers with the lowest indexes will never purchase.

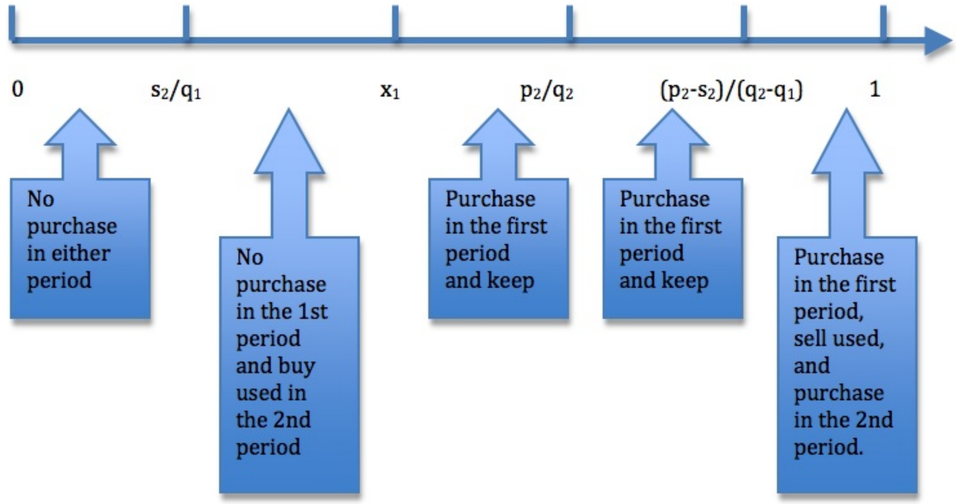

Figure 2.1: Consumption Choices for All Consumers for Case III-II

Case III-III: $\frac{s_2}{q_1} < \frac{p_2}{q_2} \leq x_1 < \frac{p_2 - s_2}{q_2 - q_1} < 1$

If a consumer does not purchase in the first period, she will still stay out of the market if her index is smaller than $\frac{s_2}{q_1}$; she will only purchase a unit of used good if her index is between $\frac{s_2}{q_1}$ and $\frac{p_2}{q_2}$ or her index is between $\frac{p_2}{q_2}$ and x_1. For consumers who have purchased in the first period, she will keep the used product version 1 if her index is between x_1 and $\frac{p_2 - s_2}{q_2 - q_1}$ and she will sell the used good and buy a new product version 2 if her index is greater than $\frac{p_2 - s_2}{q_2 - q_1}$.

$$\forall x \in [0, \frac{s_2}{q_1}], U_{00} > \max\{U_{01}, U_{02}\}; \forall x \in [\frac{s_2}{q_1}, x_1], U_{01} \geq \max\{U_{00}, U_{02}\};$$

$$\forall x \in (x_1, \frac{p_2 - s_2}{q_2 - q_1}], U_{11} \geq \max\{U_{10}, U_{12}\}; \forall x \in (\frac{p_2 - s_2}{q_2 - q_1}, 1], U_{12} \geq \max\{U_{10}, U_{11}\}.$$

The derivation of the market clearing used good price is eventually the same situation as in Case III-II. I will be equalizing Eq (2.33) and Eq (2.34) to find used good price. All consumers' respective consumption choices will be illustrated

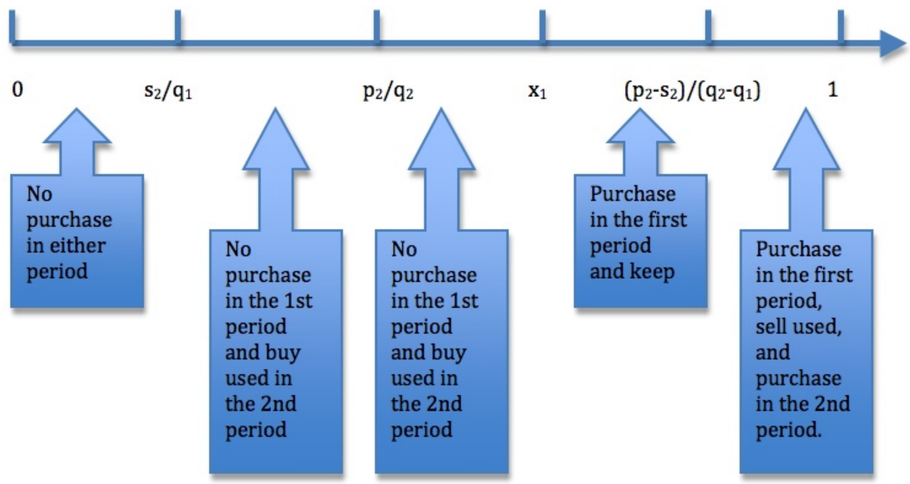

Figure 2.2: Consumption Choices for All Consumers for Case III-III

by Figure 2.2.

Case III-IV: $\frac{s_2}{q_1} < \frac{p_2}{q_2} < \frac{p_2-s_2}{q_2-q_1} \leq x_1 < 1$

If a consumer does not purchase in the first period, she will stay out of the market in the second period if her consumer index is smaller than $\frac{s_2}{q_1}$, she will purchase a unit of used good if her index is between $\frac{s_2}{q_1}$ and $\frac{p_2-s_2}{q_2-q_1}$, and she will purchase a unit of new product version 2 if her index is between $\frac{p_2-s_2}{q_2-q_1}$ and x_1. For all consumers who have purchased in the first period, their second period choice will be selling in the used good market and buying a new product version 2.

$$\forall x \in [0, \frac{s_2}{q_1}], U_{00} > \max\{U_{01}, U_{02}\}; \forall x \in [\frac{s_2}{q_1}, \frac{p_2 - s_2}{q_2 - q_1}], U_{01} \geq \max\{U_{00}, U_{02}\};$$

$$\forall x \in (\frac{p_2 - s_2}{q_2 - q_1}, x_1], U_{02} \geq \max\{U_{00}, U_{01}\}; \forall x \in (x_1, 1], U_{12} \geq \max\{U_{10}, U_{11}\}.$$

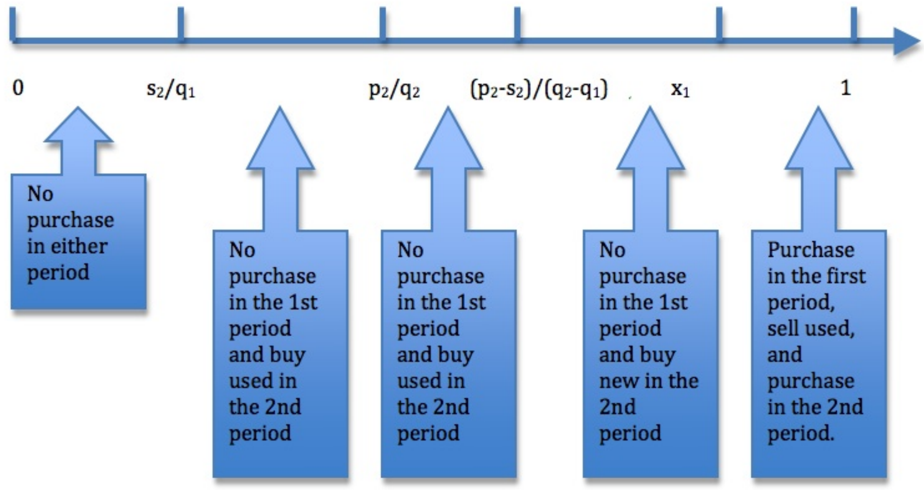

Figure 2.3: Consumption Choices for All Consumers for Case III-IV

In this case, the used good supply is

$$S^u = 1 - x_1, \tag{2.36}$$

and the used good demand is

$$D^u = \frac{p_2 - s_2}{q_2 - q_1} - \frac{s_2}{q_1}. \tag{2.37}$$

I will need to equalize the supply and demand in the secondary market in order to solve for the market clearing used good price.

$$\frac{p_2 - s_2}{q_2 - q_1} - \frac{s_2}{q_1} = 1 - x_1. \tag{2.38}$$

It is straightforward to see that Eq(2.38) is equivalent as Eq(2.35). In this case, consumers with the highest consumer indexes will choose to purchase a unit of new product in both periods and sell their used product in the second period.

Consumers with indexes relatively high will only purchase a unit of new product in the second period. Consumers with lower indexes will only purchase the used products in the second period. Consumers with the lowest indexes will never purchase any products. In Case III-IV, the consumers' consumption choices are illustrated in Figure 2.3.

2.3.6 Solving for Equilibrium

I will use backward induction to solve for the equilibrium results of the model. Thus, I will first solve for the equilibrium choices for the monopolist producer in the second period treating first period variables as given.

Solving for the Second Period

In the second period, the firm makes choices of p_2 and q_2 in an attempt to maximize the second period profit. However, unlike in the first period, it now faces competition from the used good market. The buyers in the first period become potential sellers of the used good and their decision to participate in the used good market raises competition against the monopolist producer's products. Both the firm's pricing choice and quality improvement will affect the second-hand market activities.

When the subgame perfect equilibrium is contained in Case III-II or Case III-III, the used good market supply and demand curves are described by Eq (2.33) and Eq (2.34). When the firm wants to reduce the secondary market activity in order to kill off the competition from the used products, it can either shift the supply curve or shift the demand curve. According to Eq (2.34), the demand curve does not directly contain any firm choice variables so changing either the new good price or the new good quality in the second period will not shift the demand curve directly. If the firm wants to make the second period new good more competitive, it can either lower the new good price, p_2, or develop a larger quality improvement, $q_2 - q_1$. When the firm lower p_2 and keep the quality improvement constant, the supply curve is shifted to the right and the resale price of the used good is lowered. When the firm increases the quality improvement and keep p_2 constant, the supply is shifted to the right as well. Thus the resale price of the used good drops.

When Case III-IV contains the subgame perfect equilibrium, Eq (2.36) and Eq (2.37) will be the corresponding supply and demand functions in the secondary market. The supply curve does not directly involve the monopoly firm's choices. The demand curve will be lowered if the firm lowers the new good price or enlarges the quality improvement. If the monopolist producer chooses either one of these two ways to reduce the demand in the secondary market, the used good price and used good quantity will both decrease.

I see that the firm can adopt a higher quality improvement or a lower new good price in order to make the resale value of the used good price low. However, the resale value is one of the factors that consumers consider when they decide whether to purchase in the first period. If consumers expect a low resale value of the first period products, fewer consumers will be willing to purchase the first period good. In this case, the firm will need to choose an appropriate optimization strategy so that it reduces the resale value of the used good by a proper amount.

The secondary market clearing price can be solved by applying either Eq (2.35) or Eq (2.38):

$$s_2 = \frac{q_1}{q_2}[p_2 + (x_1 - 1)(q_2 - q_1)]. \tag{2.39}$$

The used good price is a function of the second period firm choice variables and the first period cut-off point, which I treat as given in the second period.

Eq(2.8) shows the firm's profit in the second period. I only have to calculate the quantity of new product version 2 sold in the second period. In Case III-II and Case III-III, the new good sales in the second period is

$$Q_2 = 1 - \frac{p_2 - s_2}{q_2 - q_1}. \tag{2.40}$$

In Case III-IV, the new good sales in the second period is

$$Q_2 = (1 - x_1) + (x_1 - \frac{p_2 - s_2}{q_2 - q_1}) = 1 - \frac{p_2 - s_2}{q_2 - q_1}. \tag{2.41}$$

Since Eq(2.40) and Eq(2.41) are identical equations, I am able to get the functional form of the second period firm profit.

$$\begin{aligned} \Pi_2 &= p_2 \cdot Q_2(p_2, q_2) - \alpha_2(q_2 - q_1)^2 \\ &= p_2(1 - \frac{p_2 - s_2}{q_2 - q_1}) - \alpha_2(q_2 - q_1)^2. \end{aligned} \tag{2.42}$$

I am able to write p_2 and q_2 as functions of the first period variables and the exogenous variable α using the F.O.C.s of Eq(2.42).

$$\frac{\partial \Pi_2}{\partial p_2} = 1 - \frac{2p_2}{q_2} - \frac{q_1(1 - x_1)}{q_2} = 0. \tag{2.43}$$

$$\frac{\partial \Pi_2}{\partial q_2} = \frac{p_2^2}{q_2^2} + \frac{p_2 q_1(1 - x_1)}{q_2^2} - 2\alpha_2(q_2 - q_1) = 0. \tag{2.44}$$

The constraints of this profit optimization problem are: $p_2 \geq 0$ and $q_2 \geq q_1$. It is obvious that a firm has no incentive to set a negative price since that will not generate positive revenues. Due to the quadratic form of the fixed cost function, q_2 will not be lower than q_1. These simple facts guarantee that the second period firm strategies will be the solution of Eq (2.43) and Eq (2.44) and neither constraint will be binding.

Solve for the First Period

I have already solved for the first period cut-off point in Lemma 2.1.

$$x_1 = \frac{p_1 - \delta s_2}{q_1}. \tag{2.45}$$

I can replace s_2 using Eq(2.39) and obtain

$$x_1 = \frac{\frac{p_1}{q_1} - \frac{\delta}{q_2}[p_2 - (q_2 - q_1)]}{1 + \frac{\delta}{q_2}(q_2 - q_1)}. \tag{2.46}$$

I can write s_2 as a function of firm choice variables as well.

$$s_2 = \frac{q_1 p_2 + (q_2 - q_1)(p_1 - q_1)}{q_2 + \delta(q_2 - q_1)}. \tag{2.47}$$

Since x_1 is the cut-off point in the first period, I am able to calculate the quantity of new good sold by the producer in the first period.

$$Q_1 = 1 - x_1. \tag{2.48}$$

Substituting Eq(2.48) into Eq(2.10), I have

$$\Pi = p_1(1 - \frac{p_1 - \delta s_2}{q_1}) + \delta p_2(1 - \frac{p_2 - s_2}{q_2 - q_1}) - \alpha_1 q_1^2 - \alpha_2 \delta (q_2 - q_1)^2. \tag{2.49}$$

Since I have p_2, q_2, and s_2 as functions of p_1 and q_1, Eq(2.49) is a function with only two endogenous variables: p_1 and q_1. I will be able to solve out these two variables by adopting the F.O.C.s of Eq(2.49). The constraints of this total profit maximization are: $p_1 \geq 0$ and $q_1 \geq 0$. It is simple to show that the these two constraints will not be binding.

As I can tell from the F.O.C.s of the second period profit function, solving for analytical solutions is difficult due to complicated functional forms of s_2, p_2, and q_2. However, I am able to use calibrations to show the subgame perfect equilibrium of this model.

2.3.7 Simulation and Results

Simulations

There are three exogenous variables in this model; they are the discount factor, δ, and the fixed cost parameters, α_1 and α_2. I need to solve for the subgame perfect equilibrium result for any given set of exogenous variable values.

After the exogenous variables are evaluated, I am able to write out four functions where I have x_1, p_2, q_2, and s_2 as unknowns for a given set of p_1 and q_1 values. These four functions are Eq(2.45), Eq(2.43), Eq(2.44), and Eq(2.39). In this equation system, I have four variables, three exogenous variables, δ, α_1, and α_2, and two given values, p_1 and q_1. I will be able to solve for the four unknowns by using computer programs.

After the four unknowns are solved for each possible set of p_1 and q_1, I am able to calculate the total profit for the firm by using Eq(2.49). In this case, for any given set of p_1 and q_1, the computer program will be able to calculate the corresponding total profit and decide what first period firm choice variable values are maximizing the monopolist's total profit.

However, it is not guaranteed that I will be able to obtain subgame perfect equilibrium results for any exogenous variable values. It is also not guaranteed that for a set of p_1 and q_1 values, the solution to the equation system is rational. I will have to drop solutions where some rational constraints are violated or where the unknown variable values violate the possible cases I discussed above.

The constraints I have here are as follows. They are either rational constraints that make sure the results make sense or constraints that are generated from previous steps.

- First period cut-off point has to be between 0 and 1: $0 \leq x_1 \leq 1$.
- Second period price must be strictly positive: $p_2 > 0$.
- Second period quality cannot be lower than the first period quality: $q_2 \geq q_1$.
- The used good price has to be lower than the new good price but still none-negative: $0 \leq s_2 < p_2$.
- Case III-II, Case III-III, and Case III-IV all require: $s_2/q_1 < p_2/q_2 < (p_2 - s_2)/(q_2 - q_1) < 1$.

I will need to check whether the solution to the equation system satisfies all the constraints. If they do, the profit maximizing bundle, (p_1, q_1), will be the firm's equilibrium strategy in the first period for a given evaluation of exogenous variables. The firm's equilibrium strategy in the second period will be calculated accordingly, as will the consumers' choices.

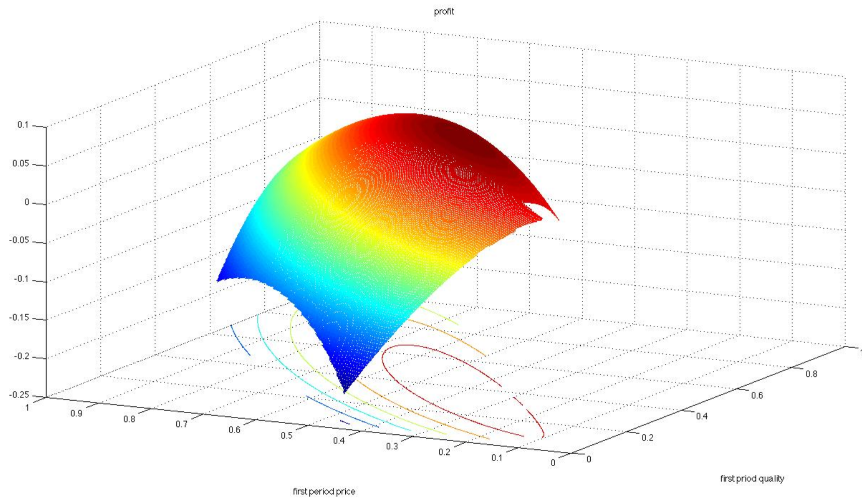

Figure 2.4: Profit Plot: $\alpha = 0.4$,$\delta = 0.6$

Results and Discussion

I obtain the simulation results for my theoretical model by checking the total profits generated by a set of (p_1, q_1) values. The range for both p_1 and q_1 is $[0, 1]$ and is divided up into 500 increments of equal size. The results show that the ranges chosen for these two variables are large enough to include equilibrium choices for these two variables. For the case where $\alpha_1 = 0.4$, $\alpha_2 = 0.4$, and $\delta = 0.6$, Figure 2.4 shows the profit function with p_1 and q_1 as variables. Although I am not able to write out the analytical form of the profit function, Figure 2.4 shows that the total profit is a well behaving function and is maximized at only one set of values for p_1 and q_1. On Figure 2.4, the profit function does not cover the entire area. This is because some values p_1 and q_1 generate other variable values that do not satisfy rational constraints. On Figure 2.4, $(p_1, q_1) = (0.362, 0.39)$ is the maximizer of the profit function. The maximized profit gained in two periods for the monopolist producer is 0.081017. I can calculate other endogenous variables

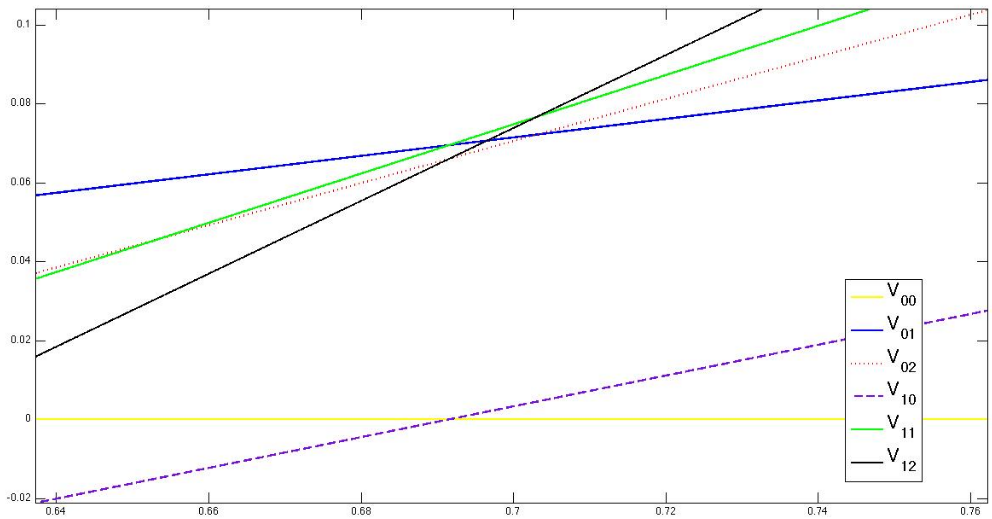

Figure 2.5: value functions: $\alpha = 0.4$,$\delta = 0.6$

accordingly and find out the firm's equilibrium strategies as well as consumer consumption choices.

Figure 2.5 contains the value functions, V_{00}, V_{01}, V_{02}, V_{10}, V_{11}, and V_{12}, for the same exogenous variable values. Figure 5 only shows the value functions for consumers with indexes within the interval $[0.64, 0.72]$[1]. Since all value functions are straight lines, for consumers whose indexes are higher and outside the range, the black solid line will be the highest. For consumers whose indexes are lower and outside the figure, the highest line is the solid yellow line or the solid blue line. Consumers with the highest consumer indexes, where the solid black line is the highest, will consume new goods in both periods. These consumers are the suppliers of the used good in the secondary market. Consumers with relatively higher consumer indexes, where the solid green line is the highest, will consume

[1]I show all value functions for this range of consumer indexes because the green line is the highest only on a short interval and it will not be visible if I show the entire $[0, 1]$ interval.

in the first period and keep the used good in the second period. Consumers with relatively lower consumer indexes, where the solid blue line is the highest, will only consume used goods in the second period. These consumers are the demanders of the used products. The population of consumers who will choose V_{01} and the population of consumers who will choose V_{12} are identical, and they are both the size of the used good market in the second period of the game. In the case shown in Fig 2.5, consumers who purchase new products in the second period all sell their purchases from the first period. These consumers occupy a dominant portion among the buyers from the first period. This illustrates that the secondary market size is considerable. Consumers with the lowest consumer indexes, where the solid yellow line is the highest, will stay out of the market in both periods. Dashed lines are never the highest for any consumers. Therefore, the corresponding consumption choices are never selected.

Table 2.1 includes simulation results I obtained for different exogenous variable values around $(\alpha_1, \alpha_2, \delta) = (0.4, 0.4, 0.6)$. I intend to show the different results for different second period fixed cost parameter given both α_1 and δ being constants. The main reason of doing so is because I want to investigate the monopolist behavior when its ability to develop a certain product from scratch is fixed but the ability of developing new features based on a already developed product is different. In the top part of the table, discount factor δ is a constant with value 0.6 and the first period fixed cost parameter is fixed at 0.4. As the second fixed cost parameter increases, it becomes more and more difficult for the monopolist to develop higher quality improvements, the total profit of the firm decreases, as well as the second period quality. However, the firm that faces a higher fixed cost parameter in the second period will develop its first period product with a relatively higher quality due to limited ability to improve quality

α_1	α_2	δ	Π	p_1	q_1	Q_1	p_2	q_2	s_2	Q_2
0.4	0.2	0.6	0.102946	0.34	0.378	0.301773	0.680692	1.247313	0.126784	0.362821
0.4	0.3	0.6	0.088008	0.352	0.384	0.304724	0.563726	1.010439	0.14169	0.326292
0.4	0.4	0.6	0.081017	0.362	0.39	0.308513	0.5046	0.888879	0.153866	0.296958
0.4	0.5	0.6	0.077171	0.37	0.396	0.314344	0.470241	0.816002	0.164134	0.271177
0.4	0.6	0.6	0.074873	0.378	0.4	0.314691	0.444366	0.762856	0.173128	0.25249
α_1	α_2	δ	Π	p_1	q_1	Q_1	p_2	q_2	s_2	Q_2
0.36	0.36	0.6	0.090017	0.402	0.434	0.310095	0.561997	0.989413	0.170969	0.295968
0.38	0.38	0.6	0.085280	0.382	0.412	0.309467	0.53276	0.93803	0.162501	0.296114
0.4	0.4	0.6	0.081017	0.362	0.39	0.308513	0.504600	0.888879	0.153866	0.296958
0.42	0.42	0.6	0.077158	0.346	0.372	0.307091	0.480385	0.846532	0.147063	0.297578
0.44	0.44	0.6	0.073651	0.328	0.354	0.309737	0.458820	0.807993	0.139411	0.296446
α_1	α_2	δ	Π	p_1	q_1	Q_1	p_2	q_2	s_2	Q_2
0.4	0.4	0.56	0.077170	0.344	0.382	0.317075	0.502306	0.883490	0.148433	0.294357
0.4	0.4	0.58	0.079075	0.354	0.386	0.310607	0.502467	0.885039	0.151542	0.296799
0.4	0.4	0.6	0.081017	0.362	0.39	0.308513	0.504600	0.888879	0.153866	0.296958
0.4	0.4	0.62	0.082987	0.37	0.394	0.306644	0.506818	0.892819	0.15616	0.297018
0.4	0.4	0.64	0.084995	0.38	0.398	0.30110	0.507288	0.894738	0.159122	0.299095

Table 2.1: Simulation Results

later in the game. As the second period quality level is reduced due to higher fixed cost, the firm is not able to charge as high of a price in the second period. Thus, the second period price drops as α_2 increases. This type of firm behavior clearly shows that the monopolist producer engages in planned obsolescence. Even when the firm is relative efficient in the first period at developing the new good quality and relatively inefficient in the second period at developing new features, it chooses to develop the first period quality of its products at a lower level so that the competition raised by these first period products will not be too sharp in the second period. Another way of saying this is, the firm voluntarily produces first period products with lower quality when it is not as powerful at competing against its own products in the second period.

I observe in the middle one third of the table, discount factor δ is fixed at 0.6. As the fixed cost parameters are the same and increase at the same time, it becomes more and more difficult for the monopolist to develop higher quality products. The total profit of the firm decreases, as well as the quality levels in both periods. The quality difference between the two period quality levels will shrink as the fixed cost parameters increase as well. In the bottom one third of the table, the fixed cost parameters are fixed at a constant level of 0.4 and the discount factor is floating. The simulation results show that the total profit of the monopolist producer is increasing as the discount factor increases. The increasing trend of the total profit could be explained by intuition. When consumers evaluate their second period utility higher, everyone expects that the second period consumption is going to be higher in either the new good market or the used good market or both. If people expect more transactions in the used good market, the first period new good sales are going to increase. Thus, the firm will have a higher total profit. In the case where the discount factor is greater,

Variable	Partial Corr.	Significance
p_2	0.9788	0.0000
$q_2 - q_1$	-0.9845	0.000

Table 2.2: Partial Correlations of s_2 with p_2 and $q_2 - q_1$

the monopolist firm is able to charge a higher price in the first period and willing to develop a higher quality as well.

According to my discussion, the firm's choice of price and quality improvement in the second period has effects on the supply and demand curves of the used goods. My discussion shows that the firm has an incentive to engage in planned obsolescence in the sense of developing quality improvement of the second period new good to compete against the used products. The firm's pricing strategy also affects the used good market activities in the second period. The used good price will be able to reach a higher level when the new good price is set higher by the firm. The top one third of Table 2.1 shows that: as the second period fixed cost parameter increases, 1) the new good price is increasing, 2) the quality improvement is decreasing, and 3) the used good price is increasing as well. I can observe the inverse relationship between the quality improvement and the used good price but I fail to see the expected correlation between the new good price and the used good price. The lower two thirds of the table shows an even weaker pattern as expected. This is because both price and quality choices are affecting the used good price in the second period. One way I can show both relationships is by showing the partial correlation between s_2 and $(p_2, q_2 - q_1)$ given all other endogenous variables as control variables.

I have the partial correlations of s_2 with these two variables shown in Table 2.2. I see both partial correlations are statistically significant. The used good price, s_2, is positively correlated with the new good price in the second period, p_2, having all other endogenous variables as controls. The partial correlation between s_2 and the quality improvement, $q_2 - q_1$, is negative. This shows that a lower resale price in the secondary market is associated with higher a quality improvement level, which reflects the idea of planned obsolescence. When firms adopt planned obsolescence by improving the new generation quality, the used good price drops.

The partial correlation table, Table 2.2, gives out an idea that leads to the empirical investigation in the remainder of the chapter. If the firm adopts planned obsolescence in order to compete with its own products, I must be able to employ real world data and estimate an equation where the used good price is the dependent variable and the new good price, the quality improvement measure, and some other control variables are used as independent variables. I will adopt instrumental variables method for estimation due to potential endogeneity of some control variables. My model clearly suggests that all firm decision choices in both periods are endogenous. On the other hand, the model shows that firms' ability levels of developing new features are appropriate instruments. The proposed estimation will generate similar results as the partial correlations. The used good price will be driven down by quality improvement and will be driven higher as the firm charges a higher new good price.

2.4 An Empirical Test

In order to test the main prediction of the theoretical model, I empirically examine the video game industry. The video-game industry lines up well with my research problem for several reasons. First, video games are clearly durable goods that suffer little in the way of physical depreciation with use. Second, video games have an active second-hand market and sales in the used game market are considerable. Third, for a select subset of games, sports games for instance, the introduction of the new generation is regular and relatively predictable. For example, football games always come out at the time when a new football season starts. Thus, timing issues with regard to the introduction of the next generation are not generally a concern for an important class of video games.

2.4.1 Empirical Investigation

Industry

In order to test the main prediction of the theoretical model, I empirically examine the video game industry. The video-game industry lines up well with my research problem for several reasons. First, video games are clearly durable goods that suffer little in the way of physical depreciation with use. Second, video games have an active second-hand market and sales in the used game market are considerable. Third, for a select subset of games, sports games for instance, the introduction of the new generation is regular and relatively predictable. For example, football games always come out at the time when a new football season starts. Thus, timing issues with regard to the introduction of the next generation are not generally a concern for an important class of video games.

Basic Data Introduction

In order to investigate the problem of role of quality upgrading in a durable goods industry with a second-hand market, I use high-frequency data for the video game industry in the United States. My data contain information on weekly sales, weekly prices, and product characteristics at the game-title level. The data contain information on prices and quantities for new games and the selling prices of used games but not information on the quantities sold in the used game market. The price data are available from mid-2008 to mid-2010. As stated in Chapter 1, the weekly price data are provided by Cosmic Shovel, Inc and the weekly sales data are obtained from the VGChartz group. The game characteristic variables are collected separately for each game. The data set includes all recent sport game and vehicle simulation game series; specifically, a game title will be included if the title was released after January 1st, 2006. The data run through May 2010 and any game title released afterwards will not be in the data set.

Regression Equation

As described in the theoretical model, firms will compete with their own used products by setting the price and the quality level of their new generation products. In this empirical investigation, I will employ a basic regression model and illustrate the effects of quality improvement and new good pricing on the used good price in the video game market. The intuition of the second stage of the model in Chapter Two and the regression results in Table 2.2 indicate that the used good price will be lower when the quality improvement is higher and will be higher as the new good price in the second period goes up.

I will adopt the following regression equation according to the relationship between the used good price and the new generation price and quality:

$$p_{it}^{used} = \alpha_i + \beta_0 Old_{it} + \beta_1 Weeks_{it} + \beta_2 Weeks_{it} \times Old_{it} + \beta_3 p_{it}^{new} + \beta_4 p_{it}^{new} \times Old_{it} + \vec{\beta}_5 \Delta_{it} + \beta_6 Stock_{it} + \beta_7 Stock_{it} \times Old_{it} + \beta_8 Xmas_{it} + \beta_9 Xmas_{it} \times Old_{it} + \varepsilon_{it}, \tag{2.50}$$

where p_{it}^{used} indicates the used good price for game title i at time t, $Weeks_{it}$ is the number of weeks that game title i has been available at time t, Old_{it} is a dummy variable that indicates whether game title i is an older generation game title at time t, p_{it}^{new} is the new good price of game title i at time t, Δ_{it} is a vector that measures the quality difference between game title i and the current most up-to-date corresponding game generation at time t[2], $Stock_{it}$ is the total historical sales of game title i up to time t, and $Xmas$ is a dummy variable that indicates the Christmas shopping season.The two interaction terms are included in order to investigate the different effects on the used good price before and after a newer generation is introduced. I have weekly observations for each variable in Eq (2.50).

Traditional planned obsolescence literature has focused on the inter-relationship between quality upgrading and competition from the used good market. I will treat three variables as endogenous in the above regression. The new good price, the stock of existing goods sold and the quality of the good. Clearly, the price of the new good and the stock of the existing good sold will be related to competition from the used good market. Lower used good prices could either affect prices or quantities in the new good market. With respect to quality choice, if firms are forward-looking they may factor in the effect of the second-hand market on their investments in quality improvements. The theory points in this direction. However, from an empirical standpoint, the endogeneity problem may not be so evident, as quality is chosen well before products change hands in the second-hand market. Still, I will treat this variable as potentially endogenous.

The structure of the empirical model allows for general trends in used goods

[2]It is quite obvious that when $Old_{it} = 0$, $\Delta_{it} = \vec{0}$. A more detailed description of this will be shown later.

prices through the $Weeks_{it}$ variable, shifts in the used good prices when new generations are released, and interatctions of these terms. Thus, I control for a very general set of price movements in the used good market, allowing both slope and intercept shifts with the introducation of the new generation of goods. My key test of the model, however, centers around the vector Δ_{it} that includes my proxy variables for quality improvements in the new generation of goods relative to the existing generation. The idea here if quality improvement is high for a given game title, relative to its previous generations, this will put downward pressure on prices in the second-hand market as consumers substitute away from the older games. A critical issue, therefore, is the measurement game quality and improvements in quality across generations. I discuss this below.

My estimation approach will be relatively straightforward, employing a standard panel data framework to analyze the evolution of the used goods price. Fixed effects are included for each game title, time is measured in weeks since a game was introduced and robust or clustered standard errors at the game title-level are incorporated in the estimation of each model.

Price Variables

The key data that form the basis of the estimation is the time-series data on new and used prices. For the new good prices p_{it}^{new}, since I have both the Amazon official new good prices and the third party new good prices available, I have to make a decision of which one to employ in my actual regression. According to an estimate done by Trefis company, the third party sales are 30% of all items sold on Amazon.com. In this case, it makes better sense to use the Amazon new good price as my p_{it}^{new} values. However, I can check the robustness of this choice. A consumer who purchases online can be afraid that the seller is not trustworthy. As one of the leading online business company, Amazon itself is well trusted by the consumers. I would think that the third party new good price will not exceed the Amazon official new good price since consumers will always buy from Amazon directly if the Amazon price is lower. The third party sellers can only charge higher prices than the Amazon price when consumers are not able to buy from Amazon directly. Figure 1.2 shows that the third party new good price can be higher during the shopping season. It is likely caused by the fact that Amazon goes out of stock and not able to provide sufficient supply to the market. If this is the case, I will employ Amazon price during regular time and employ the third party price as the actually market price for the new goods during shopping season. I can use the higher value between the third party price and Amazon price as the p_{it}^{new} in my regression.

Control and Generation Dummy Variables

There are generally strong downward trends in the used good price as a product ages and it will be important to distinguish between these trends and downward movements due to changes in the relative quality of the new generation. All my models will include a very general form of time trends controlling for the time since the game was released and allowing for shifts in the intercepts and slopes of the trends, as new generations are introduced. The idea here is that I want a generous parameterization of the model to help isolate the effects due to quality improvements from trend effects and effects due to the introduction of additional competing products. These effects are captured by the $Weeks_{it}$ and Old_{it} variables and the corresponding interactions.

Recall Fig 1.3, there are seasonal effects in the data, especially as consumption rises during the Christmas shopping season. I include a dummy for the shopping season and any week that ends between November 25th and January 2nd will have the Christmas shopping dummy value set to 1. In addition, I control for the overall stock of items sold as an estimate of the potential supply of used goods. The stock variable is calculated by adding up all historical quantity sold in every week. I show the mean game sales for all games and only football games in each week after the introduction in Figure 1.3[3]. The seasonal trend is shown better for the football game quantity series and the Christmas shopping season is easily captured by the diagram. I am able to construct this variable because I have weekly sales of each game title during the time period in my data set. When there is a larger stock, the competition among sellers in the used good market is likely to put downward pressure on the used good price.

Quality Measure and Characteristics Variables

One of the key measurement challenges I face is to quantify the quality difference between an existing good and the new generation of goods. Clearly, characterizing game product attributes is a difficult task and I will rely on a number of alternative measures; however, a main source of information on product quality differences come in the form of game reviews. I measure game quality and change in game quality by combining information from the ratings and some standards of the game titles. In the actual regression part, I include only "Critic Score" as the quality measure.

The other variable to consider that deals with game characteristics is the number of compatible platforms a game serves. Normally, a more popular game will be compatible to a greater number of platforms, which might illustrate a higher

[3]The first week is not shown since the pattern will not be as visualized if I include the extremely high football game sale in the first week of introduction.

quality game. Furthermore, since a certain game generation will not necessarily release game titles for all consoles at the same time, the number of compatible platforms can differ by game title and by game generation over time. I see some game generations start with a compatibility level and later become compatible to more consoles. In this case, it is nature to assume that this game generation has a been a success and the firm is willing to put additional R&D into developing game titles for more platforms. Since a greater compatibility level means greater investment in R&D costs, only firms with better R&D ability develop their game generations compatible to more consoles. This also tells that the compatibility level and game quality are associated.

Since I care more about the quality improvements, I develop measures of such variables by using the difference between the variable of the game title in interest and the variable of the newest generation in the game series that my game title in interest belongs to. I develop variables "Δ*GS Critics*" and "Δ*Compatibility*" as quality improvement measures[4].

Instrumental Variables

The estimation strategy discussed above involves the use of instrumental variables methodology. In particular, the new good price, the stock of existing goods sold, and product quality will be treated as endogenous variables. My approach for both the new good price and stock variables is to rely on lagged values of price and quantity variables as the instruments. Recall the new good price is measured in two ways. For each formulation, I will use the lagged value of the Amazon new good price as the instruments, with a four week lag. The assumption is that

[4]A more detailed discussion of the development of these two variables can be found in the Appendix.

consumers considering purchasing in the used good market only use relatively recent information on new good prices in their decision to purchase a used good. Thus, using a four week lag seems appropriate; however, I check the robustness of this assumption by allowing for alternative lag structures in supplementary analyses.

The stock variable is likely endogenous, as well, in my model. I take a similar approach to the new price variable and instrument the stock variable with a lagged value. In this case, I assume that shocks to the used good market price, which might effect demand in the new good, die out relatively quickly. Again, I employ the stock value lagged four weeks.

I also treat the quality improvement as endogenous in my regression equation. Lagged values are inappropriate instruments in this case, since product quality differences are measured infrequently in my data. Fortunately, I am able to construct a set of variables that I believe are correlated with game title quality. These variables are based on quality measures of the producers of the game titles. Like individual video games, there are industry rankings on game publishers and developers. I construct not only the developer score and publisher score but also the differences of these two scores as the instruments for the difference of game review rating score and the difference of compatibility level since both of these two measures of quality difference are believed to be endogenous. The way of constructing the developer score difference and publisher score difference is the same as the construction of "$\Delta GS\ Critics$" and "$\Delta Compatibility$".

p^{new} Choice	me_a		$\max\{me_n, me_a\}$	
	Coefficient	Std. Error	Coefficient	Std. Error
Old	-459.10***	172.88	-213.84	143.98
p^{new}	0.617***	0.024	0.5568***	0.0206
$p^{new} \times Old$	-0.224***	0.0354	-0.2211***	0.0301
$Weeks$	-14.38***	0.901	-14.47***	0.786
$Weeks \times Old$	9.682***	1.223	8.718***	0.997
$Xmas$	180.645***	26.282	203.92***	22.38
$Xmas \times Old$	-49.877	32.121	-104.24***	27.617
$Stock$	-0.0012***	0.000	-0.0013***	0.0001
$Stock \times Old$	0.0003***	0.000	0.0002***	0.000
$\Delta Compatibility$	-335.83***	32.464	-142.08**	27.144
$\Delta GS\ Critics$	343.43***	76.833	324.82***	61.60
$Cons$	1181.56***	120.38	1307.31***	109.25
R-squared	0.4740		0.6130	
# of Obs	8704		8704	

***: significant at 1% level; **: significant at 5% level; *: significant at 10% level.

Table 2.3: Regression Results

2.4.2 Empirical Results

I offer two alternative specification that vary with the specific new good price included in the model. I present my empirical results in Table 2.3. Overall, I see quite consistent estimate for both regressions. My empirical results show that the used good price decreases over time. However, when the game title is not one of the newest generation game titles, the decreasing trend has a flatter slope in the sense that the speed of depreciation is slower. On average, the used good price of newest generation product falls by 14 cents per week. After the game titles ages, the used good price will only be lowered by 4 to 5 cents every week.

Looking at the effect of the new good price, I see it is both positive and statistically significant. More competition from new goods depresses used good prices. For new generation games, if the retailers set the new good price 1 cent higher, the used good price will rise by 0.6 cents. When the game title gets old, the same increment of the new good price has a more muted effect, increasing by only 0.3 cents.

The Christmas shopping season variable has the expected effect – prices rise in the holiday season. Overall, a newest generation game title's used good price will increase by approximately $2 during the Christmas shopping season compared to goods sold in other periods.

The amount of historical sales of a particular game title indicates the potential supply in the secondary market. Not surprisingly, the coefficient on *Stock* is negative and statistically significant. The magnitude of the estimate indicates that when the total stock increases by roughly 1000 copies, the used good price drops by 1 cent. When the game title gets old, it will take around 1000 copies increment in the total stock to reduce the used good price by 1 cent.

The compatibility variable is also negative and statistically significant at the 1% level. This shows that when the new generation is compatible to more consoles, the used good price of the older game titles will be reduced. This is consistent with the idea that quality improvement can reduce the resale price of the used goods and the number of consoles served by a game is a proxy for game quality. That is, higher quality games are ported to a wider variety of consoles.

Up to this point, all my findings agree with either the theory presented or with basic priors. However, my current models show that my main measure of quality – based on game critics' reviews, is positive and statistically significant. This result is clearly not consistent with the theory. However, there may be several plausible explanations for the finding. One is purely a measurement issue in the data. In general, I observe a downward sloping trend of the overall game ratings. This means that the consumers have been more and more critical towards new games. A decrease in the absolute rating score does not necessarily show that the new game is worse than the older games. In further extension, I will develop models that remove this trend in critics' game reviews from the analysis. The other reason is that if the new game generation has a better quality, consumers raise their interests towards the older generation game titles. This increasing interest makes the used good price increase.

2.4.3 Robustness Check

An alternative way to measure the quality of a game title is using the system requirements. When a game requires a more sophisticated platform to run, this game tends to have a better image quality and higher standards. Unfortunately, there are problems with employing system requirements as quality measures. First of all, a game title is only compatible to one game console and the console features are fixed relative to different game titles in the sense that all games compatible to a certain game console will have the same system standard observations. A game title might have the same game generation compatible to personal computers. However, this raises the second problem. PC system requirements will vary across different game generations but will be the same across different game titles within the same game. Still, PC system requirements may be used as a good measure of the quality levels of game generations. The third problem with adopting the system requirements is that not all games have a title that is compatible to personal computers. So the data availability will be limited if I measure game qualities in this way. The last potential problem is that consumers have to purchase a console first in order to buy video game discs. When the newer generation games have much higher system requirements, the newer generation games may be too sophisticated for a consumer's current console to run. In this case, a consumer might be forced to purchase the used product instead of the new one.

A PC game will have a set of minimum system requirements and a set of recommended system requirements. They include system requirements for memory space, hard drive space, video, and processor speed. Due to the greater data availability, I employ the minimum system requirements as quality measures rather than recommended system requirements. Since I only have two instrumental variables for the quality measures, I will include one system requirement variable and the variable $\Delta GS\ Critics$ as quality measures. Due to the high correlation between $\Delta Memory\_Req$ and $\Delta Hard\_Req$, I only include results where $\Delta Memory\_Req$ is included in the regression equation. Table 2.4 shows estimation results of some alternative regressions where me_a is used as the new good price in all regressions.

I observe similar estimation results as in Table 2.3. More importantly, the coefficients for the quality change variables now make much better sense. The change in rating variable is now negative and significant for two cases. This shows the negative effect of quality improvement of the newer generation on the older generation used good prices. On average, if the rating of the newer generation is increased by 1, the used good price for the older generation game title will be reduced by $4.8. The change in system requirements have statistically insignificant positive coefficients. This fact shows that the last problem with using system requirements to measure game quality level can be critical in affecting my estimation. However, since the system requirement change variable is never significant, it seems a new generation video game with higher PC system requirements is not going to raise the resale price of the old generation of the same game.

	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
Old	2150.148***	344.168	2345.986***	361.23	2122.087***	291.43
p^{new}	0.443***	0.0605	0.442***	-0.689	0.519***	0.067
$p^{new} \times Old$	-0.669***	0.082	-0.688***	0.088	-0.648***	0.08
$Weeks$	-5.78***	1.67	-6.01***	1.667	-6.971***	2.197
$Weeks \times Old$	-13.79***	2.381	-13.81***	2.41	-10.68***	2.233
$Xmas$	120.398***	37.22	116.768***	38.15	150.13***	41.097
$Xmas \times Old$	-165.96***	62.42	-169.69**	63.299	-183.18***	62.53
$Stock$	-0.005***	0.0003	-0.005***	0.0003	-0.0045***	0.0003
$Stock \times Old$	0.0014**	0.0006	-0.0012***	0.0003	0.001***	0.0003
$\Delta Prcsr\_Req$	125.15	222.747				
$\Delta Memory\_Req$			0.357**	.638		
$\Delta Video\_Req$					-0.444	.998
$\Delta GS\ Critics$	-484.707**	212.34	-482.55 **	212.698	-268.37	260.62
$Cons$	2056.991***	262.64	2062.91***	263.72	1833.99***	288.68
R-squared	0.2548		0.2479		0.3912	
# of Obs	2939		2939		2571	

***: significant at 1% level; **: significant at 5% level; *: significant at 10% level.

Table 2.4: Alternative Regression Results

2.5 Conclusions

The theoretical model in this chapter shows that the producers of durable goods are able to reduce the competition from the secondary market of their own products. While firms has a strong incentive to develop new generation products with highest possible quality level in order to make the products they previously sold as obsolete as possible, their ability of developing high quality products are limited. This restriction on R&D makes the firms combine pricing strategies and quality improvement in order to compete with their own products in the secondary market. The regression results of my empirical model mainly supports the hypothesis raised by the theory. The firm is always able to compete against its own used good by adopting lower new good prices. Since the firm always likes higher price margins, it has to use quality improvement to kill off the competition. I find the inverse relationship between quality improvements and used good prices in one of the two quality measures I employ.

For further extension, I will develop a better measure for game title quality levels. I will need to adjust all rating scores of a game title according to the average ratings received by similar games that are released in the same time span in order to accommodate for the decreasing trend of the overall game ratings. I may consider more sophisticated econometrics techniques that I may employ to analyze my data. Since I have affluent time variance in the price and quantity data. I will be able to consider a dynamic panel structure of my data set and investigate the effects of prices and quality improvements on the used good price.

Due to the availability of the weekly sales data, some research along the line of BLP models may result in interesting insights as well. Since all consumers of durable goods will have a chance to sell their purchases in the secondary market, consumers are not really paying the retail prices of the durable goods. By imposing a structural model to consumer consumption choices and firms' behaviors, I will be able to obtain different results than a traditional differentiated product model. This work is shown in Chapter 3.

Chapter 3

Discrete Choice Model Estimation with Used Market Activities

3.1 Introduction

When you step into a video game store, you will find almost all the newest releases of the current year on the shelves and many other older generations of video games in the baskets near the shelves. If you open the Amazon.com or other online stores' websites, you will see it is even easier to find older generations of video games. A video game consumer knows the existence of the secondary market and uses the secondary market to earn resale prices for the games she does not want any more. Since a video game owner is able to participate in the second hand market, she does not necessarily incur the full retail price in order to own a video game for a period of time.

In this chapter, I employ data from the video game market in order to estimate a differentiated products model and quantify the impact of the second hand market on new good prices. Video games have an active second hand market because they are durable goods that suffer little from wear or tear. Video game producers frequently introduce new generations of video games into the market. The new games compete with those of other video game producers and with the firm's own older generations of products. Such behavior is defined as planned obsolescence. These properties require me to emphasize rental price, which is the difference between the retail price and future resale price, as well as the retail price and to consider carefully how to calculate the actual price incurred by a consumer in order to play a video game.

The most important hypothesis I test is that rental price plays a more important role than the straight retail price. For instance, if the resale price for a certain video game is very high, a consumer might still be willing to purchase this game at a very high retail price. This is because the actual price paid by the consumer in order to experience all the features of the game is not very high if she is going to sell the game in the second hand market. I construct the demand side equation in multiple ways in order to show the difference between models with just retail prices included and models where both retail prices and used good prices are considered. The results show that it is necessary to include not only the retail prices but the resale prices as well.

Traditional differentiated products models developed by Berry (1994), Berry, Levinsohn, and Pakes(1995), henceforth BLP, Nevo (2001), and others employ retail prices as the prices actually paid by the consumers. This is valid when the product of interest is either non-durable or does not have an active second hand market. The scarcity of data from secondary markets has also restricted researchers from looking into rental prices. More recently, Gordon (2006) and

Gowrisankaran and Rysman (2008) change the traditional BLP model into a dynamic model. However, in these dynamic BLP models, retail prices are still used primarily as the actual price for the product of interest. In this chapter, rental prices in the video game market will be used as the prices paid by consumers. Schiraldi (2011) includes the second hand car market in his investigation of the Italian automobile industry. Although the main purpose of his paper is to estimate the transaction cost, his paper is able to show the significance of the second hand market in the automobile industry. With the rental prices, I am able to show more reasonable and accurate estimation results compared to the ones obtained by employing only retail prices.

The mechanism that decides the resale price of a durable good plays an important role in determining the rental prices. Most durable good producers face competition not only from their competitors but also from the used versions of their own products. In this case, durable goods competitors engage in planned obsolescence in order to reduce the competition from the secondary markets. Such behavior is studied by Rust (1986), Waldman (1996) and others. When the producers are using the new generation products to compete against older generations of products, the resale value of a used product of older generations will rely on the quality improvement of the newest generation. Dhebar(1994) and Kornish (2001) attempt to explain the effects of quality improvements, they find it difficult to guarantee the existence of subgame-perfect equilibrium when the secondary market activities are not included. Chapter 2 incorporates endogenous quality improvement levels chosen by the producer and the second hand market activities and find out a relationship between the used good prices and the quality improvement levels.

With the development of the video game market, more and more studies are done in this industry. Nair (2007) uses a dynamic model to investigate producers' pricing decisions when they face forward-looking video game consumers who tend to hold their transaction decision and wait for lower prices. Ishihara (2010) adopts a dynamic differentiated product model with second hand market transactions and finds out that the existences of the second hand market and the rental price actually help the video game producers to raise their overall revenue. Due to the availability of the prices and quantities of new and used video game titles combined with used game titles' trade-in prices and the inventory levels for each used game title, he is able to estimate the depreciation of consumption values and the elasticity values that account for inter-temporal substitution. His results show that the existence of the secondary market in the video game industry is indeed able to influence the demand of the new game titles. Lee (2010) attempts to show that video game market incumbents are able to create higher profits by making some video game titles only compatible to their own consoles. From the previous literature, I see a clear platform effect. Video games can only be played on certain consoles. I am not going to explore this network effect in this project, but I will include video games that are compatible to a large number of consoles.

The main structure of this chapter is as follows. Section 2 provides an introduction of the data. Section 3 of this chapter introduces the empirical model and estimation methods. The section after the model consists of estimation results and some further discussions. Section 5 shows future extensions and conclusions.

3.2 Data Introduction

As stated in Chapter 1, my data covers video games of two genres: sports and vehicle simulation. I include all video games of these two genres that are a member of a game series and are released between January 1, 2006 and May 1, 2010. I only include games that belong to a series of games since I intend to investigate the impact on the future resale values of video games that is caused by characteristics differences between different generations of games. In this case, I only collect data for games that are a part of a game series. My data set for this chapter contains new good price, second hand good price, new good weekly sales, and product characteristics for each game title that is included.

3.3 Model and Estimation Methods

In my model, I adopt the basic settings from the Berry(1994) model. I assume that consumer i will obtain utility u_{ijt} if she owns product j in time period t:

$$u_{ijt} = x_{jt}\beta - \alpha p^r_{jt} + \xi_j + \Delta\xi_{jt} + \varepsilon_{ijt}, \tag{3.1}$$

where x_{jt} are product characteristics at time t, p^r_{jt} is the rental price at time t (retail price at time t minus potential resale price at time t), ξ_j are unobserved product specific value, $\Delta\xi_{jt}$ is a product time specific deviation from the all time mean value, and ε_{ijt} is a zero-mean idiosyncratic error term. Assume $i = 1, 2, \cdots, N$, $j = 1, 2, \cdots, J_t$, and $t = 1, 2, \cdots, T$. J_t is number of new video game titles available at time t.

More specifically, my model is different from the typical discrete choice demand model due to the price term in the utility function. Since durable good owners will be able to sell their products in the second hand market for a resale price, consumers in durable good markets do not actually pay the retail prices in order to enjoy the utility of a durable goods. If one wants to obtain accurate estimates of the own and cross price elasticities and price elasticities of other product characteristics, adopting a correct rental price, p^r_{jt}, is critical. I will explore multiple ways to construct the rental price in the later part of the chapter.

In the notation of the previous literature, the mean utility for game title j in period t is:

$$\delta_{jt} = x_{jt}\beta - \alpha p^r_{jt} + \xi_j + \Delta\xi_{jt}. \tag{3.2}$$

If a consumer chooses not to own a good at time t, she will obtain an indirect utility level that is given by the outside option, indicated by $j = 0$:

$$u_{i0t} = \delta_{0t} + \varepsilon_{0t}, \tag{3.3}$$

where δ_{0t} is normalized to zero.

Consumers are assumed to purchase at most one copy of a new video game title in each time period. Consumers choose product j that maximizes their utility at time t.

I adopt the Logit model, where the market share for product j at time t is calculated as:

$$S_{jt} = \frac{e^{\sum_{j>0}\delta_{jt}}}{1 + e^{\sum_{j>0}\delta_{j,t}}}. \tag{3.4}$$

Berry (1994) shows that the parameters of the utility function can be recovered using regression Eq(3.5),

$$\ln S_{jt} - \ln S_{0t} = x_{jt}\beta - \alpha p^r_{jt} + \xi_j + \Delta\xi_{jt}. \tag{3.5}$$

The market share for game title j in period t is constructed by using the quantity of game title j sold in period t divided by the total sales of the console that plays game title j by the end of the year that week t belongs to. The outside share is calculated using one minus the summation of weekly quantities at time t of all game titles that are included in my data.

The product characteristics vector x_{jt} includes a quality measure of product j, the quality difference between product j and the newest product in the game series that product j belongs to, the total sales of product j until time $t-1$, the total sales of the console that plays product j until the year before time t, a dummy variable (old) that indicates whether this game title j is the newest generation game, the number of weeks this game title has been released, a dummy variable ($xmas$) that indicates whether time period t is during the Christmas shopping season, and some interaction terms.

For the game quality measure, I include a measure of quality and a measure of quality improvement. I adopt the critic rating on Gamespot.com, "$GSCritics$", to measure game quality. I use the difference between the rating of the game title of interest and the rating of the newest generation game title of the same game series ("$\Delta GSCritics$") to measure the quality improvement of the game title of interest. Obviously, the quality measure will show a zero if the game title of interest is of the newest generation in that game series at time t. Due to the limited ability to collect data, the game quality measures are time-invariant and the quality improvement measures are time variant since they change when a new generation is released. A game series dummy is included as well to pick up the common facts of all game titles in each game series.

The error term in Eq(3.5) has the form of $\xi_j + \Delta\xi_{jt}$. If I do not include game title dummies, I am likely to have a problem with endogeneity that ξ_j is correlated with prices. I would be able to take care of the endogeneity problem by adopting fixed effects. However, due to the lack of time-variant quality measures of game titles, I have to estimate the model using random effects. In order to control for the overall quality of each game series, I include game series dummies. I include console dummies to control for the effects brought by each different gaming consoles. Some instrumental variables will be considered for taking care of the endogeneity problem. I show later in the results that the endogeneity problem is not very severe to begin with.

3.3.1 Identification

In order to obtain unbiased estimators for Eq(3.5), I need to make sure that both price and characteristics are not correlated with the error term. However, an endogeneity problem is likely to be in existence. So, the estimation discussed above involves the use of instrumental variables methodology. In particular, the price and product quality will be treated as endogenous variables. My approach for the price variable is to rely on lagged values of new good and used good price variables as the instruments. Since I have both the Amazon new good price, the third party new good price, and the used good price in my data set, I will used lagged values for all three variables as instruments for price observations in Eq(3.5). I also treat the quality improvement as endogenous in my regression equation. Lagged values are inappropriate instruments in this case, since product quality differences are measured infrequently in my data. Fortunately, I have variables in my data set that describe the video game producers' ability levels. According to the model in Chapter 2, these variables can be used as instruments for quality measures. Variables "developer" and "publisher" will be employed as instruments.

3.3.2 Different Estimation Models

Before I actually run any regression based on Eq(3.5), I consider several possible models that I can estimate. These models are different across the the choice of price observations and rental price constructions.

Model One

In order to obtain a comparison between the adoption of rental prices and the adoption of retail prices in Eq(3.5), I first consider only the retail price. Recall that I have two price series in the data: Amazon official new good price and the third party new good price. At most times, the third party new good price is lower than the Amazon official price for a certain product. According to an estimate done by Trefis company, the third party sales are only 30% of all items sold on Amazon.com. It makes better sense to utilize the Amazon price over the third party new good price. However, the third party new good price can be higher during the shopping season. It is likely caused by the fact that Amazon goes out of stock and is not able to provide sufficient supply to the market. I can use the higher value between the third party price and Amazon price as the price in my regression. The retail price can be shown in an equation as follows,

$$p_{jt}^{new} = \max\{p_{it}^{a}, p_{jt}^{n}\}. \tag{3.6}$$

I use p_{jt}^{new} as p_{it}^{r} in Eq(3.5) to run the regression.

Model Two

Model two adopts a rental price instead of the retail price. This rental price is constructed by using the retail price at time t minus the used good price at time

$t+1$. In this case, I am assuming that consumers have perfect foresight of the future resale price and the future resale price is exogenous to consumers at time t. For the used good price p^u, I simply adopt the used good price observations, us^u, from my data set. This rental price can be shown as:

$$p^1_{jt} = p^{new}_{jt} - p^u_{j,t+1}. \tag{3.7}$$

I employ p^1_{jt} as the rental price in the main regression in Model Two.

Model Three

Some may argue that consumers do not have perfect foresight about the future resale price. The used good price in the future is decided based on some known knowledge at the current time period and a random error. As in Gowrisankaran and Rysman (2008) and Schiraldi(2011), I assume the used good price at time $t+1$ is decided solely based on the information at time t. Furthermore, I assume the used good price at time $t+1$ is decided according to an equation as follows,

$$\begin{aligned} p^u_{j,t} = {} & \gamma_0 + \gamma_1 p^{new}_{j,t-1} + \gamma_2 p^u_{j,t-1} + \gamma_3 stock_{j,t-1} + \gamma_4 old_{j,t} \\ & + \gamma_5 weeks_{j,t} + \gamma_6 weeks^2_{j,t} + \gamma_7 xmas_{j,t} + \alpha_i + u_{j,t}. \end{aligned} \tag{3.8}$$

I believe that the used good price is determined by previous new and used good prices combined with some other characteristics. According to Fig 1.1, the used video game price declines over time. However, the slope of the used good price is becoming flatter as the game title gets older. I include both the linear and quadratic terms for the number of weeks the product j has been released. $stock_{j,t-1}$ is the number of product j sold until time period $t-1$. This variable describes the population of potential sellers in the secondary market.

Dummies *old* and *xmas* indicate wether product j is already not one of the newest generation game titles and wether period t is during a Christmas shopping season. Both of these two variables affect the resale price at time t. Since the price and stock variables are from the previous time period, there is not a strong endogeneity problem in estimating this first stage.

I can test whether Eq(3.8) contains autocorrelation. By running a Wooldridge test, I reject the hypothesis that there is no autocorrelation in the panel data regression in Eq(3.8). This conclusion suggests that there is autocorrelation in Eq(3.8). After I have estimated all the parameters for this first stage, I will be able to obtain a prediction of the future resale price, $\widehat{p^u_{i,t+1}}$, for each product at each time period by calculating the fitted value of Eq(3.8). Now I can construct a new rental price using the current retail price and the predicted future used good price:

$$p^2_{jt} = p^{new}_{jt} - E(p^u_{j,t+1}) = p^{new}_{jt} - \widehat{p^u_{j,t+1}}. \tag{3.9}$$

I will use this rental price in Eq(3.5) for model three.

Model Four

It is true that consumers who purchase brand new video game titles do not all participate in the second hand market. If only a small portion of new video game buyers intend to sell their video games for the resale price, the rental price might not play such an important role in their decision making. In this case, I attempt to show that both the retail price and the expected future resale price have to be included in my main regression, Eq(3.5). Assuming perfect foresight of the future resale price, I can rewrite Eq(3.5) as follows,

$$\begin{aligned} \ln S_{jt} - \ln S_{0t} &= x_{jt}\beta - \alpha(p_{jt}^{new} - \kappa \cdot E_t(p_{j,t+1}^{u})) + \epsilon_{jt} \\ &= x_{jt}\beta - \alpha(p_{jt}^{new} - \kappa \cdot p_{j,t+1}^{u}) + \epsilon_{jt}. \end{aligned} \tag{3.10}$$

I am assuming that consumers include both the current period retail price and the next period resale price into their considerations before they purchase a video game title. The adoption of the actual future resale price is based on the assumption of perfect foresight. By regression Eq(3.10), I can test the significance of κ and illustrate the participation of video game buyers in the second hand market using the estimated κ value as well. When κ takes a small value, it means that the majority of consumers who buy brand new video games do not consider reselling in the second hand market. A large κ value confirms my idea that rental price is the real price paid by a consumer for a video game title. Model two can be interpreted as a specific version of this model where κ is fixed at 1.

Model Five

If I do not assume that consumers can predict the next period used good price perfectly, I will employ the predicted future used good price instead of the actual value. I rewrite the main regression equation as

$$\begin{aligned} \ln S_{jt} - \ln S_{0t} &= x_{jt}\beta - \alpha(p_{jt}^{new} - \kappa \cdot E_t(p_{j,t+1}^{u})) + \epsilon_{jt} \\ &= x_{jt}\beta - \alpha(p_{jt}^{new} - \kappa \cdot \widehat{p_{j,t+1}^{u}}) + \epsilon_{jt}. \end{aligned} \tag{3.11}$$

The same idea applies here. I will be able to use the regression results of Eq(3.11) to show two things. First, consumers include the possibility of selling the video game title in the second hand market when they decide to purchase a new video game title. Second, the magnitude of κ shows how often consumers actually think of and participate in the secondary market.

Obviously, all of the five models listed above have an endogeneity problem. Prices and quality measures are endogenous variables. Thus, instruments will be used to obtain unbiased estimates. In order to differentiate game series, dummy variables that indicate which game series the game title of interest belongs to are included in all five models. Dummy variables that indicate which platform is each game title compatible to are included as well.

Model Six

I adopt the settings in model five and ignore the possible endogeneity problem. Model six will run an OLS regression. I show in the results that the OLS regression and IV panel data regression generate similar but not identical results. Thus, the endogeneity problem is worth some attention in my investigation.

3.4 Empirical Results and Experiments

3.4.1 Empirical Results

When I estimate the demand model using model three or model five, I need to obtain predicted future resale prices. I have to run a first stage regression using Eq(3.8). As discussed and tested before, I will run the regression using fixed effects with AR(1) error term. The first stage results are shown in Table(3.1). With these results, I am able to use the fitted values for $\widehat{p^u_{j,t+1}}$ as the expected used good price. I will be able to fully execute my empirical investigation with model three and model five.

The first stage results tell me how consumers of new video games predict the future resale value of their game titles. The current new game title price and current used good price both have positive and statistically significant effects on the next period used good price. The quality difference of the game title of interest and the game title of the newest generation has a negative but not statistically significant effect on the future resale price. When the current retail price and used good price is one dollar higher, the used good price will be increased by 13 cents and 49.6 cents respectively. The total stock of this game title, which is the total number of copies sold up till the current time period, indicates the supply side of the used games. When the population of potential sellers in the secondary market goes up, the used good price decreases. The coefficients for *weeks* and $weeks^2$ shows that the predicted used good price is decreasing over time but the overall trend is convex. The *xmas* dummy shows that the used good price will be raised by one dollar sixteen cents on average during the Christmas shopping season. A negative and statistically significant *old* dummy shows that video game titles that do not belong to the newest generation in the market will have a lower resale value.

With all the variables in the main regression equation Eq(3.5) constructed, I am able to obtain the estimation results based on different models listed before. The regression results are shown in Table(3.2) and Table(3.3)[1].

According to Table (3.2), consumers obtain higher utility levels when the prices they pay are lower or the product ratings are higher. The utility levels are influenced by the number of weeks the game title of interest has been released, whether the time period of interest in during a Christmas shopping season, and

[1]The first stage results of this panel data IV estimation for model five is shown in the appendix.

	Coef	Std. Error
$p^{new}_{j,t-1}$	0.14***	0.01
$p^{u}_{j,t-1}$	0.51***	0.01
$stock_{j,t-1}$	-8.6×10^{-4}***	8×10^{-5}
$old_{j,t}$	-66.45***	17.59
$weeks_{j,t}$	-15.00***	0.81
$weeks^2_{j,t}$	0.06***	0.00
$xmas_{j,t}$	124.11***	12.10
constant	911.96***	39.11
ρ_{AR}	-0.1522	
# of obs	7979	
R^2	0.7131	

***: significant at 1% level; **: significant at 5% level; *: significant at 10% level.

Table 3.1: First Stage Results

whether the game title of interest is the current newest generation game title or not. If the game title of interest is not among the newest generation games, the utility levels generated by this game title will be lower if the quality difference between this game title and the corresponding newest generation game title is larger.

More specifically, I can compare model one to models two and three. In model one, the retail prices are treated as actual prices paid by consumers. However, the parameter estimate is not statistically significant. When I employ rental prices as actual prices paid by consumers, the coefficients are statistically significant and negative. In the mean time, the magnitudes of the parameter estimates for the non-price variables in model one are generally greater than the ones from model two and model three. This is because these variables are related to the future resale prices. By excluding the used good price in model one, all other variables seem to matter more. This shows the importance of including rental prices instead of retail prices in such settings. I will be able to get more accurate

	Model One $p^r_{jt} = p^{new}_{jt}$		Model Two $p^r_{jt} = p^{new}_{jt} - p^u_{j,t+1}$		Model Three $p^r_{jt} = p^{new}_{jt} - \widehat{p^u_{j,t+1}}$	
	Coef	Std. Error	Coef	Std. Error	Coef	Std. Error
p^r_{jt}	-0.007	0.015	-0.029***	0.009	-0.031***	0.012
$gscritics$	3.224***	1.099	2.544***	0.472	2.644***	0.459
$\Delta gscritics$	-2.547*	1.499	-3.065***	0.527	-3.316***	0.723
$stock$	-0.001***	0.000	-0.001***	0.000	-0.001***	0.000
$console\_sales$	-3.851×10^{-4}***	1.09×10^{-4}	-4.419×10^{-4}***	0.727×10^{-4}	-4.487×10^{-4} ***	0.837×10^{-4}
old	-0.199***	0.065	-0.179***	0.060	-0.191***	0.065
$weeks$	-0. 043***	0.003	-0.037***	0.004	-0.036***	0.005
$weeks^2$	1.054×10^{-4}**	0.431×10^{-4}	0.573×10^{-4}**	0.327×10^{-4}	0.536×10^{-4}	0.407×10^{-4}
$xmas$	1.316***	0.075	1.244***	0.044	1.243***	0.048
$constant$	-32.499***	7.400	-27.798***	3.435	-28.607***	3.347
$\# of Obs$	6649		6473		6473	
$R - sq$	0.4127		0.4453		0.4196	

***: significant at 1% level; **: significant at 5% level; *: significant at 10% level.
All regressions include game dummies and console dummies. Random effects estimations.
Data Sources: Price data is obtained from VGChartz Group. All sales data is obtained from Cosmic Shovel, Inc. Characteristics data is obtained from Amazon.com and Gamespot.com.

Table 3.2: Regression Results: Model One, Model Two, and Model Three

estimates when I include rental prices.

When I assume the rental price really takes the form $p^r_{jt} = p^{new} - \kappa E_t(p^u_{j,t+1})$ as in Eq(3.10) and Eq(3.11), I am not imposing a specific value for κ. Table(3.3) shows that the coefficients for the future used good price are statistically significant in both models four and five. Furthermore, the current new good price has a negative estimate while the future resale price's estimate is significantly positive. This shows that consumers obtain higher utility when the retail price is lower or the future resale price is lower. Consumers are more likely not able to perfectly predict the future resale price of a certain video game title. By employing the predicted future used good price, I show that consumers care about the future resale value even more when they are considering whether or not to purchase a new video game title. When I compare Table(3.3) to Table(3.2), I find that some parameter estimates lose statistical significances. For variables *stock* and *console_sales*, this loss of significance is easy to explain and more intuitive to illustrate. When a consumer is obtaining a certain utility level from a video game, whether this video game has many other players is not really important. Since most of console video games do not have interaction between players on the internet compared to the personal computer video games, the number of copies sold by a video game title does not affect how much an individual consumer enjoys the game title. A similar story applies to the total number of consoles sold. After a consumer has already owned the console that plays the game title, the storage base of the console does not influence his utility of playing this specific game title. I notice that the quality difference measure loses the statistical significance as well. This is because that the quality difference affects the future resale price more than it affects the functions of a game title. For instance, Madden NFL 2009 for Xbox360 has certain features and consumers will be able to derive

	Model Four		Model Five		Model Six(OLS)	
	Coef	Std. Error	Coef	Std. Error	Coef	Std. Error
p_{jt}^{new}	-0.008	0.007	-0.023***	0.007	-0.014***	0.002
$p_{j,t+1}^{u}$	0.052***	0.009				
$\widehat{p_{j,t+1}^{u}}$			0.103***	0.018	0.047***	0.003
$gscritics$	1.058**	0.429	1.023**	0.441	0.313***	0.076
$\Delta gscritics$	0.056	0.865	0.270	0.895	-0.056**	0.031
$stock$	2.112×10^{-4}	2.765×10^{-4}	6.539×10^{-4}*	3.967×10^{-4}	9.217×10^{-4}***	1.188×10^{-4}
$console\_sales$	2.741×10^{-4} **	0.606×10^{-4}	-2.77×10^{-4}***	0.611×10^{-4}	-1.915×10^{-4}***	0.268×10^{-4}
old	-0.219***	0.036	-0.162***	0.038	-0.243***	0.031
$weeks$	-0.031***	0.003	-0.016***	0.005	-0.037***	0.002
$weeks^2$	1.08×10^{-4}***	0.21×10^{-4}	0.48×10^{-4}**	0.23×10^{-4}	1.20×10^{-4}***	8.65×10^{-6}
$xmas$	1.065***	0.056	0.952***	0.071	1.094***	0.022
$constant$	-18.24***	2.864	-18.91***	2.845	-13.39***	0.989
$\# of Obs$	6473		6252		6473	
$R-sq$	0.8630		0.8746		0.7578	

***: significant at 1% level; **: significant at 5% level; *: significant at 10% level.

Table 3.3: Regression Results: Model Four, Model Five, and Model Six

certain utility levels by playing this game. When the Madden NFL 2010 game generation are released, this introduction of a newer generation reduces the resale price of the 2009 game title. The fancier the 2010 generation turns out to be, the lower the resale price will be for the 2009 game title. Since I have included the future resale price in my regression, the quality difference does not influence the utility function for the 2009 game title any more. It is reasonable to believe that models four and five do a better job estimating the demand side than models one, two, and three.

The main reason that models four and five are different from models two and three is that the coefficient of the future resale price is allowed to deviate from the coefficient of the current resale price. The value of the parameter κ tells me how much relative weight consumers put on the future resale price when they decide whether to buy a product. A higher κ values shows consumers pay more attention to the used good market and are more likely to participate in the used good market. The estimated κ value is 6.14 and 4.50 in model four and model five respectively. I can run an F-test to see whether the κ value is significantly different from 1 in each model. The test results show that both estimates for κ are greater than one. Since an econometrician is not able to fully observe the quality of each game title, the quality measures are the best I can do to describe how good each game title is. However, the quality measure does not fully capture the true story. The future used good price, on the other hand, contains information about the product quality levels that are not observable and are not listed on paper. Once I eliminate the restrictions on the resale price during the construction of rental price, the future used good price becomes more than a price indicator. It contains unobserved product characteristics information. When the future resale price is higher, the product of interest must have a better quality. This is why the results seem to state that consumers pay more attention to the used good price instead of the new good price. Nonetheless, the κ value shows that the inclusion of the rental price in the demand side equation is an important and correct choice.

Similar to the results from model five, the OLS regression generates a significantly negative new good price and a statistically significantly positive used good price. However, the magnitudes of these coefficients are smaller than the ones I obtain for model five. Other estimates from OLS are slightly different than the results for models four and five. This difference shows that the consideration of instrumental variables and endogeneity is necessary in the identification.

3.4.2 Price Elasticities and Rate of Substitution

Price Elasticities

After I have obtained the estimates for the demand side equation, I am able to construct the self price elasticities for every one of the game titles in my data. I use the results of model five to calculate the elasticity values. Since there are hundreds of game titles in my data set, I choose the game titles that belong to the FIFA Soccer game series to illustrate the significances of the elasticity estimates. In order to show different features of the estimates, I show separate tables with possible overlapped contents in them. The median elasticity for each game title year are shown in the tables that follow.

Table(3.4) includes all elasticity estimates for the game generation FIFA Soccer 2010. This generation is compatible to five consoles. Two of these five consoles (Playstation 3 and XBOX 360) belong to the seventh generation consoles while the other three (Nintendo DS, Playstation 2, and Playstation Portable) are of

Game Generation	Platform	Year	Price Elasticity	
			New Good Price	Used Good Price
FIFA Soccer 10	DS	2009	-0.64	2.55
FIFA Soccer 10	PS2	2009	-0.64	2.74
FIFA Soccer 10	PSP	2009	-0.85	3.25
FIFA Soccer 10	PS3	2009	-1.22	4.10
FIFA Soccer 10	X360	2009	-1.27	4.09

This table contains all FIFA Soccer 2010 game titles.

Table 3.4: Price Elasticities Table One

Game Generation	Platform	Year	Price Elasticity	
			New Good Price	Used Good Price
FIFA Soccer 08	PS2	2008	-0.46	0.65
FIFA Soccer 08	PS2	2009	-0.46	0.33
FIFA Soccer 09	PS2	2008	-0.69	2.67
FIFA Soccer 09	PS2	2009	-0.69	1.81
FIFA Soccer 10	PS2	2009	-0.64	2.74
FIFA Soccer 08	PS3	2009	-0.69	1.06
FIFA Soccer 09	PS3	2008	-1.32	4.27
FIFA Soccer 09	PS3	2009	-1.10	2.76
FIFA Soccer 10	PS3	2009	-1.22	4.10

This table contains all FIFA Soccer game titles that are compatible to a Playstation console.

Table 3.5: Price Elasticities Table Two

the sixth generation consoles. I observe higher elasticities for the seventh console game titles. The same patterns can be found if I look at the estimates for the game generation FIFA Soccer 2009.

I concentrate on the elasticity estimates for all Playstation 2 and Playstation 3 game titles. Table(3.5) shows the corresponding estimates. As a newer gaming console, Playstation 3 game titles have higher elasticities than Playstation 2 game titles. Combined with the properties of Table(3.4), I find that consumers who own the newest consoles are more price responsive. This is because that consumers who own the newest generation gaming consoles are the ones who are more interested in playing video games. More interested players tend to pay more attention to the market changes. Thus, these consumers tend to be more responsive to a price change due to a higher awareness of other options in the market.

One other key feature I observe is that the used good price elasticity has a higher absolute value than the new good price elasticity for a game title year. This matches the story where the used good price contains information about unobserved quality. If a game title can be sold at a price that is one percent higher, the percentage change of market share is going to be larger than the change corresponding to a one percent drop in the new good price. This is showing that consumers like video games that are going to generate higher future resale price. This is caused by both a higher return from the secondary market and a higher quality level of the product.

Rate of Substitution

Differentiated product models assume that consumers obtain utility through all different kinds of product characteristics. It is interesting to looking into how consumers substitute between different product characteristics. Later discussions will be based on the estimates obtained from model five in Table 3.3.

According to the model five estimates, a consumer is willing to pay one more dollar in retail price for some product characteristic that is $-\hat{\alpha}/\hat{\beta}$ higher. This product characteristic has $\hat{\beta}$ as the estimated coefficient in Eq(3.11). In this case, if a game title is one dollar more expensive, an average consumer will still be willing to purchase if the *GSCritics* rating is 0.022 higher. Given the rating is ranged between 0 to 10. This estimate is quite reasonable.

Using the same idea, I can try to show how people's willingness to pay changes with respect to time. As the coefficient for $weeks^2$ is very small, I can ignore this term at the beginning of a game title's life span. I can calculate that an average consumer is willing to to pay one dollar higher in retail price if a game title is approximately 0.64 weeks (approximately 4.5 days) younger right after the release of a game title. A consumer is willing to pay twenty dollars higher in the retail price is a game is around three months newer. This matches the price trends I see on Fig 1.1.

3.5 Conclusions

This chapter of the dissertation attempts to develop the traditional differentiated product models in a way of adjusting the price measures. Authors of earlier literature employ retail prices as the prices paid by consumers. However, according to planned obsolescence literature and the theoretical model in Chapter 2, the future resale price is not negligible. Thus, I propose various ways of constructing the rental price, which is the difference between the retail price and potential resale price.

According to the estimation results and some calculations based on those results, including rental price instead of retail price generates more accurate and reasonable estimates. Consumers become more likely to purchase a video game title not only when the retail price is lower, but when the future resale price is higher as well. The estimation results infer that future resale prices contain information that is related to the unobserved product characteristics.

For future expansion of this line of research, a development from a static model to a dynamic model is certainly feasible. Agents are forming expectations in each period and react to different expected future situations. A dynamic model will be able to capture such evolution better. One can look into the determination of the used good price further. As pointed out before, it is possible to reveal some unobserved characteristics, such as product quality, from investigating the used good prices.

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Appendix A

Case I: $\frac{p_2-s_2}{q_2-q_1} < \frac{p_2}{q_2} < \frac{s_2}{q_1} \leq 1$

x_1 could be located in four intervals: $[0, \frac{p_2-s_2}{q_2-q_1}]$, $(\frac{p_2-s_2}{q_2-q_1}, \frac{p_2}{q_2}]$, $(\frac{p_2}{q_2}, \frac{s_2}{q_1}]$, and $(\frac{s_2}{q_1}, 1]$. I need to analyze consumers' choices when x_1 in located in each one of the four intervals.

A.1 Case I-I: $x_1 \leq \frac{p_2-s_2}{q_2-q_1} < \frac{p_2}{q_2} < \frac{s_2}{q_1} \leq 1$

In this case, all consumers who do not purchase in the first period will not buy, and consumers who have purchased product version 1 will all sell their used products and some of them will purchase a new unit.

$$\forall x < x_1, U_{00} > \max\{U_{01}, U_{02}\};$$

$$\forall x \in [x_1, \frac{p_2}{q_2}), U_{10} > \max\{U_{11}, U_{12}\}; \forall x \in [\frac{p_2}{q_2}, 1], U_{12} \geq \max\{U_{10}, U_{11}\}.$$

I do not have equilibrium results since consumers with indexes no less than x_1 will be willing to supply in the used good market and no other consumers want to purchase in the used good market.

A.2 Case I-II: $\frac{p_2-s_2}{q_2-q_1} \leq x_1 < \frac{p_2}{q_2} < \frac{s_2}{q_1} \leq 1$

In this case, I have a similar situation as in Case I-I.

$$\forall x < x_1, U_{00} > \max\{U_{01}, U_{02}\};$$

$$\forall x \in [x_1, \frac{p_2}{q_2}), U_{10} > \max\{U_{11}, U_{12}\}; \forall x \in [\frac{p_2}{q_2}, 1], U_{12} \geq \max\{U_{10}, U_{11}\}.$$

I do not have equilibrium results in this case due to the same reason from Case I-I.

A.3 Case I-III: $\frac{p_2-s_2}{q_2-q_1} < \frac{p_2}{q_2} \leq x_1 < \frac{s_2}{q_1} \leq 1$

For all consumers whose consumer index smaller than $\frac{p_2}{q_2}$, they will choose to stay out of the market. For consumers with indexes between $\frac{p_2}{q_2}$ and x_1, they will buy a new good in the second period. Consumers with indexes greater than x_1, they will choose to participate in the secondary market by selling their used product and purchase a product version 2 in the second period.

$$\forall x \leq \frac{p_2}{q_2}, U_{00} \geq \max\{U_{01}, U_{02}\}; \forall x \in (\frac{p_2}{q_2}, x_1], U_{02} \geq \max\{U_{00}, U_{01}\};$$

$$\forall x \in (x_1, 1], U_{12} > \max\{U_{10}, U_{11}\}.$$

There is no subgame perfect equilibrium in this case since the used good supply will be positive, while the used good demand is zero.

A.4 Case I-IV: $\frac{p_2-s_2}{q_2-q_1} < \frac{p_2}{q_2} < \frac{s_2}{q_1} \leq x_1 \leq 1$

For consumers with consumer indexes smaller than $\frac{p_2}{q_2}$, they will stay out of the market. Consumers, whose consumer indexes are between $\frac{p_2}{q_2}$ and x_1, will purchase a new product version 2. The rest of the consumers purchase in the first period, sell their used products and purchase again in the second period.

$$\forall x \leq \frac{p_2}{q_2}, U_{00} \geq \max\{U_{01}, U_{02}\}; \forall x \in (\frac{p_2}{q_2}, x_1], U_{02} \geq \max\{U_{00}, U_{01}\};$$

$$\forall x \in (x_1, 1], U_{12} > \max\{U_{10}, U_{11}\}.$$

Similarly, I do not have equilibrium results.

Appendix B

Case II: $\frac{s_2}{q_1} < \frac{p_2}{q_2} < 1 < \frac{p_2 - s_2}{q_2 - q_1}$

In this case, x_1 could be located in three intervals since x_1 will not exceed 1. I will analyze all three possibilities and show that a subgame perfect equilibrium does not exist in this case.

B.0.1 Case II-I: $x_1 < \frac{s_2}{q_1} < \frac{p_2}{q_2} < 1 < \frac{p_2 - s_2}{q_2 - q_1}$

For all consumers who do not purchase in the first period, they will still not purchase anything in the second period. For consumers who have consumer indexes between x_1 and 1, they will either sell their used products and stay out of the market or choose to keep their used product.

$$\forall x \leq x_1, U_{00} > \max\{U_{01}, U_{02}\};$$

$$\forall x \in [x_1, \frac{s_2}{q_2}), U_{10} > \max\{U_{11}, U_{12}\}; \forall x \in [\frac{s_2}{q_2}, 1], U_{11} \geq \max\{U_{11}, U_{12}\}.$$

In this case, there is positive supply in the used good market but zero demand. I do not have equilibrium results.

B.0.2 Case II-II: $\frac{s_2}{q_1} \leq x_1 < \frac{p_2}{q_2} < 1 < \frac{p_2 - s_2}{q_2 - q_1}$

For consumers who do not have a first period purchase, they will stay out of the market if their consumer indexes are smaller than $\frac{s_2}{q_1}$ and they will buy a unit of the used product version 1 if their indexes are between $\frac{s_2}{q_1}$ and x_1. For consumers who have purchased in the first period, they will keep their product version 1 if their indexes are between x_1 and 1, they will keep their used product 1.

$$\forall x \leq \frac{s_2}{q_1}, U_{00} > \max\{U_{01}, U_{02}\}; \forall x \in (\frac{s_2}{q_1}, x_1], U_{01} > \max\{U_{00}, U_{02}\};$$

$$\forall x \in [x_1, 1], U_{11} \geq \max\{U_{10}, U_{12}\}.$$

I can adopt the same reasoning as in Case II-I and conclude that I will not have a subgame perfect equilibrium in this case.

B.0.3 Case II-III: $\frac{s_2}{q_1} < \frac{p_2}{q_2} \leq x_1 < 1 < \frac{p_2 - s_2}{q_2 - q_1}$

I can derive the second period utility function orders for all consumers as follows:

$$\forall x \leq \frac{s_2}{q_1}, U_{00} \geq \max\{U_{01}, U_{02}\}; \forall x \in (\frac{s_2}{q_1}, \frac{p_2}{q_2}], U_{01} \geq \max\{U_{00}, U_{02}\};$$

$$\forall x \in (\frac{p_2}{q_2}, x_1), U_{02} > \max\{U_{00}, U_{01}\}; \forall x \in [x_1, 1], U_{11} \geq \max\{U_{10}, U_{12}\}.$$

Similarly, I can show that this case will not have a subgame perfect equilibrium.

Appendix C

"$\Delta GSCritics$" and "$\Delta Compatibility$"

I hope to calculate the difference between the characteristics of the game title of interest and the respective characteristics of the newest generation of the game series. If the game title of interest and the newer game generation are both compatible to the same console, the quality difference will be measured by the characteristics differences between the newest generation game title for the same console and the game title of interest. However, it is possible that the newer generation of the game series will not be compatible to the same console during some weeks or not at all. This could be caused by either the rm has decided not to produce game titles for a certain console any more or the rm has not released the new generation for that platform yet. In either case, the quality difference measure will be the difference of the best selling game title in the next generation and the game title of interest. For example, when the game title of interest is the Madden NFL 2008 for Xbox360, which was the newest game generation in the Madden NFL game series on console Xbox360 during the ma jority of 2008, the quality difference measure were zero before the Madden NFL 2009 was released. After the Madden NFL 2009 was released and it is immediately compatible to Xbox360, the quality difference became the difference between the characteristics of the Madden NFL 2009 for Xbox360 and the Madden NFL 2008 for Xbox360. Suppose the Madden NFL 2008 for PS2 is the game title of interest and EA sports decides not to produce any more Madden NFL game titles for PS2 after 2008, the quality difference measure for Madden NFL 2008 for PS2 after the introduction of Madden NFL 2009 generation will be the characteristics difference between the best selling Madden NFL 2009 game title and Madden NFL 2008 for PS2.

Appendix D

First Stage Results for Model Five in Table 3.3

In the first stage of a panel data IV method, each endogenous variable will become the dependent variable in a regression and the instrumental variables and other exogenous variables are the dependent variables in the same equation. Table D.1 shows the first stage results for G2SLS random-effects IV regression for model five in Table 3.3. It is quite clear that the choices of instruments fit well in the regressions.

	p_{jt}^{new}		p_{jt}^{u}		$GSCritics$		$\Delta GSCritics$	
	Coef	Std. Error	Coef	Std. Error	Coef	Std. Error	Coef	Std. Error
$us_{j,t-4}^{n}$	0.22209***	0.0123	0.08463***	0.00561	0.000213	0.000395	0.00187***	0.000598
$us_{j,t-4}^{a}$	0.46466***	0.46466	0.09993***	0.00637	0.000551	0.000449	0.00322***	0.000680
$us_{j,t-4}^{u}$	0.2081618***	0.0172375	0.2289925***	0.0078551	0.0028145***	0.0005536	-0.0032987***	0.0008378
$developer$	-0.0123533	0.0201849	0.0005283	0.0091982	-0.0097731***	0.0006482	-0.0036163***	0.000981
$publisher$	0.0958236	0.1281362	-.048566	0.0583912	0.0038578	0.0041151	-0.0158987**	0.0062276

***: significant at 1% level; **: significant at 5% level; *: significant at 10% level.

I have suppressed the coefficients for dummy variables and exogenous variables in Eq (3.11).

Table D.1: First Stage Results for Model Five in Table 3.3