Optimal timing of home video releases: A dynamic model of movie distribution

Working paper*

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Abstract

In this paper we study how innovations in the home video viewing experience affect the optimal release timing strategies of the movie industry. We specifically analyze versioning through home video release windows - the time between theater market exit and home video release - when there are two home video products with different technological qualities; DVDs and Blu-rays. We develop a dynamic discrete choice model for action movies in theaters and home videos. This model connects theater and home video markets through the home video window, theatrical performance, and the discounted value of waiting. Our model differentiates from the current literature in that consumers are forward looking and may postpone their purchases for higher expected utilities periods in the future. Furthermore, all markets are connected to each other, so changing the release date for one technological quality home video will have an impact on the box office revenue, which will impact all other technological quality home videos. We estimate the model parameters using panel data on the weekly level for home videos and box office. We conduct a counterfactual analysis in which the home video windows for DVDs and Blu-rays are jointly optimized. We find that decreasing the home video window increases the home video demand by increasing freshness and the advertising spillover from the theatrical run. However, this change can simultaneously cannibalize some demand from theaters as consumers have a larger home video discounted value. This cannibalization of theater demand has further impact on home video demand because the box office revenue - a driver for home video demand - is reduced. We find that an immediate after-theater release of lower technological quality home videos (DVDs) combined with a 5-week delay on higher technological quality home videos (Blu-rays) is optimal. We attribute this result to consumer heterogeneity, where there is greater substitution between higher technological quality home videos and theaters.

*All mistakes are my own, Franco Berbeglia

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1 Introduction

Home video release timing is arguably the most important decision for movie distribution; as a market segmentation strategy, it separates two different consumer experiences, theaters and home videos. For the last few decades the home video window, the time between theater market exit and home video release, has been decreasing. At the same time the technological quality of the home video experience has improved, from VHS in the 1990s to 4K Ultra HD today. This poses a question for the movie industry; is it optimal to decrease the home video window as the technological quality of home videos increase? Furthermore, as several technologies of home videos are available at the same time, e.g. DVD and Bluray during the 2010's, which technological quality home video should be released first in order to maximize studio revenue?

Besides release timing, advertising plays an important role in movie distribution. In general, 80% of the advertising budget is spent during theatrical release, while the remaining 20% is left for the home video release. This generates incentives for studios to release their home videos early, as the advertising expenditure in theaters will have a stronger effect on home video consumption. However, at the same time, some consumers may be willing to delay the box office purchase decision to the home video market, reducing the box office revenue. This impacts the home video market as well, as it is well known that the box office revenue serves a quality signal that drives home video demand. This trade-off clearly illustrates how difficult it is to choose an optimal home video window, which might differ between different technological quality home videos.

This paper develops a dynamic structural model for the box office market and the home video market, consisting of two technological qualities, DVDs and Blu-rays[1]. The model is built around release timing strategies, and it is able to quantify the change revenue associated with advancing or delaying home video releases. In order to do this, modeling consumer forward looking behavior is critical. We model the home video market as an infinite horizon model for each movie and technological quality, where consumers decide whether to buy the disc, or to delay their purchase in each period. We model the box office market for each movie as a dynamic program with a finite horizon. During each period consumers face the decision whether to buy a ticket or wait for the next period. The terminal continuation value of the box office market is set to the discounted value of the home video market, which depends on whether the consumer owns a DVD or Blu-ray player.

Consumer forward looking behavior is critical to model distribution in the movie industry. The time a movie remains in theaters is not a decision the studios make, but one each theater decides on their own, depending on performance. Thus, consumers in the box office market don't know the horizon of such market, and have to form expectations on its duration in each period. Under our setting, consumers form dynamic expectations about the time a movie remains in theaters. These expectations depend on movie performance and time since release. Consumers are also forward looking in the evolution of the movie quality over time, the home video market value, and the home video window, which determine the terminal continuation value

[1] It is simple to add other home videos as the data becomes available

of the box office market.

Once the consumer decision problem in terms of movie qualities is solved, we recover movie/medium fixed effects, and time dependent characteristics that depend on each market, such as age, advertising build-up, average price and seasonality. In a second stage, we regress the fixed effects on time independent characteristics, such as the home video window, theatrical revenue, production budget, distributor, release year and poster colors. We analyze the poster image for each movie and identify the percentage of pixels that belong to each color in a 12 color palette. We then analyze the correlation between using specific colors, and pairs of a color and its complement, with consumer preference for a movie.

With the demand estimates for the box office, DVD and Blu-ray markets, we are able to perform a series of counterfactuals. First, we estimate the impact of modifying the simultaneous release of DVDs and Blu-rays, which was the industry practice at the time of data collection. We leave everything constant, while adjusting the advertising build-up, (as having a shorter home video window increases the advertising build-up coming from theaters), and the box office revenue signal. We find that it is optimal to set the DVD and Blu-ray release 2.3 weeks after theatrical exit to achieve a 4.47% increase in studio revenue[2], while having little impact for theaters with respect to the data. Second, we estimate the impact of separately modifying the home video window for DVDs and Blu-rays. This allows the exploit of market segmentation strategies, as consumers express heterogeneous preferences depending on the technological quality of the home video player they possess. We find that the optimal strategy is to release DVDs within a week of theatrical exit, while to delay Blu-rays about 5.15 weeks from theatrical exit. This strategy increases studio revenue by 5.36% with respect to the data, and again, the impact to theaters is minimal. This result is driven by the different substitution patterns that different technological quality home videos present to theaters. Lower technological quality home videos, such as DVDs, have a low ex-ante value function for their market compared to the market of higher technological quality home videos, such as Blu-rays. This makes DVD owners less likely to delay the box office purchase decision compared to Blu-ray player owners when shortening the home video window. Thus, the studios can reap all the benefits of the advertising spillover effect from theaters while posing minimal competition to theaters. The trade-off is more balanced for Blu-rays. Shortening their home video window will increase substitution from theater, and will have further impact on the DVD market, as the quality signal coming from box office revenue is reduced. This result captures consumer heterogeneity in the box office market; Blu-ray player owners value picture quality above everything else, while DVD player owners value timing and pricing above picture quality. This allows the studios to perform market segmentation strategies on releases to boost revenue.

The remainder of this paper is organized as follows; Section 2 presents the related literature, Section 3 describes the industry and shows the main attributes of the dataset used, Section 4 presents the structural model including consumer utility specifications and the consumers' optimal purchase problem, Section 5

[2]Studio revenue is capturing all of the home video revenue, and a share of the box office revenue that comes from imposing a standard theater-distributor contract.

explains the estimation and identification procedure for the model parameters, Section 6 shows and describes the parameter estimates of the model, and Section 7 presents the counterfactual analysis on the home video windows.

2 Literature Review

In the past few decades, several researchers have studied the motion picture industry, which intersects several fields such as marketing, operations management, and economics. We separate the relevant literature for this paper into two groups, demand estimation and release timing. Within each of these groups we discuss the papers related to the movie industry.

2.1 Demand Estimation

This paper uses the frameworks of Nevo (2000), Gowrisankaran and Rysman (2012) and Berry et al. (1995) to present and estimate a dynamic discrete choice model for movie distribution that captures consumer forward looking behavior. Unlike these papers, we consider a setting with two different markets, box office and home video, that are connected to each other through the home video window and the home video market value. In a similar fashion to this paper, Derdenger (2014) has analyzed the technological tying of software and hardware in the 128-bit video game industry.

Advertising plays a critical role in this paper, as it drives a side of the home video window trade-off. We treat advertising as exogenous, where it enters the model as a covariate, following Dubé et al. (2005) to analyze the long-term effects of advertising. In a different setting, Yan (2020) analyzes equilibrium advertising and theatrical releases while treating advertising as endogenous. Its setting is quite different from ours, as it finds equilibrium advertising levels and release dates in a competitive environment with consumers that are not forward looking, whereas in our paper we focus in finding optimal release timing strategies in a dynamic monopolistic setting that captures consumer forward looking behavior in theater and home video markets.

There is an abundant number of papers that do an empirical analysis of demand in the movie industry. This includes Eliashberg and Shugan (1997), Eliashberg et al. (2000), Elberse (2007), Eliashberg et al. (2014) and Packard et al. (2016) studying the impact of critics' reviews, star actors, networks of cast and crew, and opening weekend box office on overall revenue performance. Lehmann and Weinberg (2000), Elberse and Anand (2007) and Rao et al. (2017) analyze the impact of advertising on box office revenue.

2.2 Release Timing

The problem of finding the optimal inter-release times of sequentially released products has been widely studied in several industries. Moorthy and Png (1992) analyze the optimal timing and quality of sequential product releases. Lehmann and Weinberg (2000) analyze the problem of demand cannibalization between box office and home videos while trying to reap gains as quickly as possible. This line of work is extended by

Luan and Sudhir (2006) capturing box office consumer forward looking behavior. This is the closest line of research to this paper, as they study the optimal inter-release time between box office and DVDs using box office sales, and DVD sales and rental data. However, their analysis only uses advertising expenditure and does not capture advertising build up over time, which lowers the incentives to shorten inter-release times. In our paper, advertising build up is a major driver for shorter inter-release times. We specifically focus on how the optimal inter-release times change as the technological quality of home videos increases from DVDs to Blu-rays, while creating heterogeneous consumer preferences between these products. Another distinction with Luan and Sudhir (2006), is that in our model, consumers also form expectations about the evolution of movie quality during each market, as well as on the time a movie remains in theaters. We develop a discrete hazard model to asses the probability distribution of the remaining time in theaters of a movie, that is dependent on the time since release and performance.

Other relevant work on movie release timing may be found in the study of the trade-off between seasonality and freshness for DVDs, see Mukherjee and Kadiyali (2018). August et al. (2015) is, to the best of our knowledge, the only theory work on optimal release timing strategies for the movie industry. It analyzes the conditions under which day-and-date, direct-to-video, or delayed home video releases are optimal release timing strategies for the movie industry.

3 Industry Setting and Data

The motion picture industry consists of three stages: production, distribution and exhibition. The production stage consists of the development of a motion picture and is a creative process with important economic implications for the parties involved. The process usually begins with an idea, concept or true event, which a writer captures in a screenplay. If a producer is interested in the screenplay, it may sign an option agreement with the writer, which gives the producer the possibility of purchasing the complete screenplay, and provides an upfront payment for the writer. Substantial financing is needed to begin production, which is lowered when the producer is affiliated with a studio. Upon the signature of a studio contract, the producer gives up several rights, including sequels, spin-offs, and merchandising. At the same time, the producer increases its chances of obtaining bank loans and securing favorable distribution and exhibition deals. These contracts benefit the studios, as they provide a constant inflow of products from successful firms. Many producers face financing issues when they cannot reach a deal with a studio; in such case the studio must obtain financing from other sources, which is difficult when no distribution deals are guaranteed (Vogel 2014).

The distribution stage begins once a movie has completed production, and it includes the distribution to theaters, home video markets, as well as the marketing activities in each market where the movie is released. Distributors face a wide range of decisions in this stage, including when to release the movie in each channel and the advertising strategy for the motion picture. Among distributors there is a clear distinction between major and independent firms. The major distributors, usually referred to as *"The*

Big Six", include *Paramount, Sony, Twentieth Century Fox, Universal, Walt Disney* and *Warner Bros.*. These studios produce, finance and distribute their own movies. At the same time, they also finance and distribute films produced by independent film makers that are associated with the studio. Ensuring a strong US theatrical box-office gross is very important for these studios, because it is a performance metric to indicate sales potential in other distribution channels such as global theatrical, home video, and pay television (Eliashberg et al. 2006). Simultaneously, the growing importance of non-theatrical channels as a source of revenue is generating incentives for the studios to reduce the time between theatrical and non-theatrical releases. Figure 1 shows the evolution of the average DVD release windows, (time between theatrical and DVD releases), for major studios and years. This reduction in non-theatrical windows poses several questions, which we address in this paper. One of them was proposed by Eliashberg et al. (2006), "To what extent are theatrical and nontheatrical windows substitutes or complements (i.e., either negatively or positively affecting each other's revenue potential)? For example, does the availability of DVDs deter people from going to the theater?". Building upon this question, we analyze the optimal non-theatrical window across different technological quality home videos, which present different substitution patters with theaters.

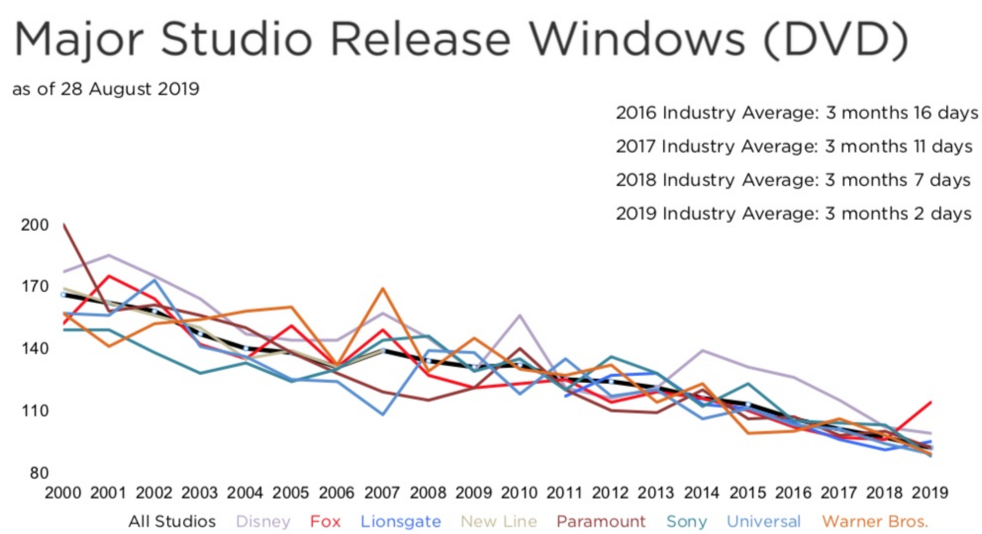

Figure 1: Evolution of the number of days between theatrical and DVD release for major studios. Source: https://www.natoonline.org.

The exhibition stage is the only stage in which major studios have limited control. The contractual agreements between exhibitors and distributors only involve a minimum playing time, as well as terms on how the box office revenue is shared between the parties involved. In the end, it is up to each individual theater to control the total playing time for each movie (beyond that set minimum). Studios generate a strong buzz prior to and during their theatrical release - combining advertising, word of mouth, and media attention - which drives demand for the motion picture in other distribution channels (Eliashberg et al.

2006).

3.1 Data Discussion

We estimate our model using panel data for box office, DVD and Blu-ray sales. The data is at the weekly level for all panels. For each week that a movie is in the box office, our data includes revenue ($), ticket sales, number of theaters, and other characteristics. For each movie and week in a home video environment, our data includes unit sales, revenue ($) and average price. We observe 149 movies, across box office, DVD and Bluray, with observations between the years 2009 and 2018. Out of those 149 movies, only 113 had Blu-ray releases, while all of them had a DVD release. We also obtain advertising expenditure data for each movie at the monthly level from Ad$pender. For each movie we also have information on its characteristics, such as distributor, domestic box office revenue, production budget, home window lengths and release dates. We also scraped poster images from www.themoviedb.org and applied color theory on them to extract hue information, the procedure is described in section 5.3.4. We create market shares by dividing the unit sales with the number of consumers, for the box office, or number of DVD/Blu-ray player owners for the home videos. We use data from the U.S. Census Bureau to get the number of consumers within each movie rating per year, and data from the Consumer Electronic Association to get information on DVD/Blu-ray player ownership. This data is interpolated to the monthly level, assuming a linear growth rate. We adjust inflation in all revenues to January 2019 dollars using data from the Bureau of Labor Statistics. To create our final dataset, we remove box office panel weeks with less than 100 theaters and we define the start of the home window as the week in which a movie is in less than 100 theaters. The final dataset consists of $1,797$ observations across 149 movies for the box office, $44,800$ for DVDs (across the same 149 movies), and $25,373$ observations for Blu-rays across a subset of 113 movies. Table 1 presents a summary statistics of the production budget, advertising expenditure, and revenue per medium of the final dataset, while Table 2 presents a summary of the home windows and time in theaters. It is important to note that the difference between the DVD and Blu-ray home video windows is due to the different sample sizes, and not due to different home video release dates for the same movie.

	Mean	**Median**	**Standard Deviation**
Production budget	$ 121,775,960	$99,979,420	$ 77,255,980
Domestic box office revenue	$ 122,169,272	$ 82,897,417	$ 106,867,804
Total DVD revenue	$ 37,480,615	$ 26,050,639	$ 42,840,121
Total Blu-ray revenue	$ 22,478,904	$ 16,729,886	$ 19,335,287
Total advertising expenditure	$ 27,612,363	$ 27,170,200	$ 11,091,510

Table 1: Data summary on revenues, advertising and budgets.

	Mean	Median	Standard Deviation	Maximum	Minimum
DVD home window (weeks)	6.6951	6.2857	3.6906	16.2857	0.2857
Blu-ray home window	6.1871	6.2857	3.6453	16.2857	0.2857
Time in theaters (weeks))	11.4007	11.0000	3.1829	22.0000	6.0000

Table 2: Data summary on timing characteristics.

3.2 Data Analysis

In this section we present reduced form results that show the connection between relevant covariates and revenue. We retrieve estimates in a two stage process; with a first stage fixed effects regression that includes time dependent characteristics, and a second stage retrieval of movie characteristics from movie fixed effects.

Table 3 shows the box office reduced form using panel data on weekly box office ticket sales. It shows the first stage regression on top, while the fixed effect GLS (General Least Squares) retrieval of static movie characteristics at the bottom. The sign of the coefficients is quite intuitive; as a movie ages, the demand for it decreases, while an increase in advertising expenditure yields greater demand [3]. The average box office price per week is not significant, probably due to the low variation of price across both, time and titles[4]. The "lag 1st3weeks box revenue" covariate represents the total lagged box office revenue until the current period, or period 3 included, whichever comes first. This shows that if a movie performs well in the first few weeks since release, it will drive demand up for the consecutive weeks, but with diminishing returns as the quadratic component is negative. The fixed effects regressions shows that production budget and time in theaters are major drivers for box office demand. The home window contribution is smaller in magnitude, but presents the expected substitution pattern with a positive sign, which means that box office revenue increases by delaying home video releases.

Table 4 shows the home video reduced form using panel data on home video sales. The top of the table shows the first stage regression in which DVD and Blu-ray weekly sales are regressed against time dependent covariates, and an interaction between them and a Blu-ray indicator variable with movie/medium fixed effects. We then run a fixed effects GLS regression for DVDs and Blu-rays separately on time independent characteristics. In the first stage regression we controlled for price endogeneity using lagged prices as instrumental variables. We can see that home video demand lowers with age and price. Advertising expenditure has a positive impact on home video sales, but this effect is lower for Blu-rays. The fixed effects GLS regression shows an increasing demand for home videos with an increase in box office opening revenue within the ranges of box office revenues observed. As for the home video window, DVD demand seems to be larger with lower windows, while Blu-rays exhibit concave demand shape with a maximum in around 8 weeks.

With these reduced form results, we can see several features that are important to embed into a struc-

[3]We create advertising covariates following Dubé et al. (2005), we describe the procedure in Section 5.3.3.

[4]To control for price endogeneity we used lagged prices as an instrument.

Box office: two-stage reduced form

Time Dependent Variables	**Estimates**
Age (weeks)	-0.8184 (0.0161)***
Age^2 ($weeks^2$)	0.0223 (0.0008)***
Price ($)	-0.6720 (0.5636)
Advertising	0.50933 (0.1361)***
log(lag 1st3weeks box revenue)	0.23651 (0.0474)***
log(lag 1st3weeks box revenue) ^{2}	-0.0128 (0.0027)***
Movie fixed effects	
Month fixed effects	
N	1,797
Time Independent Variables	**Estimates**
Constant	7.3604 (1.3068)***
log(production budget)	0.2551 (0.0343)***
Time in theaters (week)	0.4945 (0.0297)***
Time in $theaters^2$ ($week^2$)	-0.0111 (0.0011)***
Home window (week)	0.0039 (0.0170)
Home $window^2$ ($week^2$)	0.0024 (0.0010)***
Release year fixed effects	
Distributor fixed effects	
Color fixed effects	
N	149

$^{***}p < .01$, $^{**}p < 0.05$, $^{*}p < .1$

Table 3: Reduced form estimates of a two stage fixed effects model on weekly box office ticket sales.

Home video: two-stage reduced form

Time Dependent Variables	**Estimates Home Video**	**Estimates Blu-ray Indicator**
Age (weeks)	-0.0119 (0.0035)***	-0.0866 (0.0263)***
Age^2 (weeks^2)	0.0000 (0.0000)***	-0.1119 (0.0365)***
Price ($)	-0.0182 (0.0012)***	-0.2212 (0.0499)***
Advertising	0.6462 (0.0078)***	-0.2832 (0.0647)***
Movie fixed effects	✓	✓
Month fixed effects	✓	✓
Year fixed effects	✓	✓
N	70,253	25,373
Time Independent Variables	**Estimates DVD Indicator**	**Estimates Blu-ray Indicator**
Constant	33.3590 (0.5997)***	51.2524 (0.9777)***
log(1st3week box revenue)	-3.3500 (0.0705)***	-5.6018 (0.1139)***
$\text{log(1st3week box revenue)}^2$	0.1030 (0.0021)***	0.1709 (0.0033)***
Home window (week)	-0.0233 (0.0053)***	0.0989 (0.0061)***
Home window^2 (week^2)	0.0015 (0.0003)***	-0.0056 (0.0004)***
Release year fixed effects	✓	✓
Distributor fixed effects	✓	✓
Color fixed effects	✓	✓
N	149	113

$^{***}p < .01$, $^{**}p < 0.05$, $^{*}p < .1$

Table 4: Reduced form estimates of a two stage fixed effects model on weekly home video sales.

tural model. These include expectations about the home video window and time in theaters during the theatrical market, box office revenue as a signal of movie quality for the home video market, and advertising. Furthermore, the significant coefficients for age in both markets, show that consumers should be able to form expectations about movie quality evolution, which would be relevant in the case they decide to delay their purchase decision to later periods.

4 Demand model

In this section we discuss the structural model that captures the relationship between box office ticket sales, home video sales, and the forward-looking behavior of consumers. The box office and home video markets are linked through the home video window, which is the time between theatrical exit and home video release. Shrinking this window leads to higher freshness on the home video market and a greater spillover of advertising spent for the theatrical market, but it may lead to demand cannibalization from theaters. Consumers in the box office market form expectations about this home video window and decide whether to watch the movie in the current week, or delay their decision to the following one. Consumers form expectations about the home video window, as well as the evolution of prices, movie quality and the theatrical run time. Since we are interested in analyzing the aforementioned trade-off disregarding competition, we consider each movie to be a monopoly.

The timing of the model is as follows: Consumers own either a DVD or a Blu-ray player when a movie is released in theaters. In each week of the theatrical market, consumers decide whether or not to buy a box office ticket. They continue to make such a decision until they elect to watch the movie, or until the theatrical run time is over. After the theatrical runtime is over, we enter the home video window. During this period, consumers are not able to watch the movie in theaters, nor buy a home video for this movie. Then, the home video is released and we enter the video time. In each period (week) of the home video market, consumers decide whether or not they will purchase the their respective disc (DVD or Blu-ray). They continue to make such a decision in each period until they elect to purchase the home video. Figure 2 shows the described timeline of the model. In order to estimate the model involving the discussed forward-looking behavior, we use the frameworks of Gowrisankaran and Rysman (2012) and Derdenger (2014). The former paper embeds consumer expectations about price, movie characteristics and unobservable factors that might evolve over time. The later paper is used to link the utilities between the theatrical and home video markets.

Next, we present the utility specifications for the home video and theatrical markets, first discussing the associated utilities for home videos and then for box office tickets.

4.1 Home video utility

We now outline the utility model for home video consumption. The home video utility specification follows that of Gowrisankaran and Rysman (2012); it is an infinite horizon model. Our specification allows for

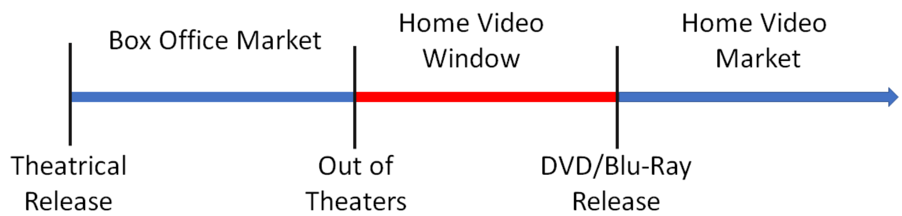

Figure 2: Timeline of movie distribution.

model parameters to differ between DVDs and Blu-rays so that the expected value of the home market for users who hold a DVD or a Blu-ray player are different. This term plays an important role in the box office market, since it enters through the terminal continuation value of such finite horizon model.

In the home video market, each consumer decides in each time period t whether or not to purchase a home video for movie/medium j. If consumer i decides to purchase a home video for movie/medium j of technological quality $k \in \{\text{DVD, Blu-ray}\}$[5] in time period t, she obtains a utility given by

$$u^h_{i,j,t} = f^h_{j,t} + \alpha^{p,h}_k p^h_{j,t} + \epsilon^h_{i,j,t} \tag{1}$$

where $f^h_{j,t}$ is the flow utility from the home video, $p^h_{j,t}$ is the price of the home video, and $\epsilon^h_{i,j,t}$ is an idiosyncratic shock which we assume to be the realization of a Type-1 Extreme Value distribution which is independent and identically distributed across consumers, products, and time periods.[6]

A consumer who does not purchase a movie/medium j of technological quality $k \in \{\text{DVD, Blu-ray}\}$ in period t receives

$$u^h_{0,j,t} = \beta \mathbb{E}[V^h_k(\Omega^h_{j,t+1})|\Omega^h_{j,t}] + \epsilon^h_{0,j,t}, \tag{2}$$

where $\Omega^h_{j,t}$, is industry state of movie/medium j at period t; involving the flow utility, price disutility, and all history factors that influence the home video's future attributes. Finally, $V^h_k(\Omega^h_{j,t})$ represents the value of having the purchase possibility of home video j of technological quality $k \in \{\text{DVD, Blu-ray}\}$, when the state of home video j is $\Omega^h_{j,t}$.

The home video flow utilities depend on movie characteristics with the following relation:

$$f^h_{j,t} = \alpha^{fe,h}_j + \alpha^{x,h}_k x^h_{j,t} + \xi^h_{j,t}, \tag{3}$$

where $x^h_{j,t}$ are time dependent observable movie characteristics (for DVD and Blu-ray), such as age, advertising expenditure, price, month and year, $\alpha^{fe,h}_j$ are movie/medium fixed effects, $\alpha^{x,h}_k$ are time dependent characteristics coefficients which depend on whether the technological quality of the home video is a DVD or a Blu-ray, and $\xi^h_{j,t}$ are unobservable characteristics that vary both over time and across movies. It is

[5] Movie/medium j includes information about the technological quality of the home video, so we defer from adding subscript k to denote such technological quality when subscript j is present.

[6] Let superscript h and b denote utility specification for home video and box office respectively.

important to remark that we don't explicitly express the dependence of $f^h_{j,t}$ on k since j (movie/medium) already includes that information.

The estimation of the model parameters involves a second stage in which the movie medium fixed effects are regressed on time fixed movie characteristics following Nevo (2000). Examples of movie characteristics involve opening box office revenue, distributor, the home window length, poster colors and release year.

4.2 Box office utility

Unlike the home video market, the box office market has a finite horizon. The consumer type is denoted by the subscript $k \in \{\text{DVD, Blu-ray}\}$, which provides a source of heterogeneity that depends on the technological quality of the home video player owned. This heterogeneity enters exclusively in the outside option and not in the purchase utility, as we assume that the box office ticket purchase continuation value is zero for both consumer types. In each period t, consumer i considers whether or not to watch a particular movie j. Once a consumer watches movie j, she exits the box office market for movie j. If consumer i decides to purchase a box office ticket for movie j in time period t, she obtains utility given by

$$\begin{aligned} u^b_{i,j,t} &= \phi(\tilde{f}^b_{j,t} + \tilde{\alpha}^{p,b} p^b_{j,t}) + \epsilon^b_{i,j,t} \\ &= f^b_{j,t} + \alpha^{p,b} p^b_{j,t} + \epsilon^b_{i,j,t}, \end{aligned} \tag{4}$$

where $f^b_{j,t}$ is the flow utility from observable and unobservable box office characteristics, $p^b_{j,t}$ is the price of the box office ticket, $\epsilon^b_{i,j,t}$ is an idiosyncratic shock, and β is the weekly discount factor. The parameter ϕ is a scaling parameter which permits the comparison between the home video and box office markets, it serves as a utility normalization factor, since we forced the error terms for both markets to have the same variance.

A consumer who does not watch movie j in period t, and owns a home video player of technological quality $k \in \{\text{DVD, Blu-ray}\}$ receives

$$u^b_{0,k,j,t} = \beta \mathbb{E}[V^b_k(\Omega^b_{j,t+1}) | \Omega^b_{j,t}] + \epsilon^b_{0,j,t}, \tag{5}$$

where $\Omega^b_{j,t}$, is industry state of movie j in theaters at period t; involving the flow utility, price disutility, and all history factors that influence the movie's future attributes (for instance, revenue and time since release, number of theaters available, etc. are important to form expectations about the last period of the market). Finally, $V^b_k(\Omega^b_{j,t})$ represents the value of having a box office ticket purchase possibility when the state of movie j is $\Omega^b_{j,t}$ and the consumer has a home video player of technological quality $k \in \{\text{DVD, Blu-ray}\}$. Note that the outside option depends on j since we are modeling each movie as a monopoly, and the continuation value of delaying the box office purchase decision is different for each movie.

The box office flow utilities depend on the movie features with the following relation:

$$f^b_{j,t} = \alpha^{fe,b}_j + \alpha^{x,b} x^b_{j,t} + \xi^b_{j,t}, \tag{6}$$

where $x^b_{j,t}$ are observable box office movie characteristics that vary over time, $\alpha^{x,b}$ are the coefficients of observable time dependent movie characteristics, $\alpha^{fe,b}_j$ are movie fixed effects and $\xi^b_{j,t}$ are the unobservable components of the flow utility that vary both over time, and across movies. Examples of time-dependent box office movie characteristics include advertising expenditure, average price, month, age, and performance up to current period. Similarly to the home video market, the estimation of the model parameters involves a second stage in which fixed effects are regressed on movie characteristics. Examples of movie characteristics involve distributor, production budget, and release year. Note that in (4) and (6) we assume that the consumer purchase utility specification about movies in theaters does not depend on the type of home video owned (DVD or Blu-ray), but this heterogeneity enters in (5), the outside option.

This utility specification generates a challenge. The box office market has a finite horizon, thus the model has to embed consumer's expectations about the market's horizon, the home window length, and the value of the home video market in order to quantify continuation values. To embed consumer's expectations we must make assumptions on what factors affect the movie's industry state $\Omega^b_{j,t}$. This is analyzed within the consumer's problem, in section 4.3.2.

4.3 Consumer's problem

We now outline the consumer's decision process, which incorporates the forward looking behavior about the evolution of the movie industry states $\Omega^b_{j,t}$. We begin by describing the decision process for the home video market as it is independent of the value functions of the box office market. We then describe the finite horizon model of the box office market, where the home video value enters through the terminal continuation value.

4.3.1 Home video market

The home video market consists of two separate markets that differentiate on the technological quality, we distinguish between them with subscript $k \in \{\text{DVD, Blu-ray}\}$. Each of them can be seen as an optimal stopping problem with an infinite horizon. In each period, consumers have the possibility to purchase their respective home video disc, or to wait. Following Equations (1) and (2), the value function prior the realization of $\vec{\epsilon}^{\,h}_{j,t} \doteq (\epsilon^h_{i,j,t}, \epsilon^h_{0,j,t})$ for consumer that owns home video player $k \in \{\text{DVD, Blu-ray}\}$ can be written as

$$V^h_k(\Omega^h_{j,t}) = \int \max\left\{f^h_{j,t} + \alpha^{p,h}_k p^h_{j,t} + \epsilon^h_{i,j,t}, \beta \mathbb{E}[V^h_k(\Omega^h_{j,t+1})|\Omega^h_{j,t}] + \epsilon^h_{0,j,t}\right\} g_\epsilon(\vec{\epsilon}^{\,h}_{j,t}) d\vec{\epsilon}^{\,h}_{j,t}. \tag{7}$$

From (7), the first element of the max operator indicates the purchase utility, while the second indicates the expected discounted value of delaying the purchase decision to the next period.

We proceed by using the aggregation properties of the extreme value distribution to express (7) in a rather simpler form, and then we make assumptions on how consumers form expectations about future movie industry states. Specifically, we can write

$$V^h_k(\Omega^h_{j,t}) = \ln\Big(\exp(\delta^h_{j,t}) + \exp(\beta \mathbb{E}[V^h_k(\Omega^h_{j,t+1})|\Omega^h_{j,t}])\Big), \tag{8}$$

where $\delta^h_{j,t} = f^h_{j,t} + \alpha^{p,h} p^h_{j,t}$, the *logit inclusive value*, is defined as the ex-ante present discounted lifetime value of buying a home video at period t, as opposed to waiting for the next period. We make the assumption that consumers only take into account the current value of $\delta^h_{j,t}$ to form the expectations of the evolution of V^h to the next period. So the history of the past values of $\delta^h_{j,t}$ does not matter. Thus, we have

$$V^h_k(\delta^h_{j,t}) = \ln\Big(\exp(\delta^h_{j,t}) + \exp(\beta \mathbb{E}[V^h_k(\delta^h_{j,t+1})|\delta^h_{j,t}])\Big). \tag{9}$$

We employ rational expectations for future values of $\delta^h_{j,t}$ by imposing a simple linear autoregressive specification:

$$\delta^h_{j,t+1} = \nu^h_{1,k} + \nu^h_{2,k}\delta^h_{j,t} + \eta^h_{j,t+1,k}, \tag{10}$$

where $\eta^h_{j,t+1}$ is normally distributed with zero mean and unobserved at time t, while $\nu^h_{1,k}$ and $\nu^h_{2,k}$ are general parameters to be estimated for $k \in \{\text{DVD, Blu-ray}\}$. This assumption ensures consumers are on average correct about the movie quality evolution. It is important to remark that the optimal consumer decisions, given a movie state $\delta^h_{j,t}$, will depend on the joint solution of the Bellman equation (9) and the movie state regression (10).

Once these two equations are solved, we can obtain the value functions $V^h_k(\delta^h_{j,t})$, and we then use them to estimate the individual purchase probabilities. The movie/medium j purchasing probability for a consumer at period t is given as a function of $\delta^h_{j,t}$, and is

$$\hat{s}^h_{j,t}(\delta^h_t) = \frac{\exp(\delta^h_{j,t})}{\exp(V^h_k(\delta^h_{j,t}))}. \tag{11}$$

4.3.2 Box office market

The box office market is similar to the home video market, but with a few differences. First, the market has a finite horizon which is unknown by the consumers, and second, the discounted home video value enters the box office model through the terminal continuation value of this unknown horizon. This allows for consumers to substitute between the box office market and the home video market, if this terminal continuation value is large enough. Furthermore, the home video value differs between the technological quality of the home video, i.e. DVD or Blu-ray, which may drive different substitution patterns between the different technological quality markets and the box office.

In order to model the unknown finite horizon, we use the time and revenue since release as drivers for a distribution of possible horizons. We use the data in order to fit a discrete hazard model that gives the probability for each possible horizon. This captures the endogeneity of theatrical runtime, where each theater decides based on performance whether to keep a movie in theaters or not. This procedure is described in Section 4.3.3

Following Equations (4) and (5) and using the aggregation properties of the extreme value distribution, similarly to how we arrived to Equation (8) in the home video market, we obtain the following value function equation for $V^b_{k,|T}$, the box office value function at time period t conditional on having an horizon at T and owning a home video player of type $k \in \{\text{DVD, Blu-ray}\}$;

$$V^b_{t,k|T}(\Omega^b_{j,t}) = \ln\Big(\exp(\delta^b_{j,t}) + \exp(\beta \mathbb{E}[V^b_{t+1,k|T}(\Omega^b_{j,t+1})|\Omega^b_{j,t}])\Big) \quad \forall t = 1, \dots, T-1, \tag{12}$$

where $\delta^b_{j,t} = f^b_{j,t} + \alpha^{p,b}_k p^b_{j,t}$, ($\Omega^b_{j,t}$ is the state of industry of movie j at time t, and T is the unknown horizon of the market, following a probability distribution that depends on t and the revenue since release. Finally, the terminal value function is set using expectations on the home video window (NT), and the home video value of movie j with technological quality k ($V^h_{k,j}$);

$$V^b_{T,k|T}(\Omega^b_{j,T}) = \ln\Big(\exp(\delta^b_{j,T}) + \exp(\mathbb{E}[\beta^{NT} V^h_{k,j}])\Big). \tag{13}$$

Since the horizon of the problem is unknown, consumers form a probability distribution over probable horizons, $g_T(\Omega^b_{j,t})$, which depends on the industry state of the movie $\Omega^b_{j,t}$ at time t. Then Equations (12) and (13) can be solved for each T and aggregated using the probability distribution over possible horizons for each time period. Finally we have

$$V^b_{t,k}(\Omega^b_{j,t}) = \sum_T V^b_{t,k|T}(\Omega^b_{j,T}) g_T(\Omega^b_{j,t}) \quad \forall t = 1, \dots, T, \text{ and } k \in \{\text{DVD, Blu-ray}\} \tag{14}$$

where the probability distribution over values of T is created from data using a hazard model that depends on the revenue and weeks since release. Subsection 4.3.3 provides details on this procedure.

We assume that consumers only take into account the current value of $\delta^b_{j,t}$, the time since release, t, and the revenue since release, r_t, to form expectations about the future values of purchase decisions. Then our state variables can be assumed to be (t, r_t, and $\delta^b_{j,t}$), since time (t) and revenue since release (r_t) are important to determine the probability distribution over possible horizons. Then, Equations (12), (13) and (14) can be rewritten as

$$V^b_{t,k|T}(\delta^b_{j,t}) = \ln\Big(\exp(\delta^b_{j,t}) + \exp(\beta \mathbb{E}[V^b_{t+1,k|T}(\delta^b_{j,t+1})|\delta^b_{j,t}]\Big) \quad \forall t = 1, \dots, T-1, \forall k \in \{\text{DVD, Blu-ray}\} \tag{15}$$

$$V^b_{T,k|T}(\delta^b_{j,T}) = \ln\Big(\exp(\delta^b_{j,T}) + \exp(\mathbb{E}[\beta^{NT_{k,j}} V^h_j])\Big), \text{ and} \tag{16}$$

$$V^b_{t,k}(\delta^b_{j,t}, r_t) = \textstyle\sum_T V^b_{t,k|T}(\delta^b_{j,t}) g_T(t, r_t) \quad \forall t = 1, \dots, T, \text{ and } k \in \{\text{DVD, Blu-ray}\}. \tag{17}$$

Once again, we employ rational expectations for future values of δ^b, by imposing a linear autoregressive specification:

$$\delta^h_{j,t+1} = \nu^b_1 + \nu^b_2 \delta^h_{j,t} + \eta^b_{j,t+1} \tag{18}$$

where $\eta^b_{j,t+1}$ is normally distributed with zero mean and unobserved at time t, while ν^b_1 and ν^b_2 are general parameters for all movies to be estimated. This assumption ensures consumers are on average correct about the movie quality evolution.

We assume that consumer expectations about the home video window and the home video value to quantify $\mathbb{E}[\beta^{NT_{k,j}} V^h_{k,j}]$ in (13), are based on perfect foresight. This is because if we did not use perfect foresight we would need to model consumer beliefs, and when we run a counterfactual analysis on these home video windows, they won't be consistent with the estimated beliefs. By using perfect foresight we ensure that estimated beliefs are consistent with our counterfactual home window lengths video windows.

Note that equations (12), (13), (14) and (18) must be solved jointly. This is because a change in the Bellman equation will yield different ν_1^b and ν_2^b coefficients, and that will impact the Bellman equations. Specifically, these equations need to be solved twice, one time for DVD player owners, and another time for Blu-ray player owners. The difference between these two comes in the terminal continuation values used in (13)[7]. The fixed point will depend on the continuation value used, but we refrain from using it as a variable for V_t^b. Note that both consumer types have the same quality vector, $\delta_{j,t}^b$, since the difference between types lies in the outside option.

Once these equations are solved, we can compute the individual purchase probabilities for each consumer segment. For simplicity, we now refrain from using k to identify consumer types and we use the suprascript $b-dvd$ for DVD player owners and $b-blu$ for Blu-ray player owners instead. The probabilities that a DVD and a Blu-ray player owner purchase a ticket for movie j in period t is given by

$$\hat{s}_{jt}^{b-dvd}(\delta_{j,t}^b, r_t) = \frac{\exp(\delta_{j,t}^b)}{\exp(V_t^{b-dvd}(\delta_{j,t}^b, r_t))} \text{ and } \hat{s}_{jt}^{b-blu}(\delta_{j,t}^b, r_t) = \frac{\exp(\delta_{j,t}^b)}{\exp(V_t^{b-blu}(\delta_{j,t}^b, r_t))}, \tag{19}$$

respectively. And based on the remaining weight of Blu-ray player owners for movie j at time period t, $w_{j,t}^{b-blu}$ we can compute the purchase probability of a random consumer

$$\hat{s}_{jt}^b(\delta_{jt}^b) = (1 - w_{j,t}^{b-blu})\hat{s}_{jt}^{b-dvd}(\delta_{jt}^b, r_t) + w_{jt}^{b-blu}\hat{s}_{jt}^{b-blu}(\delta_{jt}^b, r_t). \tag{20}$$

4.3.3 Discrete-Time Proportional Hazard Model for time in theaters

Theaters decide when to stop showing a movie, which is dependent on how the movie is performing. To capture this, we build a Discrete-Time Proportional Hazard Model following Cameron and Trivedi (2005) (section 17.10.1). This model gives a probability distribution for the remaining time in theaters, given the number of weeks the movie has been in theaters and the total revenue until then. Let T be the number of weeks a movie is in theaters, and $R(t)$ the box office total revenue by period t, we define the discrete time hazard function

$$\lambda^d(t|R_{t-1}) = Pr[T = t|T \geq t, R_{t-1}], \quad t = 1, \ldots, M,$$

which denotes the probability t is the last week this movie is in theaters, given it is in theaters in week t and the the total revenue until week $t-1$ is R_{t-1}. Then, the associated discrete-time survivor function is

$$S^d(t|R_{t-1}) = Pr[T \geq t|R_{t-1}] = \prod_{s=1}^{t-1} \left(1 - \lambda^d(s|R_{s-1})\right).$$

[7] Both, the home video value as well as the home window length may differ between DVDs and Blu-rays.

We can then specialize the continuous PH model to obtain the following expression for the discrete time hazard

$$\lambda^d(t|R_{t-1}) = 1 - \exp\Big(- \exp\left(\ln \lambda_{0t} + \beta \log(R_{t-1})\right)\Big),$$

where λ_{0t} for $t = 1, \ldots, M$ and β are parameters to be estimated. The associated discrete-time survivor function is

$$S^d(t|R_{t-1}) = \prod_{s=1}^{t-1} \exp\Big(- \exp\left(\ln \lambda_{0t} + \beta \log(R_{t-1})\right)\Big).$$

We can finally write the likelihood function as

$$L(\beta, \lambda_{01}, \ldots, \lambda_{0M}) = \prod_{i=1}^{N} \Big[\prod_{s=1}^{T_i - 1} \exp\Big(- \exp\left(\ln \lambda_{0s} + \beta \log(R_{s-1})\right)\Big)\Big] \times \Big(1 - \exp\Big(- \exp\left(\ln \lambda_{0T_i} + \beta \log(R_{T_i - 1})\right)\Big)\Big),$$

where i refers to each individual movie, and T_i for the time in theaters of such movie. We can the use the data to maximize this function over the parameters, and obtain our final Discrete-Time Proportional Hazard Model.

5 Estimation and identification

The estimation procedure to recover model parameters follows that of Gowrisankaran and Rysman (2012) and Derdenger (2014). Since the estimation of the box office market depends on the home video value, we estimate the home video market first and then we proceed with the box office market.

We will use $\vec{\alpha}^b$ and $\vec{\alpha}^h$ to denote $(\alpha^{fe,b}, \alpha^{x,b}, \alpha^{p,b})$ and $(\alpha^{fe,h}, \alpha^{x,h}, \alpha^{p,h})$, respectively, these are the vector of all fixed effects and observable characteristics coefficients. We now discuss the identification of the structural parameters $(\vec{\alpha}^h, \vec{\alpha}^b, \beta)$, which requires solving the home video market and use its results to solve the box office market. We do not attempt to estimate β, since it is well known that estimating the discount factor in dynamic decision models is a notoriously difficult task (Gowrisankaran and Rysman 2012, Magnac and Thesmar 2002). This is because consumer waiting can be explained by moderate preferences for movies, or by little discounting of the future. Thus, we set $\beta = 0.9995$ on a weekly level (equivalent to 0.974 yearly), leaving $(\vec{\alpha}^h, \vec{\alpha}^b, \phi)$ to estimate.

In order to allow for the comparison between box office and home video utilities, we must identify the scaling parameter ϕ. To do so, we must impose the following constraint in estimation.

$$\alpha^{p,b} = \phi \alpha^{p,dvd}. \tag{21}$$

With ϕ identified, we redefine $\vec{\alpha}^b \doteq (\alpha^{fe,h}, \alpha^{x,h})$, since $\alpha^{p,b}$ is not to be directly estimated.

Following Berry (1995) and Gowrisankaran and Rysman (2012), we specify a generalized method of moments (GMM) function

$$G(\vec{\alpha}^h, \vec{\alpha}^b, \phi) = Z' \vec{\xi}(\vec{\alpha}^h, \vec{\alpha}^b, \phi), \tag{22}$$

where $\vec{\xi}(\vec{\alpha}^h, \vec{\alpha}^b, \phi)$ is the stacked vector unobserved characteristics of the box office market (ξ^b_{jt}), DVD market (ξ^{dvd}_{jt}) and Blu-ray market (ξ^{blu}_{jt}), for which the predicted shares equal the observed shares, and Z is a matrix of exogenous instrumental variables. These instrumental variables consist of lagged home video prices, and box office prices which control for price endogeneity. We estimate the parameters to satisfy

$$(\hat{\alpha}^h, \hat{\alpha}^b, \hat{\phi}) = \underset{(\vec{\alpha}^h, \vec{\alpha}^b, \phi)}{\arg\min} \left\{ G(\vec{\alpha}^h, \vec{\alpha}^b, \phi)' W G(\vec{\alpha}^h, \vec{\alpha}^b, \phi) \right\}, \tag{23}$$

where W is a weighing matrix. Thus, to estimate $(\vec{\alpha}^h, \vec{\alpha}^b, \phi)$ we must first solve for $\xi(\vec{\alpha}^h, \vec{\alpha}^b, \phi)$, which requires solving for the shares of all markets. We first discuss how to solve for home video shares and then for box office shares. In the following sections, we explain how to obtain $\hat{\alpha}^h, \hat{\alpha}^b(\phi)$ and $\vec{\xi}(\hat{\alpha}^h, \hat{\alpha}^b(\phi), \phi)$ based on an initial guess of ϕ. The optimal value $\hat{\alpha}^h$ is independent of ϕ and can be solved separately. Given a guess for ϕ, one can solve for the optimal $\hat{\alpha}^b(\phi)$ easily, which will depend on the chosen ϕ. Finally, the optimal solution for $\hat{\phi}$ can be obtained by solving a single variable optimization problem, that includes a subproblem that finds $\hat{\alpha}^b(\phi)$,

$$\hat{\phi} = \underset{\phi}{\arg\min} \left\{ G(\hat{\alpha}^h, \hat{\alpha}^b(\phi), \phi)' W G(\hat{\alpha}^h, \hat{\alpha}^b(\phi), \phi \right\}. \tag{24}$$

5.1 Home video shares

The consumer decision problem for the home video market is defined in Section 4.3.2 as the fixed point of the Bellman equation (9), and the market evolution equation (10). We stack the DVD and Blu-ray panel data, to find the vector $\delta^h_{j,t}$ for which the predicted shares ($\hat{s}^h_{jt}$) equals the observed shares ($\hat{s}^h_{jt}$) for each movie and time period, namely

$$s^h_{j,t} = \hat{s}^h_{j,t}(\delta^h_{j,t}) \quad \forall j, t. \tag{25}$$

Following Gowrisankaran and Rysman (2012) and Berry et al. (1995) the solution to equation (25) can be solved using a fixed point iteration:

$$\delta^{h.new}_{j,t} = \delta^{h.old}_{j,t} + \psi^h \cdot \Bigg(\log(s^h_{j,t}) - \log\left(\hat{s}^h_{j,t}(\delta^h_{j,t})\right) \Bigg), \tag{26}$$

where ψ^h is a tuning parameter set to 0.6.

After finding the vector $\delta^h_{j,t}$ that satisfies the Bellman equation (9), the market evolution equation (10), and makes the predicted shares equal the observed shares, we compute the home video value for each movie j and medium k, DVD or Blu-ray, at the beginning of this market. We then use this value, $V^h_{k,j}$, as the terminal continuation value for the box office market as used in equation (13).

5.2 Box office shares

Once the home video market is solved, the home video values enter the terminal continuation values in the box office market and we seek a fixed point between equations (12), (13), (14) and (18). This is done for

DVD and Blu-ray player owners separately, and then we use (19) and (20) to compute the predicted box office market shares.

Like in the home video market, we wish to find a vector $\delta^b_{j,t}$ for which the predicted shares equals the observed shares for each movie and time period, namely

$$s^b_{j,t} = \hat{s}^b_{jt}(\delta^b_{j,t}) \quad \forall j, t. \tag{27}$$

We solve (27) by iterating over

$$\delta^{b.new}_{jt} = \delta^{b.old}_{jt} + \psi^{box} \cdot \left(\log(s^b_{j,t}) - \log\left(\hat{s}^b_{j,t}(\delta^b_{j,t})\right)\right), \tag{28}$$

where ψ^h is a tuning parameter set to 0.6.

5.3 Recovery of $\vec{\xi}$, $\vec{\alpha}^h$ and $\vec{\alpha}^b$

We use the estimated δ^b and δ^h on a set of regressions involving different movie characteristics. We begin by exposing the retrieval of characteristic coefficients for the home video market, and we proceed with the box office market. By the end of this subsection we describe our procedure to generate advertising and poster color covariates.

5.3.1 Home video

To recover the unobserved characteristics ξ^{dvd} and ξ^{blu}, which are required to compute the GMM objective function (24), we regress δ_{hv} as the purchase utility from equations (1) and (3) on a set covariates. The covariates involve movie-technology specific dummy variables [8] ($\alpha^{fe,h}_j$), age and the squared age of the movie in weeks, goodwill advertising stock, price, and, month and year dummies. The formation of the goodwill advertising stock follows that of Dubé et al. (2005) and it is explained in detail in subsection 5.3.3. For each covariate, we create a new one that is multiplied by a Blu-ray dummy as shown in (3).

Like other studies of market power since Bresnahan (1981), we allow price to be endogenous to unobserved characteristics (ξ^h), but we assume that movie characteristics are exogenous. This assumption is justified when movie characteristics are determined in advance, independently of unobserved ones at the moment the home videos are sold. As it is common in the literature, we use lagged prices and price differences from the mean as instruments in a two stage least squares regression.

This first stage regression to identify the contribution of time-dependent characteristics, must be performed after every fixed point on $\delta^h_{j,t}$ is achieved. This is because we need $\alpha^{p,h}$ to obtain $\alpha^{p,b}$ according to equation (21) in order to obtain the flow utilities for the box office after finding a fixed point in such market.

A second stage regression of our model can be performed after estimating $\hat{\phi}$ to recover estimates of non-time varying characteristics. This involves regressing the fixed effects obtained in the first stage regression

[8] A movie that is both on DVD and Bluray will have separate dummy variables for the panel rows that correspond to DVD and Bluray.

with movie specific characteristics such as logarithm of total first three weeks box office revenue and its squared term, home window and its square term, logarithm of the production budget for the film, distributor dummies, and poster color dummies (subsection 5.3.4 explains in detail the creation of the poster color dummies). Following Nevo (2000), we perform a minimum distance procedure, let $y = (y_1, \ldots, y_J)'$ denote the $J \times 1$ vector of fixed movie-technology coefficients ($\alpha_j^{fe,h}$) from Equation (3), X be the $J \times K(K < J)$ matrix of movie characteristics, and $\xi^{fe,h}$ is the movie specific deviation of the unobserved characteristics. Then, we have

$$y = X\beta^h + \xi^{fe,h}. \tag{29}$$

We do not make any assumptions on the error variance covariance matrix (Ω) since we can compute it from our first stage regression, thus, instead of of using an Ordinary Least Squares (OLS) procedure we perform a Generalized Least Squares (GLS) one. The GLS estimator is defined as

$$\beta_{GLS}^h = \arg\min_b (y - Xb)'\Omega^{-1}(y - Xb), \tag{30}$$

which can be rewritten as $\arg\min_b [\Omega^{-1/2}(y - Xb)]'[\Omega^{-1/2}(y - Xb)]$. This can be seen as OLS objective function of $\tilde{y} = \tilde{X}b + \tilde{\xi}^{fe,h}$, with $\tilde{y} \doteq \Omega^{-1/2}y$, $\tilde{X} \doteq \Omega^{-1/2}X$ and $\tilde{\xi}^{fe,h} \doteq \Omega^{-1/2}\xi^{fe,h}$. Thus, the GLS estimator can be written as $\hat{\beta}_{GLS}^h = (\tilde{X}'\tilde{X})^{-1}\tilde{X}'\tilde{y} = (X'\Omega^{-1}X)^{-1}X\Omega^{-1}y$, with $\hat{\xi}^{fe,h} = \hat{y} - X\hat{\beta}_{GLS}^h$. Furthermore, we can write the variance of the GLS estimator as $VAR(\hat{\beta}_{GLS}^h) = (X'\Omega X)^{-1}$.

5.3.2 Box office

For each value of ϕ, we impose constraint (21) and regress $\hat{\delta}_{j,t}^b \doteq \delta_{j,t}^b - \phi\alpha^{p,dvd}p_{j,t}^b$ as the flow utilities in equation (6), which involves movie specific dummy variables, the logarithm of the first three week revenue[9], age and the squared age of the movie in weeks, goodwill advertising stock and current month. This yields $\xi^b(\phi)$ which allows for the computation of the GMM objective function (24). We refrain from using a two stage least squares regression as used in the home video market because the endogeneity of price has already been subtracted with the use of the utility scaling parameter.

We then perform a second stage regression that finds the taste components for the movie specific characteristics, i.e. release year, logarithm of production budget, distributor dummies, and poster color dummies. We use the same GLS regression as in the home video second stage regression.

The procedure to compute the GMM objective function and estimate ϕ may be summarized as follows:

1. Recover $\hat{\delta}_{j,t}^b = \delta_{j,t}^b - \phi\alpha^{p,dvd}p_{j,t}^b$ given ϕ.
2. Run a movie fixed effects regression of $\hat{\delta}_{j,t}^b$ on time dependent movie characteristics to estimate $\alpha_j^{fe,b}$ and $\alpha^{x,b}$ from equation. (6)
3. Compute $\xi_{j,t}^b(\vec{\alpha}^b(\phi)) = \hat{\delta}_{j,t}^b - \alpha_j^{fe,b} + \alpha^{x,b}x_{j,t}^b$.
4. Construct $\xi(\vec{\alpha}^h, \vec{\alpha}^b, \phi)$ and compute the objective function of equation (24).

[9]For the first week we set this covariate as 0, while for weeks 2 and 3 we add all revenue in previous weeks until then.

5.3.3 Goodwill advertising stock

Following Dubé et al. (2005), we implement a simple advertising model that captures the "carry-over" of advertising to posterior periods. Let $A_{j,t}$, $g_{j,t}$ and $g^a_{j,t}$ denote the advertising expenditure, goodwill stock and augmented goodwill stock for movie j in period t. The augmented goodwill stock is what enters in the consumers' utility function, and it is increased by advertising over an already present goodwill stock:

$$g^a_{j,t} = g_{j,t} + \psi(A_{j,t}), \tag{31}$$

where ψ is the goodwill production function. Dubé et al. (2005) discuss some possibilities for ψ, we particularly assume that $\psi(x) = \log(1 + x)$. Augmented goodwill stock in period t depreciates over time, with a discount rate $\lambda \in (0, 1)$ per period, and becomes the beginning of goodwill stock in period $t + 1$:

$$g_{j,t+1} = \lambda g^a_{j,t}. \tag{32}$$

Our advertising data shows advertising expenditure per movie per month. Given the difficulty of estimating discount rates, we assume $\lambda = 0.75$. Once we find the augmented goodwill for a given month, we use that amount for all weeks that start during such month.

5.3.4 Poster Colors

In this section we describe the procedure to apply color theory in consumer preferences for movie posters. Several online articles discuss the importance of color choices in marketing, see Morton (2012), O'Grady (2019) and Hauff (2018), suggesting that color theory might be used as a persuasion mechanism to increase purchases. Generally, color theory suggests that the use of complementary colors is used to drive sales.

In order to apply color theory in our model, we downloaded poster images with a resolution of 500×750 for each movie in the data using the API at https://www.themoviedb.org/. Following Ivasic-Kos et al. (2014), we extract color information from each movie poster by transforming the RGB values of pixels to HSV (hue/saturation/value) and extracting its hue. Then, we transform the hue from each pixel to a color by using a discretized 12 color palette, and finally we obtain a 12-color spectrum for each movie poster. As an example, Figure 3 shows the hue spectrum obtained for the poster of the movie "Iron Man 2". We can see that this poster makes use of complementary colors - two hues positioned exactly six spaces away from each other - using orange and azure to attract viewers. This a common practice in action pictures - most of them make use of red/orange/yellow explosions and contrast it with some form cyan/azure/blue.

In order to identify consumer preference for different poster colors and to identify preference for the use of complementary colors, we first create a dummy variable for the color peak in each movie spectrum. We then create two different covariates:

1. peak color strength: we generate it by multiplying a peak color dummy with the percentage of pixels that belong to this color in the poster.

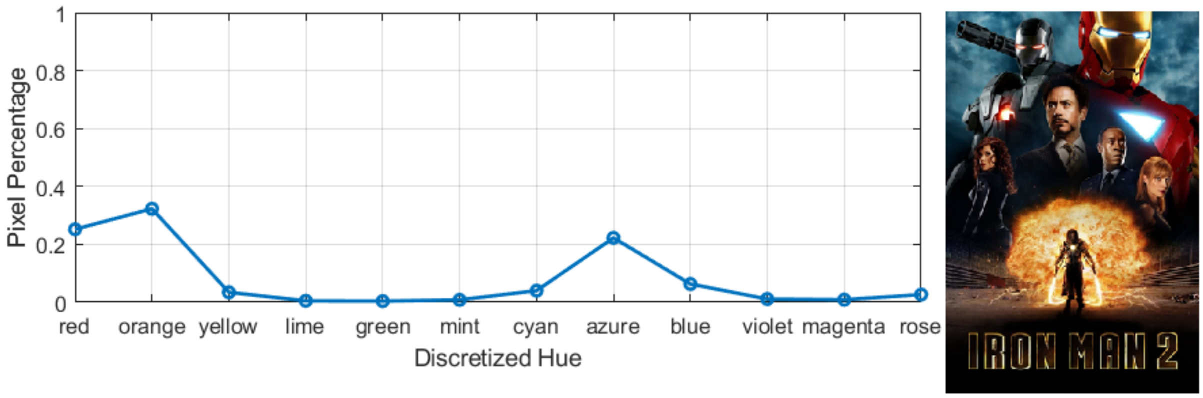

Figure 3: Discretized hue spectrum for the poster of the movie "Iron Man 2" seen on the right.

2. complement color strength: we generate it by multiplying a peak color dummy with the percentage of pixels that belong to this color's complement in the poster.

6 Results

We present our time dependent parameter estimates in Table 5. For all markets, the average price coefficient is negative, which means consumers have marginal disutility towards price. Consumers dislike consuming older products, as seen with the negative values in the age coefficients. Advertising affects utility with a positive effect on all markets, and based on the coefficients it affects Blu-ray purchase utility the most, followed by DVDs and then box office tickets. The "lag 1st3weeks box revenue" variable represents the total box office lagged revenue until a given period or week 4, whichever comes first. The overall contribution of the linear and quadratic logarithmic terms of this variable is increasing with revenue. This means that movies that perform better during the first few weeks since release drive purchase utility up for the upcoming weeks.

We present time independent parameter estimates in Table 6. The estimates for the logarithm opening box office revenue show a convex response for the utility, and specifically for the ranges of box office revenue dealt in the data, it is increasing for both DVDs and Blu-rays. This means that the better a movie performs in theaters, the better it will perform in the home video market. The home video window coefficients for DVD and Blu-ray show a concave response to utility. DVDs present a maximum at 5.2 weeks, while Blu-rays present a maximum 9.1 weeks. These non-zero maximums could be capturing the effects of word of mouth, and it is important to note that this is the case when everything else is held constant, as the advertising spillover effect from theaters will most likely shift these maximums to lower values. The production budget estimate for the box office and Blu-rays is positive, suggesting that higher production budget films generate greater revenue for the box office and Blu-rays. This effect is opposite for DVDs, showing that increasing the production budget reduces the DVD revenue.

Time Dependent Characteristics

Variable	**Box Office**	**Home Video**	**Blu-ray Indicator**
log(lag 1st3weeks box revenue)	0.2356 (0.0459)***	-	-
log(lag 1st3weeks box revenue)^2	-0.0126 (0.0026)***	-	-
Age (weeks)	-0.8158 (0.0157)***	-0.0154 (0.0042)***	-0.0004 (0.0069)
Age^2 (weeks^2)	0.0221 (0.0009)***	0.0000 (0.0000)***	-0.0000 (0.0000)***
Advertising	0.5048 (0.1334)***	0.6645 (0.0009)***	0.1043 (0.0159)***
Price	-0.0113 (-)	-0.0330 (0.002)***	-0.0194 (0.0037)***
ϕ	0.3421	-	-
Month fixed effects	✓	✓	✓
Year fixed effects		✓	✓
Movie medium fixed effects	✓	✓	✓
N	1,797	70,253	25,373

$^{***}p < .01$, $^{**}p < .05$, $^{*}p < .1$

Table 5: Time dependent parameter estimates.

Our results on movie colors are significant and present some interesting features. The use of yellow and its complement in a poster yields the largest contribution to purchase utility for both box office and Blu-rays. This is not surprising, as action movies exhibit explosions and fires in their posters, (which contribute to the yellow hue), and use a complementary color to make these stand out. What is interesting to note is that for DVDs, the contribution of yellow and complement is negative, which suggests that DVD consumer behavior is different from the behavior of box office and Blu-ray consumers.

Time Independent Characteristics

Variable	**Box Office**	**DVD**	**Blu-ray**
log(1st3weeks box revenue)	-	-3.8676 (0.0884)**	-5.2108 (0.1340)***
log(1st3weeks box revenue)^2	-	0.1226 (0.0027)***	0.1580 (0.0041)***
Home window (weeks)	-	0.0263 (0.0065)***	0.0752 (0.0076)***
Home window^2 (weeks^2)	-	-0.0025 (0.0004)***	-0.0042 (0.0005)***
log(production budget)	0.4902 (0.0324)***	-0.2251 (0.0122)***	0.1652 (0.0187)**
Red indicator × %	0.5099 (0.1055)***	0.1034 (0.0371)***	0.1120 (0.0614)**
Orange indicator × %	0.0635 (0.1146)	0.0797 (0.0384)**	-0.0345 (0.0729)
Yellow indicator × %	-0.3011 (0.2506)	0.2615 (0.0803)***	1.7793 (0.1225)***
Cyan indicator × %	0.5175 (0.1822)***	0.6823 (0.0807)***	1.5314 (0.0985)***
Azure indicator × %	0.2789 (0.0962)***	-0.0409 (0.0404)	0.2504 (0.0618)***
Red indicator × complement%	-2.8862 (0.7920)***	6.1720 (0.3358)***	-0.5325 (0.4289)
Orange indicator × complement%	-1.1732 (0.4195)***	1.0549 (0.1668)***	2.3883 (0.2000)***
Yellow indicator × complement%	14.1576 (3.2520)***	-3.3738 (1.0169)***	21.6641 (1.1852)***
Cyan indicator × complement%	-5.8510 (0.7074)***	-1.31377 (0.2467)***	-1.9363 (0.2581)***
Azure indicator × complement%	-2.6716 (0.3524)***	0.4767 (0.1268)***	0.9212 (0.1793)***
Distributor fixed effects	✓	✓	✓
Release year fixed effects	✓	✓	✓
N	149	149	113

$^{***}p < .01$, $^{**}p < 0.05$, $^{*}p < .1$

Table 6: Time dependent parameter estimates.

7 Counterfactuals

For this section we use the 113 movies for which we have DVD and Blu-ray sales data. We modify the data by setting the DVD and Blu-ray home windows to a specific number of weeks NT_{dvd} and NT_{blu}, respectively. At the same time, we readjust the advertising goodwill by discounting through longer or shorter periods of time. For each market (box office and home video), we must reach an equilibrium described in Section 4.3, the Consumer's problem. As both markets depend on the box office revenue during the first three weeks of the theatrical run, and the box office market terminal continuation value depends on the home video value, this becomes a challenge. We begin with a guess of the box office revenue during the first three weeks of the theatrical run, and solve the home video market. We use that home video value and box office revenue to solve the box office market. We iterate between both markets until we find a fixed point in box office revenues and home video values. This must be done for each counterfactual set of values of the home video window.

We first analyze the case where both technological qualities, DVD and Blu-ray, are released simultaneously, and then we allow for versioning, where each of them may have different release strategies. We take the point of view of the studios and try to maximize their revenue from both box office and home videos. In order to split the box office revenue between studios and theaters we impose a standard contract (Vogel 2014). This contract involves a house nut of \$2,000 per theater per week, and after subtracting the nut the split starts at 70% in favor of the studios, decreasing 10% every two weeks until it reaches 0%. These contracts generate incentives for theaters to exhibit movies for a longer period of time, as the share they keep from box office revenue is greater with the age of the movie.

For each movie, we find the optimal home video windows and then we compute the average across optimals.

7.1 Simultaneous DVD and Blu-ray Release

In this section we describe the counterfactual analysis in which the DVDs and Blu-rays are released simultaneously, as this was the current industry practice during the data time period. Figure 4 shows a histogram of the home video windows for the data, and for the studio optimals. As we see, for most movies it is optimal to shrink the home video window to a range between 0 to 4 weeks. This means that advertising spillover effect from theaters and the home video freshness are dominating over the increased competition to theaters that an early home video release may provide. Furthermore, the demand cannibalization of the box office, generated by this early release, reduces the box office signal which could impact home videos, but again the advertising spillover effect dominates.

Figure 5 shows the studio revenue from the box office and home videos for a particular movie as a function of the home video window. We see a steep increase in the home video revenue from shrinking the home video window, while the demand cannibalization to theaters is minimal. Table 7 shows the average home

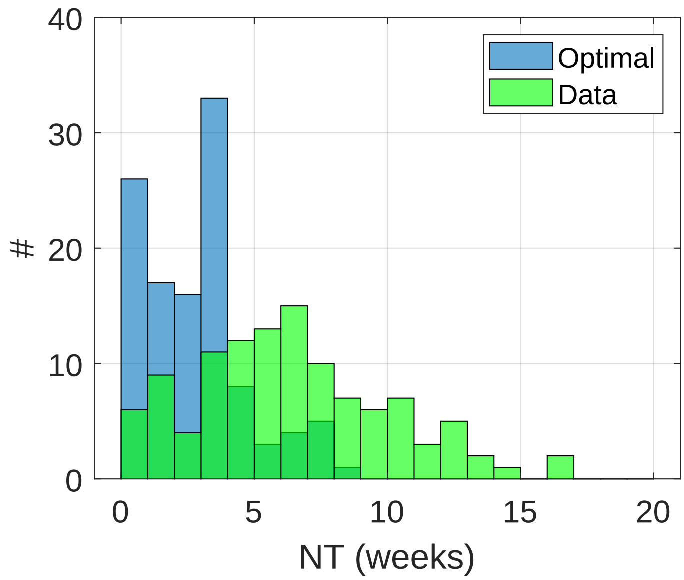

Figure 4: Histogram of the home window lengths, for the data and the optimal.

video window, studio revenue and theater revenue, under the optimized strategy and the data. We can see that the average optimal strategy shrinks the home video window to about 2.3 weeks, providing an increased studio revenue of 4.47% and an increase in theater revenue of 0.04%.

Simultaneous Release Revenues

Averages	**NT (weeks)**	**Studio Revenue ($)**	**Theater Revenue ($)**
Optimal Simultaneous Release	2.3186	124.34M (+4.47%)	64.59M (+0.08%)
Data	6.1960	119.02M	64.45M

Table 7: Home video windows and revenue information for the optimal simultaneous release strategy and the data. Studio revenue accounts for the home video window as well as the box office revenue studio share, while theater revenue accounts for the portion or box office revenue that corresponds to theaters.

In the following section we allow for separation between DVD and Blu-ray releases and analyze its benefits.

7.2 Versioning: Separate DVD and Blu-ray releases.

We now analyze the counterfactual in which the home video window may differ for different technological qualities. We denote NT_{dvd} and NT_{blu} as the home video window for DVD and Blu-ray respectively.

In order to ensure that Blu-ray player owners benefit from choosing a Blu-ray over a DVD for each movie, we must impose an incentive compatibility constraint. In general, the value of the Blu-ray is larger than

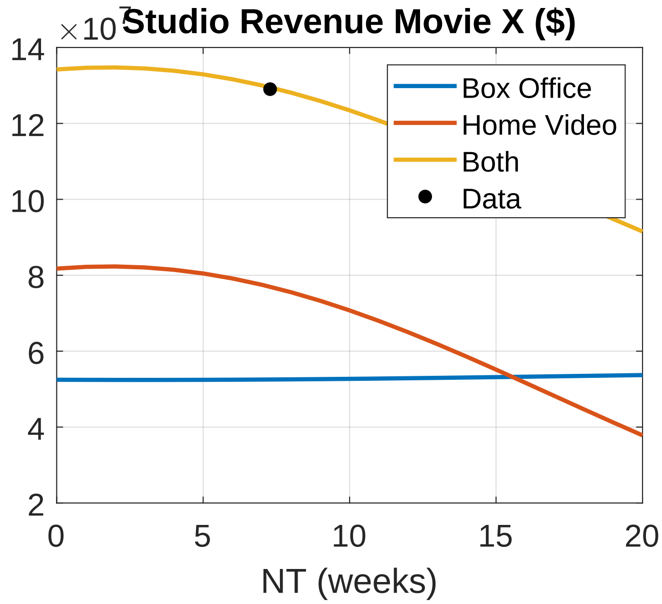

Figure 5: Studio revenue from the box office, home videos, and both, as a function of the home video window for a particular movie. The gray circle represents the studio revenue at the data home video window of 7 weeks.

value of the DVD, but if the Blu-ray release was to be delayed, some consumers might switch to the DVD. By imposing this constraint we ensure that our market size for Blu-rays would be better-off choosing Blu-rays over DVDs. This constraint is as follows:

$$\beta^{NT_{dvd}} V_{dvd} \leq \beta^{NT_{blu}} V_{blu}, \tag{33}$$

the discounted ex-ante value of the Blu-ray has to be greater than or equal to the discounted ex-ante value of the DVD. This is imposing an upper bound on the difference between home video windows. We can rewrite constraint (33) to

$$NT_{blu} - NT_{dvd} \leq \frac{\log\left(\frac{V_{blu}}{V_{dvd}}\right)}{|\log\beta|}. \tag{34}$$

We now search over (NT_{dvd}, NT_{blu}) to find the optimal studio revenue satisfying the incentive compatibility constraint (34). Figure 6 shows the histogram of home video windows for the data, the DVD optimal and the Blu-ray optimal. We can see a clear difference with the simultaneous release from Figure 4. Now it is optimal to have an immediate after theater release for DVDs, while it is optimal to delay the Blu-ray release to an average of about 5 weeks. We see that for DVDs, the advertising spillover from theaters offsets the increased competition. For Blu-rays, these two effects are more balanced. This happens because the ex-ante value function for DVDs is smaller than the one for Blu-rays, so shrinking the home video window for DVDs has very little effect on box office purchases. Then you can shrink the window and reap the benefits of the advertising spillover effect. This result supports the idea that higher technological quality home videos are closer substitutes to Blu-rays. Shrinking the home video window for Blu-rays will not only impact the box office demand, but it will reduce the box office revenue, reducing the movie quality signal for the home video market (DVD and Blu-ray).

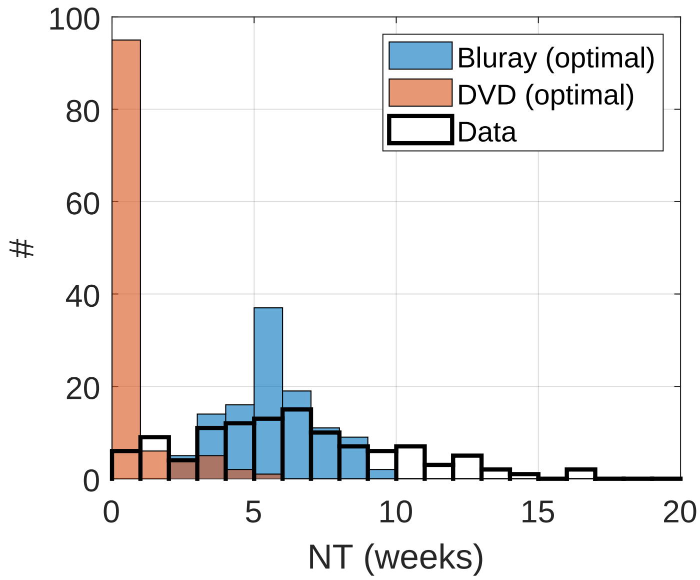

Figure 6: Histogram of the home window lengths, for the data, and the optimal ones for DVD and Blu-ray.

Figure 7 shows the optimal studio revenue as a function of the DVD and Blu-ray home video windows for the same movie as in Figure 5. We clearly see that there is a greater steepness in the DVD home video window axis compared to that of the Blu-ray one. This is because DVD and theaters experience very little competition between each other, and shortening the home video window allows DVD to benefit from the advertising spillover effect. While for Blu-rays, we see lower steepness in the revenue because the trade-off is more balanced. Table 8 illustrates the new average optimal release windows, studio revenues and theater revenues. We can see that the average optimal DVD and Blu-ray windows are about 0.4 and 5.2 weeks respectively. The studio revenue increases almost an extra 1% with respect to the simultaneous release in Table 7, while the theater revenue remains almost the same. This result highlights the benefit of exploiting market segmentation strategies in a consumer base that expresses heterogeneous preferences on home video technological qualities. Further improvements could be made by optimizing over advertising periods, and home video pricing, but that is out of the scope of this paper.

8 Conclusion

In this paper we build and estimate a dynamic discrete choice model about movie distribution involving the box office, DVDs, and Blu-rays. We capture consumers value for delaying purchase decisions, allowing for substitution between box office tickets and home videos. We run counterfactuals on the home video

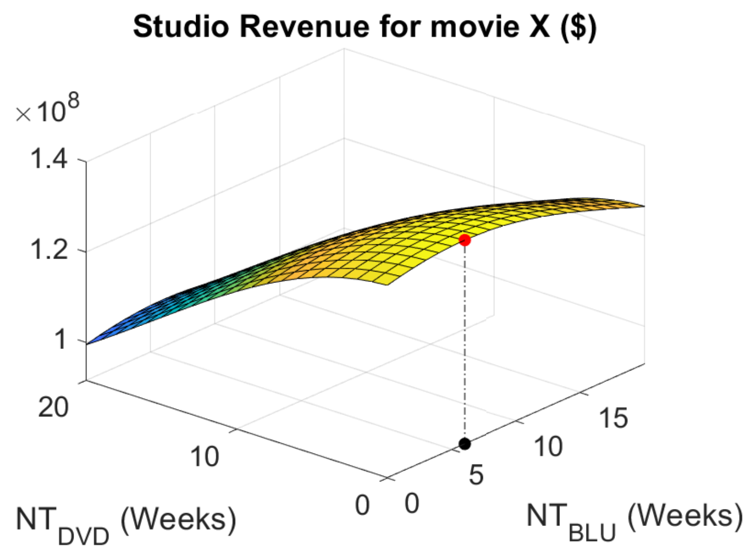

Figure 7: Studio revenue from the box office, home videos, and both, as a function of the home video window for a particular movie. The gray circle represents the studio revenue at the data home video window of 7 weeks.

Separate Release Revenues

Averages	**NT (weeks)**	**Studio Revenue ($)**	**Theater Revenue ($)**
Optimal Release (DVD,Blu-ray)	(0.3717, 5.1504)	125.40M (+5.36%)	64.56M (+0.03%)
Data	6.1960	119.02M	64.45M

Table 8: Home video windows and revenue information for the optimal separate release strategies and the data. Studio revenue accounts for the home video window as well as the box office revenue studio share, while theater revenue accounts for the portion or box office revenue that corresponds to theaters.

windows and we find that releasing DVDs 0.4 weeks after the theatrical run, and Blu-rays about 5.2 weeks after, is optimal on average. This strategy achieves an average revenue increase of 5.36% for the studios with respect to the current practice, while having minimal impact on theaters. This analysis suggests that higher technological quality home videos are closer substitutes to theater, and their release balances advertising spillover effect from theaters with demand cannibalization. Releasing higher technological quality home videos early cannibalizes theater demand, which impacts theatrical revenue and further impacts all home video markets. For lower technological quality home videos such as DVDs, this is not the case, as they don't compete with theaters, one can release them early reaping all the benefits of the advertising spillover effect. These results highlight the benefit of exploiting market segmentation strategies in a consumer base that expresses heterogeneous preferences on home video technological qualities.

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