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Eliminating digital rights management from the E-book market[☆]

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ABSTRACT

We examine the impact of removing Digital Rights Management (DRM) from electronic book devices. We derive a Bayesian hierarchical logit model based on the consumer's utility maximization problem and estimate the model using data from a choice-based survey. We then simulate the counterfactual market outcomes when DRM is removed; on average, the consumer surplus increases nontrivially holding everything else constant. However, the gain in consumer surplus is diminished when we re-calibrate e-book device prices. Further, if there is a negative shock to content supply, then the consumer surplus could in fact decrease after DRM removal.

1. Introduction

With the supply and demand for creative goods such as music, films, and books increasingly migrating from physical format to the digital, a new form of copyright management system has been widely adopted by market participants in the past couple of decades: Cryptographic engineering allowed rights holders to directly control access to and use of copyrighted works via Digital Rights Management (DRM). Specifically, a DRM system is an encryption scheme applied to digital content which can only be decrypted by authorized users and devices. The Digital Millennium Copyright Act of 1998 famously criminalized the act of circumventing DRM as well as disseminating knowledge about how to circumvent DRM.

While being perfectly legal, DRM has been criticized for over-protecting the rights holders beyond the scope of protection provided by traditional copyright laws. For instance, DRM systems most often prevent consumers from making a copy of purchased content for personal and other fair use, lending or sharing the content with others (except on

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a limited basis), and reselling the original copy to a third party.[1] The handful of exemptions from anti-circumvention of DRM systems issued by the U.S. Copyright Office indicate that there is indeed a tension between the traditional copyright laws and the DRM technology (e.g., Bechtold, 2002; Feigenbaum and Weitzner, 2018).

Despite the criticisms from consumers and the arguments by e-commerce executives that DRM would not prevent unauthorized copying, all major e-book publishers have insisted on encrypting their content with DRM prior to distribution.[2] The challenge is that we cannot readily predict what the counterfactual world without DRM systems would look like. If it led to more piracy, publishers' profits would be reduced, and the incentive to create weakened, which would ultimately reduce the supply of content. The adoption (or removal) of DRM thus involves the familiar tradeoff between the benefits to consumers and the incentives provided to producers.

This paper aims to quantitatively assess how the removal of DRM systems would change the consumer surplus in the e-book platform market. Other scholars such as Rayna and Striukova (2008) have argued that consumers are not willing to pay as much for DRM-protected goods as for DRM-free ones. While empirical evidence on DRM is growing, how much DRM removal would positively affect consumer surplus is still a policy-relevant, open question that remains to be answered.

To answer this question, we solve the consumer's utility maximization problem and derive an indirect utility function that theoretically incorporates the optimal consumption of digital content. This leads to a demand system for e-book readers that exhibits choice-specific hardware price coefficients, and we estimate the discrete-choice model using Bayesian techniques that allow for individual unit-level coefficients with flexible priors and show that it yields a plausible substitution pattern among the three major e-book platforms (the Kindle, the Nook, and the iPad).

For our counterfactual experiments, we start by turning off the DRM indicator for each of the three platforms, as well as for all of them at the same time, holding everything else constant. We find that the Kindle and the Nook can increase their market shares by a few percentage points if they unilaterally removed DRM, while the iPad's market share is little affected. The average consumer surplus increases by $18 and $15 per person if the Kindle or the Nook unilaterally removed DRM, respectively; and it increases on average by $35 per person when all three devices removed DRM at the same time.

We then allow for a supply-side response in our counterfactuals. Because the e-book platform is a two-sided market, there are two layers of supply response: The first is that the platform could re-optimize the device price; and the second is that the publishers could pull contents if a platform were to remove DRM, which would lower the platform's content availability. For the former, we use the inverse elasticity rule extended to the two-sided market (e.g., Weyl, 2010), and re-calibrate the equilibrium device prices in our counterfactual scenarios. For the latter, we assume hypothetical scenarios about the extent of a negative supply response (as we do not have any data on content supplies).

We find that the re-calibrated device prices dampen the consumer surplus gains, as the removal of DRM systems leads to an increase in residual demand elasticities which creates an upward pressure on the hardware prices. For instance, when DRM is removed from all three devices, the re-calibrated Kindle price increases by $14; the Nook increases by $13; and the iPad increases by $50. The average consumer surplus gain falls from $35 to $7 per person. We also find that a moderately negative supply response from publishers (say 20% reduction of available contents) can significantly offset the consumer surplus gains when the Kindle or the Nook removes DRM. When all three devices remove DRM, the negative supply response would in fact strictly decrease the average consumer surplus.

Some limitations to our approach need to be acknowledged upfront. First, our model is based on the premise that DRM cannot by itself increase consumer surplus. In other words, while some consumers might in fact prefer having DRM for such reason as that they believe DRM can reduce consumer piracy, our model assumes that consumers dislike having a DRM system, holding all other factors (such as the device price and content supply) constant. Our study is motivated by the general debate on this topic that tends to negatively portray the effect of DRM on consumers, thus creating tradeoffs. While our results indicate that consumers do not experience a significant disutility from DRM, we cannot test or quantify a positive impact of DRM per se.

Second, there are other impacts of DRM that cannot be built into our model. For instance, DRM could be used to limit content available to a rival platform. However, our model and data do not allow us to consider the effect of DRM on platform entry. Also, we cannot directly address how DRM removal changes the availability of contents, for instance, if a wider range of books can be made available across devices due to increased piracy. Further, we do not consider any potential antitrust issues, where DRM can be preferred by the platform-cum-device manufacturers to facilitate collusive pricing (Park and Scotchmer, 2005) or increase the hardware market power (Kim and Waldman, 2016).

The outline for the paper is as follows. Section 2 discusses some background information. Section 3 presents our model, and Section 4 describes the dataset. Section 5 discusses the estimation results, and Section 6 contains the counterfactual exercises. Section 7 concludes.

[1] The inability to resell is due to the fact that under a DRM system the content producer or publisher remains as the owner of the distributed content; that is, consumers are in fact paying for the license to access the content rather than acquiring the ownership of it.

[2] For instance, Apple CEO Steve Jobs said to music industry executives "None of this technology that you're talking about's gonna work. We have Ph.D.s here who know the stuff cold, and we don't believe it's possible to protect digital content" (Goodell, 2011).

2. Background

2.1. Industry overview

We study the e-book market that emerged in the late 2000s.[3] Digital publishing became a mass market phenomenon only after dominant e-commerce platforms introduced dedicated e-book readers (and later more versatile tablet PCs) along with a large selection of e-books on their online retail platforms. Specifically, Amazon's introduction of the Kindle e-book reader in 2007 was a major landmark in the expansion of e-book market. By mid-2010, Amazon sold more e-books (not including free Kindle e-books) than hardcover books, when Amazon had only about 630,000 Kindle e-books compared to the millions of physical copies sold on their platform (Miller, 2010).

The success of the Kindle soon prompted its competitors to enter the market. Barnes and Noble introduced the Nook in 2009, and Apple introduced the iPad in 2010. Others followed (such as Samsung's Galaxy Tab in 2011 and Google's Nexus in 2012) but did not achieve much success possibly due to their lack of a viable online retail platform. Therefore, the three platforms (Amazon, Barnes and Noble, and Apple), with their own DRM systems, have dominated the US e-book market.

The optimality of the DRM policy can vary across industries. The experiences of two industries are worth mentioning. The first is the music industry. Unlike the e-book market, where DRM has never been abandoned by any of the major platforms or publishing houses, Apple stopped selling DRM-protected music in 2009 after Amazon signed deals with some of the major labels to sell DRM-free songs in MP3 files. There are various differences between the two markets that might contribute to the different policies on DRM. First, digitization started earlier and is more prevalent in the music industry. While a significant portion of the readers still prefer physical books, most music consumers do not listen to music on CDs and cassettes. Second, music is more ubiquitously played. In other words, DRM restriction not only imposes inconveniences of playing music on multiple devices, but also increases the incentives to download pirated music. The cost of having DRM in digital music might therefore have been higher than that in the e-book market.

Digital game market is another one in which DRM has been widely adopted. In this market, the migration of sales to DRM-protected digital downloads has rapidly increased thanks to the client and launcher software called Steam, which was started in 2003 and has become the dominant marketplace with over 70 percent market share. The debate in this market is similar to that of the e-book market: While most game developers want protection from potential piracy (hence, loss of revenues), players want freedom to lend, sell, or gift the game that they paid for. On the one hand, unlike an e-book account, a Steam account holder actually receive some additional benefits such as content updates and milestone achievements. On the other hand, players have a stronger desire to re-sell when they finish playing the game, while readers may want to keep an e-book for future references. A more definitive cost-benefit analysis of the optimality of DRM in the digital game market would however require an investigation which is beyond the scope of this paper.

Overall, the above discussion implies that the effect of DRM can vary across markets, due to different characteristics of consumption, and a uniform DRM policy across markets may not be optimal. Thus, it becomes important to examine the effects of DRM in a specific market setting.

2.2. Related literature

The legal and policy literature often focuses on how DRM can make traditional copyright laws obsolete (e.g., Gimbel, 1998), while the theoretical literature does not clearly distinguish copyright laws and DRM. For instance, Ahn and Shin (2010) and Vernik et al. (2011) assume that DRM increases the cost of copying, which is similar to the role copyright laws play in the traditional law and economics literature (e.g., Landes and Posner, 1989). However, a growing number of papers started to study DRM at the platform level. For instance, Bergemann et al. (2011) argue that the content provider chooses a level of DRM flexibility not taking into account its effect on the profit of the platforms; and Leung (2015) provides some empirical evidence on this effect.

There is little empirical evidence on the effects of DRM.[4] For instance, Sinha et al. (2010) examine the consumer's willingness to pay for DRM-free music and find that DRM removal will enhance both consumer and producer welfare. On the other hand, Oestreicher-Singer and Sundararajan (2010) find that some digital rights are positively associated with e-book prices, while other rights are negatively associated. The main difference is that we model a device (hardware) choice, while folding the content consumption into the utility function. However, our finding that the average consumer is better off without DRM, when holding the supply side constant, is consistent with Sinha et al. (2010) and the theoretical prediction of Oestreicher-Singer and Sundararajan (2010).[5]

Our contribution is that we quantitatively assess the consumer valuation of DRM systems (or its removal) in the e-book market. We refine the usual logit demand model based on the consumer's utility maximization problem and estimate our model in a choice-based conjoint setting. In this regard, our approach is similar in style to that of Allenby et al. (2014), where economic value of patented features (e.g., swivel-screen display for digital cameras) is estimated assuming a standard Nash-in-price equilibrium

[3] In 1992, Sony invented one of the first e-book readers; and until mid-2000s Palm Digital Media sold personal digital assistants with about 5000 e-book titles from small and large publishers, but they remained as a relatively niche market and are not the focus of this paper.

[4] See, e.g., Rob and Waldfogel (2006), Oberholzer and Strumpf (2007), and Hammond (2014) on the general sales displacement effect due to piracy; and Handke (2012); Mortimer et al. (2012) and Waldfogel (2012) for supply response in the music industry.

[5] Zhang (2018) also finds that the removal of DRM in the music industry increased online album sales, especially for (lesser-known) albums at the tail of the sales distribution, because DRM removal would lower the search costs, facilitating product discovery.

for differentiated products. The difference is that our demand model includes multiplicative factors that take into account the effect of content consumption, and we use a two-sided monopoly pricing rule, which allows for residual demand elasticities being less than unity.

The paper that is perhaps the closest to ours is Li (2019), which estimates a dynamic demand model for e-reader adoption and subsequent book purchases. It is shown that skimming for e-book readers and harvesting on e-books can improve the platform's profitability, when the consumers are forward looking. While ours is a static consumption model, it shares the similar tradeoff between the gain in e-book consumption and the one-time device purchase. However, Li does not deal with the DRM issue and the model is estimated for a single platform (the Kindle). On the other hand, we do not have data on book consumption, whereas Li is able to estimate the consumer's utility as a function of book consumption. Therefore, we believe that ours is a complementary study.

3. Model

3.1. Demand side

With a slight abuse of notation, let us assume consumer $i \in \{1, \ldots, I\}$ faces an inside choice set $J = \{1, \ldots, J\}$. In our context, J includes the three major e-book platforms mentioned earlier and an alternative for hard copy books. Note that the hard copy option is different from the outside option (non-consumption), which is included in the choice set to more accurately elicit consumer preferences.

Let f_j denote the fixed device price of choice $j \in J$, which is zero for the hard copy option. Let x_j be a vector of non-price attributes, which includes choice-specific intercepts (dummies), a touch screen function, and a screen size. Note that the DRM feature enters the utility function via content consumption because DRM is not a standalone device feature per se, but it only matters for the content consumption.

Our key modeling assumption is that the content consumption and the device choice are simultaneously determined; that is, the desired level of content consumption is perfectly foreseen at the time of device choice.[6] One way to interpret our model given this assumption is that we estimate the consumer's utility from an ex-ante standpoint (i.e., prior to the content consumption). While both ex-ante and ex-post consumer welfare can be important, we cannot estimate ex-post welfare given the lack of data on book consumption.[7]

Given that contents (books) are often differentiated goods, we represent the consumer's preference by a constant elasticity of substitution utility function, where ω denotes an index of contents. Assuming that each consumer chooses one (and only one) option in the set J, each consumer i solves the following problem:

$$\max_{n_{ij}(\omega),\, j\in J} u_{ij} = \gamma_i' x_j + \left(\int_{\Omega_j} n_{ij}(\omega)^{(\sigma_i-1)/\sigma_i} d\omega \right)^{\sigma_i/(\sigma_i-1)} + \epsilon_{ij}$$

$$\text{s.t. } f_j + \int_{\Omega_j} p(\omega) n_{ij}(\omega) d\omega = g_i \text{ for } \forall j \in J,$$

where γ_i is a vector of subutility parameters; Ω_j is the size of content varieties available with choice j; $n_{ij}(\omega)$ is the consumption of variety ω; σ_i, $\sigma_i > 1$, is the elasticity of substitution parameter; ϵ_{ij} is an i.i.d. random utility shock; $p(\omega)$ is the price of content variety ω; and g_i is consumer i's total budget.[8] Consumers may choose an outside option, where mean utility is normalized to zero. It can be shown that the optimal consumption is $n^*_{ij}(\omega) = (p(\omega)^{-\sigma_i}/B_{ij})(g_i - f_j)$, where $B_{ij} = \int_{\Omega_j} p(\omega)^{1-\sigma_i} d\omega$. After substituting in for $n^*_{ij}(\omega)$, we obtain an indirect utility function, $v_{ij} = \gamma_i' x_j + \beta_{ij}(g_i - f_j) + \epsilon_{ij}$, where $\beta_{ij} \equiv B_{ij}^{1/(\sigma_i-1)}$ denotes the price index of differentiated content varieties.

We now elaborate on how to incorporate additional non-price attributes. First, we assume that the value of content consumption $n_{ij}(\omega)$ cannot increase by encumbering it with a DRM system. As previously discussed, DRM tends to decrease the consumption value by imposing various restrictions on what the consumer can do with the purchased/licensed content. Thus, we assume that the value of the content consumption decreases from $n_{ij}(\omega)$ to $\delta_i n_{ij}(\omega)$ due to DRM, where $\delta_i \in (0, 1)$. That is, one can think of $\delta_i n_{ij}(\omega)$ as the value of content consumption with DRM restrictions on and $(1 - \delta_i) n_{ij}(\omega)$ as the additional value from having the DRM system removed.[9]

Second, the content price $p(\omega)$ can be influenced by the platform's discount policies. For instance, online platforms offer e-book versions at a larger discount than they do for hard copies; and platforms offer different levels of book discounts. Hence, we allow for a platform-specific content discount factor, $D_j \in (0, 1)$, so the effective content price becomes $D_j p(\omega)$. In terms of the utility function, these mean that β_{ij} would be multiplied by δ_i and D_j^{-1}. Therefore, incorporating the two consumption factors, we now have an indirect utility, $v_{ij} = \gamma_i' x_j + (DRM_j \delta_i + (1 - DRM_j)) D_j^{-1} \beta_{ij}(g_i - f_j) + \epsilon_{ij}$, where DRM_j indicator is 1 if platform j has DRM and 0 otherwise.

3.2. Supply side

As previously mentioned, there are two layers of supply side. There is typically a large variety of contents being

[6] This allows for a tractable, static model of a discrete choice and continuous consumption. Such a model goes back to at least Dubin and McFadden (1984), where an appliance choice and its subsequent use are made simultaneously under perfect foresight.

[7] There is a further literature on the divergence between ex-ante and ex-post welfare; however, the standard analysis in welfare economics under uncertainty is typically concerned with optimality from an ex-ante viewpoint (e.g., (Harris and Olewiler 1979).

[8] Note that the available e-book titles vary across platforms in the real world. For instance, for multiple random weeks, we checked that as much as half the Kindle e-books listed on the Kindle's Hot New Releases were not available on the Nook.

[9] Our model does not directly capture the potential gain from increased piracy after the removal of DRM. We do not have a good way to identify such a benefit given our data, though it may possibly counteract a negative supply response by publishers.

produced, which can be thought of as an equilibrium variety of a Chamberlinian monopolistic competition model, where producers enter until the marginal producer can only expect to break even. The individually small producers do not often have the means to directly sell their goods to the consumers, so they must rely on offline and online distribution channels.

For our purpose, it is useful to think of the channels as platforms in a two-sided market, where the platform can charge different tariffs to the content producers and the consumers. In the market for e-books, the platform charges a one-time fixed price f_j to the consumers for a device that has a constant marginal cost of production mc_j. The platform does not typically charge a membership fee to the content producers, but it keeps a portion of the content price as a sales commission which we denote as $r_j(\omega)$.

Thus, in our context, an e-book platform j would maximize the profits $(f_j(I_j, \Omega_j) - mc_j)I_j + r_j(\omega)I_j\Omega_j$, where the device price, f_j, depends on the number of platform users, I_j, and the number of content producers, Ω_j. In a symmetric equilibrium, the total sales commission is proportional to the size of interactions between the two sides, $I_j\Omega_j$. Notice that in terms of the demand model, I_j is the platform j's market share times the total market size I. The profit-maximizing solution consistent with the general class of solution provided by Weyl (2010) is as follows:

$$\frac{f_j - (mc_j - r_j(\omega)\Omega_j)}{f_j} = \frac{1}{\left|\eta_j\right|},$$

where η_j is the own-price elasticity of platform j's hardware device. Thus, an additional user joining platform j creates a marginal benefit $(r_j(\omega)\Omega_j)$ offsetting the marginal cost of production (mc_j). This is a modification of the well-known inverse elasticity rule, which is the firm conduct most often assumed in differentiated product markets. The difference is that in the standard pricing rule, the royalty term is missing, so the aggregate demand must be price elastic ($\left|\eta_j\right| > 1$), but in a two-sided market, $r_j(\omega)\Omega_j$ may be greater than mc_j, so there is no restriction that the residual demand elasticities must be greater than unity.

4. Data

To estimate our discrete choice model, we need to observe consumers' repeated choice of an e-book reader when the price and non-price attributes vary. However, the major platforms (Amazon, Barnes and Noble, and Apple) have never removed DRM from their e-book devices. Lacking a real-world variation, we designed and fielded a choice-based conjoint survey following the standard practice found in the literature.[10] There are naturally some concerns with using stated preference data; however, conjoint surveys have a long tradition in academia as well as in industry, and have oftentimes yielded plausible estimates (e.g., Beggs et al., 1981; Louviere and Woodworth, 1983; Manski and Salomon, 1987; Brownstone and Train, 1999).

Specifically, we created four versions of conjoint surveys, each version comprising a set of 16 choice tasks. A typical choice task looks like Fig. 1, wherein the difference across tasks is that the values of the five product attributes were randomly varied. For instance, we draw the device price for the Kindle and the Nook from \$10 to \$240 in an increment of \$10; and similarly for the iPad from \$100 to \$850. The randomized choice-based conjoint design obeys the principles of Minimal Overlap (each attribute level is shown as few times possible in a single task); Level Balance (each level of an attribute is shown approximately an equal number of times); and Orthogonality (attributes levels are chosen independently of other attribute levels) (Sawtooth Software, 2008).

Book discount rate was varied from 0% to 60% in an increment of 10%; screen size was chosen from {6; 7; 7.9; 9.7 in.} reflecting existing models; and touch screen and DRM were either Yes or No. We include screen size and touch screen features as product attributes because they were the most frequently mentioned factors in e-book reader choices when we did a small group pilot study with college students, prior to designing our conjoint survey. (The group also revealed their maximum willingness to pay for the devices.) We believe that the inclusion of additional product attributes helps elicit the correct preferences. If our survey only included DRM and device prices, then it could make DRM more salient than it really is in the absence of other product attributes.

The survey was fielded in June 2013 by an online survey firm SurveyMonkey. We purchased 1400 completed responses targeting an approximation of the US population demographics.[11] Our survey started with an introduction explaining the five product attributes to be shown in the choice tasks. For instance, regarding DRM, we explained "When an e-book reader uses DRM protection, you cannot share the e-books you purchased with other people and/or read the e-books in incompatible devices." Regarding price discount for books, "This is the discount rate off of the full retail price of hard copies or e-books when you purchase them through the e-book reader of your choice." After completing the 16 choice tasks, we also asked the respondents about their e-book consumption experience.

There are other e-book platforms (e.g., Kobo) that were not included in our survey, but the three platforms included in our survey had over 90% market share in the e-book market (Carmody, 2013). We also did not include the tablet PC versions of the Kindle and the Nook, given their relatively small market shares compared to the iPad.[12] Including two different products of the same brand in a choice set is not common in the conjoint survey literature;

[10] "A conjoint survey can be viewed as a market simulator in which consumers are asked to choose among hypothetical products whose features (including price) are varied in a randomized design" (Allenby et al., 2014). See, e.g., Green et al. (2001) for an overview.

[11] Online panels are nonrandom samples as they were recruited by banner ads, etc., so some caution needs to be exercised. However, in terms of observables, the survey panel was representative of the broader market (to follow) and a cost-effective solution for us.

[12] While tablet PCs have become much more powerful over the years, the iPad was frequently considered as a rival of the other e-readers in the popular magazines (e.g., Falcone, 2012). Its main drawback compared to e-ink readers was the reflective, backlit screen.

	 Kindle E-Reader	 Nook E-Reader	 iPad	 Hard Copies
DRM	No	Yes	No	N.A.
Touch Screen	No	Yes	Yes	N.A.
Device Price	$20	$100	$500	$0
Screen Size	6 inch (size of an actual Kindle E-Reader)	7 inch (size of an actual Kindle Fire Tablet)	7.9 inch (size of an actual iPad mini)	N.A.
Price Discount for Books	50% off	30% off	20% off	No Discount

You would choose: Kindle _____ Nook ____ iPad _____ Hard Copies ____ None ____

Fig. 1. A Sample Conjoint Task.

and including them (i.e., having six instead of four inside choices) would lead to a longer survey, hence, respondent's fatigue. As Allenby et al., (2014) suggests, a conjoint survey needs to include the main exemplars of competing products and brands, but it is not required to include the complete set of what is available in the market.

A total of 1652 respondents took our online survey. Of these, 212 did not complete the 16 tasks or had missing demographic information, and were therefore dropped from the analysis for showing lack of interest or time. For the same reason, we dropped additional 371 respondents who chose the same option throughout the 16 tasks. Hence, our final sample includes observations from 1069 respondents, each completing 16 tasks of choosing one of the inside (reading) options or the outside option. The final sample (though it does not necessarily represent a random sample) is well represented across the demographic groups (gender, age, income, and education) as well as the US regions, where these data were provided by the survey firm.

According to the Book Industry Study Group report, 38% of US adults who read e-books own a Kindle e-ink reader, 11% own a Nook e-ink reader, and 32% own an iPad or an iPad mini (Greenfield, 2013). These figures are in line with our survey respondents' self-reported device ownership shown at the top of Table 1. That is, after the choice tasks, we asked four additional questions. One of them was "What e-book devices do you use? (you can choose more than one)." The data in Table 1 show that 32% of the respondents own a Kindle device, 10% a Nook device, and 25% an iPad. While the Kindle's and the iPad's market shares are underrepresented, this seems to be a reasonable representation.

The rest of Table 1 shows the summary statistics of our survey panel. While the aforementioned basic demographic characteristics are provided by SurveyMonkey, the last three are from the questions we asked in our survey: *Reading Habit* is 1 if the respondent chose "Yes" to the question "Do you read e-books?" *Piracy Experience* is 1 if the respondent chose "Yes" to the question "Have you ever downloaded pirated e-books?" 58% of the survey respondents read e-books, which is consistent with the 41% of them not owning an e-book device. 6% of the panel said that they have downloaded pirated e-books, which is not so far from the 3% e-book piracy rate according to online sources.[13]

Finally, we also asked, "How much do you spend on all books per year (on average)?" This represents the respondent's budget for book consumption. Because the total budget in our model includes the purchase price of an e-book device, we imputed the respondent's total budget by adding the stated book budget and the retail price of the device(s) that the respondent said he or she owned. For instance, if one owned a Kindle and an iPad, then we add their device prices ($140+$400=$540) to the self-reported book budget. *Imputed Budget* has a mean around $340 with a standard deviation of $286.

[13] Statista.com reports that US e-book sales were $3.35 billion in 2012, while the Association of American Publishers estimated in 2012 that its US members lose $80 to $100 million annually due to e-book piracy. These imply about 3% e-book piracy rate.

Table 1
Respondent Characteristics.

	Mean	Std. dev.	Min	Max
Owns Kindle	0.32	0.47	0	1
Owns Nook	0.10	0.29	0	1
Owns iPad	0.25	0.43	0	1
Owns Other	0.09	0.29	0	1
Owns None	0.41	0.49	0	1
Male	0.46	0.50	0	1
Age Group	2.64	1.06	1	4
Income Level	2.83	1.31	1	5
Education Level	3.80	0.99	1	5
Reading Habit	0.58	0.49	0	1
Piracy Experience	0.06	0.24	0	1
Imputed Budget	3.40	2.86	0.20	17

The number of respondents in the final sample is 1,069. Age is 1(18–29), 2(30–44), 3(45–60), and 4(60 or more); Income is 1($0-25K), 2($25-50K), 3($50-100K), 4($100-150K), and 5($150K or above); Education is 1(less than high school), 2(high school degree), 3(some college), 4(associate or bachelor degree), and 5(graduate degree). Budget is in hundred dollars.

5. Estimation

5.1. Bayesian posterior

Recall that the consumer's indirect utility is $v_{ij} = \gamma_i' x_j + (DRM_j \delta_i + (1 - DRM_j)) D_j^{-1} \beta_{ij} (g_i - f_j) + \epsilon_{ij}$. To estimate this models à la Fadden (1973), we assume that ϵ_{ij} is a type I extreme value random variable, so the probability that consumer i chooses option j is $P_{ij} \equiv \exp(v_{ij})/(1 + \sum_{j=1}^{J} \exp(v_{ij}))$. Letting $t = 1, \ldots, T$ denote a choice task, the likelihood of observing a series of choices made by consumer i is $\prod_{t=1}^{T} \prod_{j=1}^{J+1} \mathbf{1}_{ij}^{(t)} P_{ij}^{(t)}$, where $\mathbf{1}_{ij}^{(t)}$ is an indicator for i's choice of option j in task t.

We substitute data for $(x_j, DRM_j, D_j, f_j, g_i)$ and denote the heterogeneous (unit-level) preference as $\Theta_i \equiv [\gamma_i, \delta_i, \beta_i]$. Given the high-dimensional parameter space, we take a hierarchical Bayes approach in our estimation with flexible (mixture of normals) priors, following Rossi et al. (2005). In hierarchical Bayes, there are two stages of priors, so the priors on the unit-level parameters are drawn conditional on a set of hyperpriors, which allows for more flexible posterior distributions of Θ_i.

In the first stage, the unit-level parameters are drawn from a normal distribution, $\Theta_i \sim N(\Delta' Z_i + \mu_{ind_i}, \Sigma_{ind_i})$, where Z_i is a vector of observable characteristics (i.e., gender, age, income, education, reading habit, piracy experience, imputed budget) of consumer i, and Δ is a matrix of regression coefficients (hyperparameters). Thus, the Z_i variables shift the mean of the normal distribution. The mixture of normals prior in the first stage means that there are $1, \ldots, K$ types (or groups) of consumers in the market, and they have different values for the mean (μ_{ind_i}) and the covariance (Σ_{ind_i}), where we use a latent variable $ind_i \in \{1, \ldots, K\}$ to indicate consumer i's type.

The second-stage priors comprise the standard conjugate priors, and they are not of central interest in this paper. That is, our main interest is the posterior distribution of the unit-level parameters in Θ_i rather than the hyperparameters in Δ, μ_{ind_i}, or Σ_{ind_i}, the details of which are relegated to the Appendix. Following Rossi et al., we visually examine the posterior distributions and traceplots to determine our preferred mixture-of-normal components as $K = 3$, where the posterior mixing probabilities are (0.813; 0.180; 0.008). $K = 4$ or higher appears to be over-fitting with very small mixing probabilities; however, our results are not sensitive to the choice of K.

We re-parameterize the likelihood function by substituting β_{ij} with an exponential transformation $\tilde{\beta}_{ij} = \exp(\beta_{ij}) > 0$ for the J hardware price coefficients, to impose the sign restriction. Similarly, we substitute the DRM coefficient δ_i with a logistic transformation $\tilde{\delta}_i = 1/(1 + \exp(-\delta_i)) \in (0, 1)$, to be consistent with our model setup. Given the normal priors, these restrictions are necessary to avoid drawing negative price coefficients, which would mean that consumption creates a disutility, or DRM coefficients that are implausibly larger than unity. If we do not impose the assumption that $\tilde{\delta}_i \in (0, 1)$ but only a nonnegative restriction $\tilde{\delta}_i > 0$, then the mean of $\tilde{\delta}_i$ is still just below one (0.98).[14]

However, we acknowledge that our estimation of the model is not aimed at testing whether DRM restrictions in fact lower the consumer's utility. Our assumption, $\tilde{\delta} < 1$, already implies that DRM lowers the utility, ceteris paribus, because our goal is to quantify the degree of such a reduction in consumer's utility. While it is certainly possible that some consumers may like the fact that their e-books are DRM-encrypted, $\tilde{\delta}$ in our model is a static consumption parameter, as the model takes the content variety (Ω) as given. Whether or not some consumers truly derive a positive utility from having DRM-encrypted e-books rather than DRM-free ones is a hypothesis that would go beyond our model.[15]

[14] With the nonnegative restriction, the posterior distribution of $\tilde{\delta}_i$ is bell-shaped between 0 and 2, with a long tail leading up to 6. The extreme right tail is difficult to interpret, because the consumption utility is unlikely to double or triple because of DRM, so we prefer the logistic transformation.

[15] Potential reason why DRM systems may increase the consumer utility includes i) the consumer derives some moral utility value assuming that DRM prevents piracy; ii) the consumer enjoys some exclusive consumption value because other people may not enjoy the same content with DRM protection.

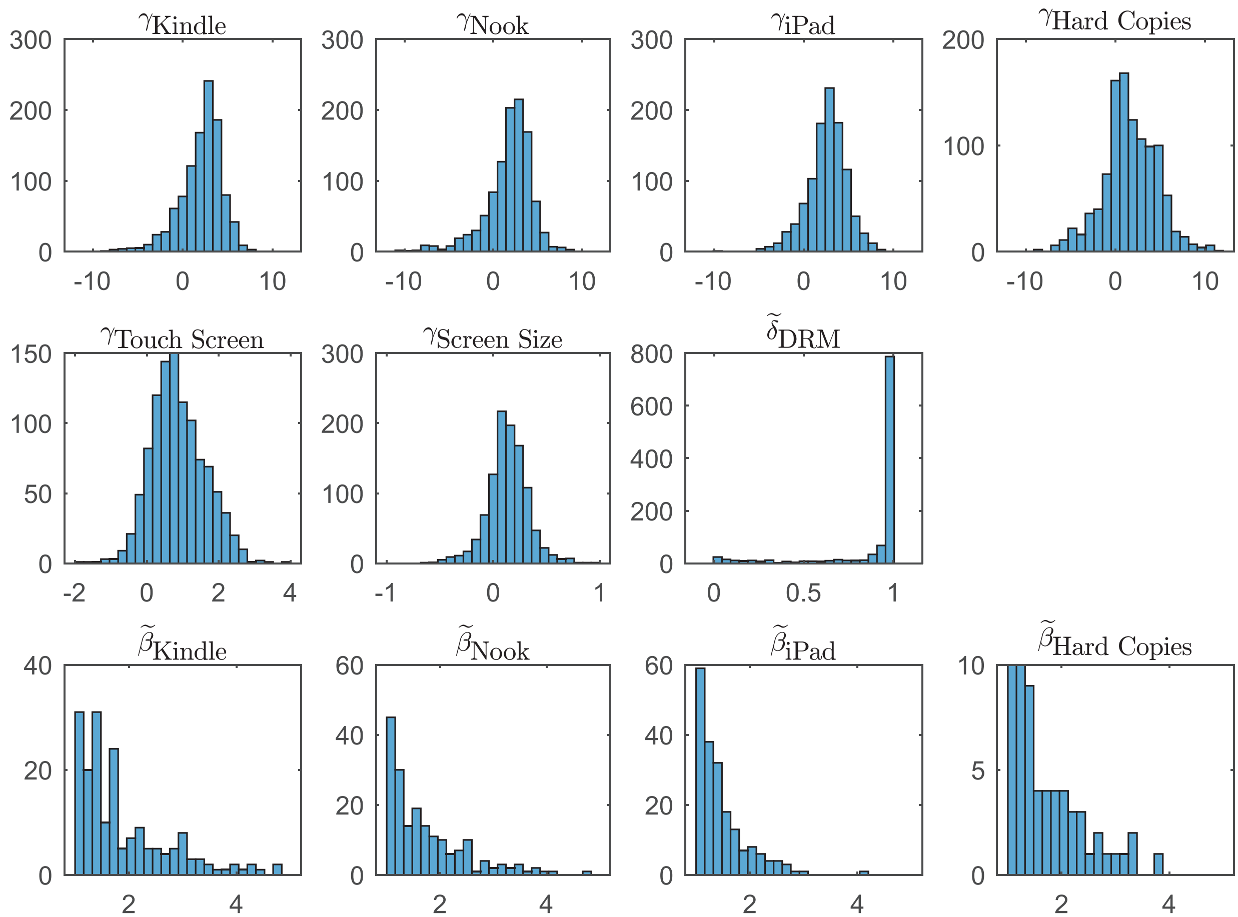

Fig. 2. Posterior Distributions of Θ_i.

We draw the posterior samples for 30,000 iterations, and after discarding the first 10,000 iterations as burn-ins we saved every 10th iteration. In Fig. 2, we present the posterior distributions (histograms) for the individual (unit-level) parameters in $\Theta_i \equiv [\gamma_i, \delta_i, \beta_i]$. Specifically, Θ_i includes a J-vector of choice-specific intercepts (constants), three coefficients on the product attributes (touch screen, screen size, and DRM), and a J-vector of choice-specific hardware price coefficients. We did not winsorize our draws of Θ_i because doing so is uncommon in the literature, but to make the scale of histograms more informative, we excluded some outliers in Fig. 2.

Fig. 2 shows that the DRM coefficient has a large mass just below one. This indicates that most consumers do not in fact experience a significant disutility due to the DRM restrictions in our model. There are a few potential reasons for the small DRM effect. First, if consumers are loyal to the brand/platform that they are currently using, then changes in the DRM feature may not affect the respondent's choices significantly. Although we removed the respondents who consistently chose the same platform throughout the survey, this effect may have some lingering effect. Second, the survey respondents, especially those who only own single devices, might not be aware of or did not care about DRM's impact as DRM was primed for them in a subtle way. We did not intend to treat respondents with an educational campaign on DRM, because we wanted to capture the consumer preference in its natural state. Third, unlike music, books are not really remixable or publicly performed, so it is possible that the majority of readers may not have had a chance to use multiple devices, share their e-books, or lend them; that is, DRM may be just less applicable to the e-book market even with perfect knowledge (Farivar, 2012).

Table 2
Benchmark Choice Attributes.

	Kindle	Nook	iPad	Hard Copies
Device Price	\$140	\$140	\$400	\$0
Book Discount	50%	50%	35%	10%
DRM Enabled	Yes	Yes	Yes	-
Touch Screen	Yes	Yes	Yes	-
Screen Size	6	6	9.7	-

5.2. Current market

We first investigate the implications of our demand system before simulating counterfactual outcomes from eliminating DRM in the next section. Table 2 shows the prod-

Table 3
Posterior Means of Current Market.

	Kindle	Nook	iPad	Hard Copies	None
Market Shares (MS)					
	0.314	0.249	0.214	0.184	0.039
	[0.305,0.321]	[0.242,0.256]	[0.206,0.222]	[0.179,0.189]	[0.036,0.041]
Demand Elasticities					
f_{Kindle}	-0.695	0.516	0.158	0.243	0.271
	[-0.742,-0.652]	[0.470,0.556]	[0.142,0.173]	[0.216,0.269]	[0.227,0.313]
f_{Nook}	0.406	-0.819	0.128	0.225	0.201
	[0.376,0.438]	[-0.865,-0.770]	[0.114,0.143]	[0.201,0.248]	[0.164,0.230]
f_{iPad}	0.285	0.301	-0.957	0.153	0.312
	[0.259,0.307]	[0.276,0.325]	[-1.022,-0.894]	[0.132,0.171]	[0.190,0.446]
Diversion Ratios					
f_{Kindle}	-1	0.591	0.155	0.206	0.049
	[-1,-1]	[0.566,0.618]	[0.139,0.169]	[0.184,0.226]	[0.040,0.056]
f_{Nook}	0.624	-1	0.135	0.203	0.039
	[0.600,0.647]	[-1,-1]	[0.120,0.149]	[0.182,0.221]	[0.032,0.044]
f_{iPad}	0.437	0.367	-1	0.138	0.059
	[0.412,0.463]	[0.345,0.390]	[-1,-1]	[0.123,0.153]	[0.036,0.082]

These are based on 30,000 draws of Θ_i, the first 10,000 of which are taken as burn-ins, saving every 10th draw. 90% highest density intervals are shown in square brackets.

uct attributes that we use to simulate the market shares (or aggregate demands) in the benchmark market. In setting these values, we took into consideration the following facts: The Kindle Touch and the Kindle Paperwhite were released in September 2011 and 2012, respectively, at a retail price of $140; the Nook Simple Touch and the Nook Simple Touch with GlowLight were released in June 2011 and April 2012, respectively, at a retail price of $139; and Apple sold the iPad 2 at $399 since 2012.

Further, we assume that e-books were sold at a 50% discount on Amazon and Barnes and Noble.[16] Given the $9.99 e-book pricing, a norm set by Amazon (and followed by Barnes and Noble), a 50% discount implies a full retail price of $20 per title. On the other hand, Apple did not follow Amazon's $9.99 e-book pricing, but it allowed the publishers to increase e-book prices to $12.99, which means a 35% discount off of the retail price $20. As for hard copy books, Amazon sold one in every three or four books at a 25% to 35% discount (Streitfeld, 2013), which amounts to a 10% discount on average. Finally, all three devices use a DRM system and a touch screen; and screen sizes are set to their true specifications.

Simulation results for the current benchmark market are summarized in Table 3. The first panel contains the predicted market shares (MS) for each choice using the posterior draws of the unit-level parameters in Θ_i. To be precise, the market in this context means the set of survey respondents. For each draw of Θ_i saved, we calculate each consumer's choice probabilities P_{ij} given the benchmark attributes and add them up to get the aggregate market demand for each j in a simulation run. We then take the average of the demands across simulation runs and divide it by the number of respondents to get the market shares reported at the top of Table 3.[17]

The second panel in Table 3 shows the own- and cross-price elasticities for the three e-book devices calculated at the benchmark device prices and market shares. The elasticity formula for market share j with respect to device price k is standard and as follows:

$$\eta_{kj} = -\frac{f_k \sum_i \left[Coeff_{ik} P_{ij} (\mathbf{1}(j=k) - P_{ik})\right]}{\sum_i P_{ij}},$$

where f_k is the device k price; $Coeff_{ik} \equiv (DRM_k \delta_i + (1 - DRM_k))D_k^{-1}\beta_{ik}$ denotes consumer i's price coefficient on device k; $\mathbf{1}(j=k)$ is an indicator for the symmetric case $(j=k)$; and P_{ij}'s are the choice probabilities. We then take the average of the elasticity across simulation runs and report the mean and the 90% highest density interval in Table 3.

Our results show that demands for all three devices are price inelastic ($\left|\eta_j\right| \equiv \left|\eta_{jj}\right| < 1$). In particular, the Kindle has a more inelastic demand (-0.70) than the Nook (-0.82), which implies that the former has strong consumer loyalty than the latter. The iPad has a more elastic demand (-0.96) than the Kindle or the Nook, with its price much higher than the other two devices. While the relatively low elasticities can be partly due to the brand loyalty (the brand dummy estimates are relatively large compared to the price coefficients), the fact that they are price inelastic necessitates an extension to the two-sided market to understand the optimal pricing strategy.

The substitution pattern among the device choices can be more intuitively summarized by using the diversion ratios (Farrell and Shapiro, 2010), which measures the increase in unit sales of substitute product j as a result of a small increase in price of product k, relative to a decrease

[16] Publishers sold their books to online retailers at a 45% to 55% discount off of retail book price (OECD, 2012); and Amazon's e-book pricing is often considered as a loss-leader strategy, so Amazon sold e-books at or near the wholesale price (De los Santos and Wildenbeest, 2017).

[17] One might think that the Nook's market share (24.9%) is overrepresented in our benchmark market; however, the Nook in fact had the peak market share of 25% in 2011, and the Book Industry Study Group report highlighted the Nook's declining sales (Bowker, 2012).

Table 4
Counterfactual Simulation (Holding Price Fixed).

	MS_{Kindle}	MS_{Nook}	MS_{iPad}	$MS_{\text{Hard Copies}}$	ΔCS
Current Market	0.314	0.249	0.214	0.184	-
	[0.305,0.321]	[0.242,0.256]	[0.206,0.222]	[0.179,0.189]	-
No Kindle DRM	0.342	0.242	0.208	0.171	$18.44
	[0.334,0.350]	[0.235,0.249]	[0.200,0.216]	[0.166,0.175]	[-$1.67,$43.74]
No Nook DRM	0.304	0.278	0.208	0.172	$15.53
	[0.296,0.312]	[0.270,0.285]	[0.201,0.216]	[0.167,0.177]	[-$1.10,$32.19]
No iPad DRM	0.315	0.251	0.212	0.183	$1.06
	[0.307,0.323]	[0.244,0.258]	[0.204,0.220]	[0.178,0.189]	[-$41.03,$40.87]
No DRM (All)	0.328	0.264	0.202	0.168	$34.96
	[0.320,0.337]	[0.257,0.272]	[0.193,0.209]	[0.163,0.173]	[$12.06,$56.23]

These are the posterior means of counterfactual outcomes where only the DRM attribute changes. 90% highest density intervals are shown in square brackets.

in unit sales of product k. The measure can be calculated as $-\eta_{kj}MS_j/\eta_{kk}MS_k$, where MS_j denotes the market share of product j. The last panel in Table 3 shows that, for instance, the diversion ratio from the Kindle to the Nook is 59.1%; and it is 62.4% from the other way around. It also suggests that, perhaps unsurprisingly, the Kindle and the Nook are closer substitutes with each other than with the iPad.

6. Counterfactuals

6.1. DRM removal

We now simulate counterfactual market shares as well as consumer surplus changes when DRM systems are eliminated. Table 4 presents the baseline counterfactual outcomes where the only change to the simulation procedure is that the DRM_j variable is turned off (i.e., set to zero) when platform j removes DRM. Specifically, the top row repeats the benchmark market shares that were presented in Table 3. The next three rows show the simulated market shares when each platform j unilaterally removes DRM; and the bottom row shows the market shares when all three platforms remove DRM at the same time.[18]

Notice that DRM lowers the hardware price coefficient, $Coeff_{ij} \equiv (DRM_j\delta_i + (1 - DRM_j))D_j^{-1}\beta_{ij}$, in consumer i's indirect utility because both in theory and estimation, δ_i is assumed to be between 0 and 1. Thus, when DRM_j is turned off for platform j, the hardware price coefficient for j will increase, and this affects the simulated choice probabilities (market shares). Table 4 shows that if the Kindle or the Nook unilaterally removes DRM, then its market share increases, drawing consumers from other options. On the other hand, the removal of DRM from the iPad has little effect on the market shares, implying that the disutility of DRM for the iPad is small.

The changes in consumer surplus (ΔCS) are summarized in the last column, which are approximated by the consumer's willingness to pay (compensating variation). In the literature, one often divides the coefficient on a product feature by the price coefficient to measure the consumer welfare changes in monetary terms. In our model, however, DRM is not a standalone feature in the consumer's utility function; and also the removal of DRM changes the hardware price coefficient itself. Thus, we use the compensating variation that applies to a broader set of circumstances. Specifically, the (ex-ante) compensating variation, cv_i, is implicitly defined by

$$\mathbb{E}_j v_{ij}(\Theta_i, g_i|DRM) = \tilde{\mathbb{E}}_j v_{ij}(\Theta_i, g_i - cv_i|\widetilde{DRM}),$$

where DRM is the set of benchmark attributes and $\widetilde{DRM}$ the set of counterfactual attributes where one or more platforms remove DRM. Notice that $\mathbb{E}_j v_{ij}$ on the left-hand side is consumer i's expected utility with respect to choice probabilities P_{ij} in the benchmark, while $\tilde{\mathbb{E}}_j v_{ij}$ on the right-hand side is with respect to the choice probabilities $\widetilde{P_{ij}}$ in the counterfactuals. Be reminded that g_i is the consumer i's total budget, so after netting out cv_i, the consumer would be indifferent between the two scenarios. If we denote the counterfactual hardware price coefficients as $\widetilde{Coeff_{ij}}$, then rearranging yields

$$cv_i = \frac{\tilde{\mathbb{E}}_j v_{ij}(\Theta_i, g_i|\widetilde{DRM}) - \mathbb{E}_j v_{ij}(\Theta_i, g_i|DRM)}{\tilde{\mathbb{E}}_j \widetilde{Coeff_{ij}}}.$$

For each posterior draw, the aggregate change in consumer surplus is approximated by the sum of the individual cv_i: $\sum_i cv_i$. The compensating variation estimates reported in Table 4 are the averages per person across simulation runs. While the mean compensating variation is moderately large if the Kindle ($18.44) or the Nook ($15.53) removes DRM, there is a large heterogeneity across individuals. On the other hand, the average consumer surplus does not change much if the iPad removes DRM; and if all three platforms remove DRM, then the average change in consumer surplus is larger ($34.96).

According to Statista (2012), the total number of e-book readers shipped worldwide in 2012 is estimated to be around 15 million units. Assuming that this measures the potential market, the aggregate increase in consumer surplus can be estimated to be around $35 × 15 million = $525 million had the three platforms removed DRM from their devices in 2012. One caveat is that the sales of the Nook have drastically decreased since 2013 (Statista 2019), while Apple's global shipments of the iPads

[18] One can think of the last case where all three platforms remove DRM as being due to the publishers deciding to remove DRM from their e-books, hence, requesting the platforms to remove DRM. Publishers may also remove DRM from a specific platform as a matter of contract.

also decreased from a peak of 26 million units in the fourth quarter of 2013 to 14 million in the third quarter of 2020 (Statista 2020). (We could not find sales trends for the Kindle, however). Thus, the aggregate increase in consumer surplus from DRM removal would be lower in today's environment.

6.2. Platform response

In the above, we assumed that everything in the benchmark market except for the DRM feature remained the same; hence, the counterfactual outcomes did not involve any re-calibration of the supply side. However, profit-maximizing platforms would change the device price if they or their competitors removed DRM. Specifically, a DRM removal would change the residual demand elasticities at the benchmark prices, because they depend on the hardware price coefficients, $Coeff_{ij}$, as well as the choice probabilities, P_{ij}, both of which change when DRM is removed. In this subsection, we re-calibrate the platform device prices using counterfactual price elasticities.

We do this by using the generalized inverse elasticity rule in Section 3.2. In two-sided markets, an additional consumer brings in a pecuniary externality to the platform in the form of sales commissions from the content producers. Therefore, the marginal sales commission, $r_j(\omega)\Omega_j$, which is proportional to the content variety, offsets the marginal cost of production, mc_j. Given a benchmark device price, f_j, an estimate of the residual demand elasticity, η_j, and a marginal production cost, mc_j, one can thus back out the implied commissions, $r_j(\omega)\Omega_j$, from an additional user on platform j.[19]

Our purpose here, however, is to come up with a sensible prediction on the counterfactual device prices, f_j', when the residual demand elasticities, η_j, change by small amounts. For this, we do not need to separately calculate mc_j and $r_j(\omega)\Omega_j$. Instead, we denote $\overline{mc}_j \equiv mc_j - r_j(\omega)\Omega_j$, which is constant, and the new elasticities as $\eta_j' \equiv \xi_j\eta_j$, where ξ_j is a scalar close to 1. By substituting in for the pricing rule, we get $f_j' f_j(1-\xi_j) = (f_j' - \xi_j f_j)\overline{mc}_j$. Since ξ is close to 1, the left-hand side is approximately equal to zero. We therefore come up with a simple prediction rule that the device price would change by the same factor as the residual demand elasticity does: $f_j' = \xi_j f_j$.

The first panel in Table 5 shows the counterfactual market shares as well as changes in consumer surplus under the same set of scenarios as before. The second panel reports the new residual demand elasticities η_j' calculated under each scenario, and the third panel reports the corresponding device prices f_j' re-calibrated by using the above prediction rule. In the first two scenarios where the Kindle or the Nook unilaterally removes DRM, all device prices increase by small amounts (a few dollars). This in turn reduces the average gain in consumer surplus compared to the estimates in Table 4. Specifically, the gain in consumer surplus goes down by about six dollars in the first two scenarios.

The reduction in consumer surplus is larger when the iPad removes DRM. The iPad demand becomes marginally price elastic and so the iPad price increases by about ten percent ($43), though the price of the Kindle or the Nook is not much affected at all.[20] The average consumer surplus decreases by $28. Similarly, if all three devices remove DRM, then the residual elasticities become larger, and the device prices increase more across the board. This reduces the average gain in consumer surplus from the previous level of $34.96 per person (before re-calibrating device prices) to $7.43. The results show that it is important to include hardware price changes when assessing consumer surplus.

We can also gauge the platform's incentives to remove DRM unilaterally. For instance, Trefis (2014) estimates that the Kindle e-ink reader sales were around 10 million units in 2013. Thus, if Amazon were to remove DRM unilaterally, the Kindle e-reader sales will increase from $10 \times 0.314 \times \$140 = \$439.60$ million to $10 \times 0.34 \times \$142.70 = \$485.18$ million, a difference of $45 million, which is dwarfed by Amazon's net sales figure of $74.45 billion in 2013. Assuming the same 10 million unit sales, the Nook sales will increase by a similar amount if Barnes and Noble removed DRM unilaterally; and the iPad sales would in fact decrease by a small amount ($18 million) if Apple removed DRM unilaterally. These suggest that the profit incentive for unilaterally removing DRM is low.

6.3. Content supply

Note that all major ("Big Five") publishers have insisted that the tech platforms encrypt their e-books with a DRM system due to fears of consumer piracy, while there are a number of small publishers and independent authors who have regularly published DRM-free e-books. Thus far, only one imprint affiliated with a major publishing house, Tor Books, a subsidiary of Macmillan, has abandoned DRM from their entire e-book catalogs. While the evidence thus far suggests that Tor's policy did not increase the supply of pirated Tor books online and it also did not hurt its sales, major publishers can still threaten to pull their e-book titles if the platforms were to remove DRM (Albanes,e 2014).

It is therefore important to consider the publishers' response to the DRM removal. We investigate this issue by assuming that the content variety Ω_j decreases to $\phi\Omega_j$ for some scalar $\phi < 1$. This is because we do not have any data to empirically measure the magnitude of ϕ. Instead, we vary ϕ within (0,1) for the platform(s) removing DRM to illustrate the sensitivity of our results above. We continue to assume that $\overline{mc}_j \equiv mc_j - r_j(\omega)\Omega_j$ remains unchanged in our counterfactual scenarios because the content price,

[19] For instance, the market research firm IHS iSuppli estimated in 2011 that based on reverse engineering the e-ink version of the Kindle would cost about $84.25 to make. By substituting the benchmark price for the Kindle ($140), the own price elasticity of the Kindle (-0.695), and the marginal production cost ($84.25) into the inverse elasticity formula in Section 3.2, we get $r_j(\omega)\Omega_j \approx \$146$ for the Kindle.

[20] One possible reason for the higher impact of DRM on the iPad than on other e-book devices is that other iPad functions are ignored in the survey, which can magnify the impact of DRM removal. Also, the iPad price is higher than the others, so the price changes are proportionally larger.

Table 5
Counterfactual Simulation (with Endogenous Price).

	MS_{Kindle}	MS_{Nook}	MS_{iPad}	$MS_{\text{Hard Copies}}$	ΔCS
Current Market	0.314	0.249	0.214	0.184	-
	[0.305,0.321]	[0.242,0.256]	[0.206,0.222]	[0.179,0.189]	-
No Kindle DRM	0.340	0.242	0.207	0.173	$12.28
	[0.333,0.349]	[0.234,0.249]	[0.199,0.214]	[0.168,0.178]	[-$9.37,$51.43]
No Nook DRM	0.303	0.279	0.206	0.174	$9.36
	[0.295,0.312]	[0.270,0.286]	[0.199,0.214]	[0.169,0.179]	[-$14.34,$42.31]
No iPad DRM	0.325	0.260	0.189	0.186	-$28.03
	[0.317,0.333]	[0.253,0.268]	[0.182,0.196]	[0.181,0.192]	[-$121.7,$56.40]
No DRM (All)	0.328	0.267	0.182	0.182	$7.43
	[0.320,0.337]	[0.259,0.274]	[0.175,0.190]	[0.176,0.187]	[-$19.61,$79.41]
	η_{Kindle}	η_{Nook}	η_{iPad}	$\eta_{\text{Hard Copies}}$	
Current Market	-0.695	-0.819	-0.957	0	
	[-0.742,-0.652]	[-0.865,-0.770]	[-1.022,-0.894]	[0,0]	
No Kindle DRM	-0.708	-0.834	-0.968	0	
	[-0.756,-0.665]	[-0.879,-0.782]	[-1.030,-0.902]	[0,0]	
No Nook DRM	-0.709	-0.831	-0.972	0	
	[-0.761,-0.667]	[-0.874,-0.781]	[-1.035,-0.905]	[0,0]	
No iPad DRM	-0.692	-0.814	-1.060	0	
	[-0.739,-0.649]	[-0.857,-0.765]	[-1.132,-0.987]	[0,0]	
No DRM (All)	-0.764	-0.894	-1.077	0	
	[-0.815,-0.715]	[-0.946,-0.838]	[-1.150,-1.004]	[0,0]	
	f_{Kindle}	f_{Nook}	f_{iPad}	$f_{\text{Hard Copies}}$	
Current Market	$140	$140	$400	$0	
	[fixed]	[fixed]	[fixed]	[fixed]	
No Kindle DRM	$142.7	$142.5	$404.6	$0	
	[137.9,147.2]	[141.2,143.9]	[399.6,409.3]	[fixed]	
No Nook DRM	$142.9	$142.1	$406.3	$0	
	[141.3,144.3]	[138.7,146.2]	[402.7,409.8]	[fixed]	
No iPad DRM	$139.5	$139.1	$443.0	$0	
	[138.8,140.2]	[138.5,139.8]	[426.5,459.0]	[fixed]	
No DRM (All)	$154.0	$152.9	$450.2	$0	
	[147.8,159.8]	[148.5,157.5]	[432.6,467.4]	[fixed]	

These are the posterior means of counterfactual outcomes where the DRM removal changes the device elasticities and prices. 90% highest density intervals are shown in square brackets.

hence sales commission $r_j(\omega)$, would increase by a factor of $1/\phi$ while the content variety Ω_j decrease by ϕ.[21]

Note that when platform j removes DRM, the device price coefficient, $Coeff_{ij}$, now changes via two channels. The first is the change in the DRM_j variable. The second is the change in β_{ij}, which is a function of Ω_j and $p(\omega)$. Specifically, when the content variety changes from Ω_j to $\phi\Omega_j$ and the content price from $p(\omega)$ to $p(\omega)/\phi$, the device price index would change from β_{ij} to $\phi^{\sigma_i/(\sigma_i-1)}\beta_{ij}$. With both sets of changes, we then simulate new demand elasticities and re-calibrate device prices using the same posterior draws and rules as above. Table 6 summarizes the results for $\phi = 0.8$ and $\sigma_i = 4.5$ for all i.

This is because we cannot identify the consumer's elasticity parameter σ_i with our conjoint dataset. Therefore, we aim to illustrate the changes by borrowing the estimate of σ_i from the literature. Specifically, Imbs and Mejean (2015) uses a representative consumer model and estimates that the elasticity of substitution parameter is around 4.5 for the 'Publishing' sector. In what follows, we thus assume that $\sigma_i = 4.5$ for all i and that the publishers pull 20 percent of the content (i.e., $\phi = 0.8$) in response to DRM removal, to illustrate our counterfactual outcomes.[22] The qualitative results are similar, though with different magnitudes, when we use different values of ϕ (e.g., 0.9, 0.7, 0.6, etc).

Instead of taking σ_i from the literature, we could alternatively calibrate σ_i as follows: The quantity of book consumption can be proxied by the number of books purchased by individual i over the lifetime of device j. Since σ_i is assumed to be common across j, consider the Kindle without loss of generality. Let C_i denote the number of books purchased by consumer i per year and S denote a life span of the Kindle. Then, the price index can be expressed as $\hat{\beta}_i = \left(S \times C_i \times p^{1-\sigma_i}\right)^{1/(\sigma_i-1)}$, where we assume that the average price of a Kindle e-book is \$10 (i.e., $\hat{p} = 10$); the Kindle's life span is about three years (i.e., $\hat{S} = 3$); and we can divide consumer i's annual budget for books by \$10 to estimate the number of books purchased per year, $\hat{C}_i$.

We can then back out the value of individual $\hat{\sigma}_i$ from the $\hat{\beta}_i$, which yields a mean of $\hat{\sigma}_i$ at 3.95. This is reasonably close to the elasticity of substitution parameter of 4.5 sug-

[21] If the publisher randomly pulls a $1-\phi$ share of content from the platform, then the content producer's expected revenue would be reduced to $\phi p(\omega) n_j(\omega)$. The monopolistic competition equilibrium implies that the optimal content (book) price $p(\omega)$ would then increase by a factor of $1/\phi$.

[22] If $\phi = 0.8$, then the content price increases by 25%. This is a similar magnitude of the change when Apple removed DRM from its music market in 2009 and sold DRM-free music at \$1.29, an increase from \$0.99. This is only extrapolating from another market, however.

Table 6
Counterfactual Simulation (with Supply Response).

	MS_{Kindle}	MS_{Nook}	MS_{iPad}	$MS_{\text{Hard Copies}}$	ΔCS
Current Market	0.314	0.249	0.214	0.184	-
	[0.305,0.321]	[0.242,0.256]	[0.206,0.222]	[0.179,0.189]	-
No Kindle DRM	0.300	0.281	0.210	0.172	-$0.13
	[0.292,0.307]	[0.273,0.288]	[0.202,0.217]	[0.167,0.177]	[-$23.82,$26.79]
No Nook DRM	0.343	0.242	0.206	0.171	$5.07
	[0.335,0.351]	[0.235,0.249]	[0.199,0.214]	[0.166,0.176]	[-$8.36,$24.12]
No iPad DRM	0.308	0.243	0.234	0.179	$8.11
	[0.300,0.317]	[0.236,0.250]	[0.225,0.243]	[0.174,0.184]	[-$21.06,$43.70]
No DRM (All)	0.310	0.249	0.232	0.172	-$15.25
	[0.302,0.318]	[0.241,0.256]	[0.223,0.240]	[0.167,0.178]	[-$38.07,$13.35]
	η_{Kindle}	η_{Nook}	η_{iPad}	$\eta_{\text{Hard Copies}}$	
Current Market	-0.695	-0.819	-0.957	0	
	[-0.742,-0.652]	[-0.865,-0.770]	[-1.022,-0.894]	[0,0]	
No Kindle DRM	-0.650	-0.756	-0.977	0	
	[-0.693,-0.611]	[-0.800,-0.716]	[-1.043,-0.914]	[0,0]	
No Nook DRM	-0.635	-0.739	-0.975	0	
	[-0.678,-0.596]	[-0.785,-0.693]	[-1.040,-0.913]	[0,0]	
No iPad DRM	-0.689	-0.815	-0.896	0	
	[-0.733,-0.644]	[-0.860,-0.766]	[-0.953,-0.830]	[0,0]	
No DRM (All)	-0.649	-0.753	-0.921	0	
	[-0.694,-0.607]	[-0.800,-0.707]	[-0.979,-0.861]	[0,0]	
	f_{Kindle}	f_{Nook}	f_{iPad}	$f_{\text{Hard Copies}}$	
Current Market	$140	$140	$400	$0	
	[fixed]	[fixed]	[fixed]	[fixed]	
No Kindle DRM	$131.1	$129.2	$408.3	$0	
	[124.8,136.9]	[125.6,133.1]	[400.5,416.3]	[fixed]	
No Nook DRM	$128.0	$126.3	$407.6	$0	
	[124.2,131.2]	[121.1,131.6]	[403.5,412.3]	[fixed]	
No iPad DRM	$138.8	$139.3	$374.4	$0	
	[137.9,139.7]	[138.4,140.3]	[356.2,392.7]	[fixed]	
No DRM (All)	$130.9	$128.8	$385.1	$0	
	[125.3,136.1]	[124.0,133.0]	[364.7,403.1]	[fixed]	

These are the posterior means of counterfactual outcomes where the DRM removal and the content supply change the device elasticities and prices. 90% highest density intervals are shown in square brackets.

gested by Imbs and Mejean. In fact, using the individual-specific, imputed elasticity parameter does not change our counterfactual results significantly at the mean, because the value of $\sigma_i/(\sigma_i - 1)$ that enters the price index adjustment does not change significantly when σ_i varies between 3.95 and 4.5. Thus, we have chosen to present the results using the representative consumer's elasticity of substitution parameter (i.e., $\hat{\sigma}_i = 4.5$).

Table 6 shows that, in contrast to the previous counterfactual outcomes, if the Kindle or the Nook unilaterally removes DRM, their market shares would decrease slightly from the benchmark figures, whereas if the iPad does so, its market share would increase by a couple of percentage points at the mean. Further, whichever platform removes DRM unilaterally sees its residual demand elasticity decrease moderately, so its device price also falls moderately relative to the benchmark prices. This suggests that if content providers pull their content in response to a platform removing DRM, there are tradeoffs between the device price and the content supply.

This means that the compensating variation from DRM removal would decrease, unless the lower device price sufficiently offsets the loss in consumer surplus. In the case of the Kindle or the Nook removing DRM, we find that the mean compensating variation falls to nearly $0 and $5, respectively. If the iPad removes DRM, on the other hand, the average consumer surplus increases by $8, because the iPad price goes down by $25 (and iPad users are not sensitive to DRM). When all three platforms remove DRM, the substitution is lessened, so more consumers suffer from the reduction in content varieties. The average consumer surplus decreases by $15.

Similarly to the previous subsection, we can calibrate the platform's incentives to remove DRM with the supply response. Assuming that unit sales are 10 million for all devices and comparing the implied sales revenues before and after the DRM removal, we find that both the Kindle and the Nook e-reader revenues would decrease by a similar amount (around $45 million), while the iPad sales revenue would increase by about $20 million. Thus, with a modest level of negative supply response from publishers, Amazon and Barnes and Noble may have little incentive to remove DRM unilaterally. This also helps explain why the platforms have not removed DRM from the e-book market.

7. Conclusion

We proposed a Bayesian hierarchical logit model to study the effect of DRM removal from the e-book platforms and estimated the model using conjoint survey data. In our counterfactual exercises, we found that consumers benefit moderately from the Kindle and/or the Nook removing DRM, holding everything else constant. However, incorporating supply response in the form of higher device prices could diminish the consumer's welfare gains. Further, if publishers respond by pulling content from the platform removing DRM, then the negative effect on content supply can outweigh the benefits, and consumers can be made worse off.

Whether these implications will hold in other digital markets needs some qualification, because physical copies are still widely available in the book market (i.e., the level of digitization is relatively lower than in other content markets), so there is an imperfect, but legal substitute that is DRM-free. Also, consumers do not seem to read e-books using multiple devices, nor do they have frequent needs or opportunities to share or sell their e-books. Thus, a larger share of the readers may not experience a disutility from DRM in this market.

However, even with the present characteristics of the e-book market, our results imply that DRM removal can increase consumer welfare non-trivially if all three platforms remove DRM at the same time and the negative supply response from the publishers are minimal or non-existent. This is more likely to occur when the major publishing houses believe that DRM does not help reduce piracy, which requires a more focused study in the future.

Author Credits

The authors made equal contributions to this article.

Appendix

Let Z_i be a vector of consumer i's demographic (and other) characteristics, and $ind_i \in \{1, \ldots, K\}$ be a latent categorical variable of consumer i's type, or a component of K mixture of normals. Then, the consumer i's preference parameters in Θ_i are modeled as follows:

$$\Theta_i - \Delta' Z_i \sim N(\mu_{ind_i}, \Sigma_{ind_i}),$$
$$ind_i \sim Cat(\rho),$$

where Δ is a matrix of hyperparameters (i.e., multivariate regression coefficients); N is a multivariate normal distribution with mean μ_{ind_i} and covariance Σ_{ind_i}; and ind_i is a draw from a categorical probability distribution $\rho \equiv (\rho_1, \ldots, \rho_K)$ with support $\{1, \ldots, K\}$.

Letting $\zeta \equiv vec(\Delta)$, the natural conjugate priors for the hyperparameters are

$$\zeta \sim N(\bar{\zeta}, A_\zeta^{-1}),$$
$$\mu_k | \Sigma_k \sim N(\bar{\mu}, \Sigma_k \times a_\mu^{-1}),$$
$$\Sigma_k \sim IW(\nu, \nu V),$$
$$\rho \sim Dir(\alpha_1, \ldots, \alpha_K),$$

where IW is an Inverse Wishart distribution with a degree of freedom ν and a symmetric and positive definite matrix V; and Dir is a Dirichlet distribution with a vector of positive scalars $(\alpha_1, \ldots, \alpha_K)$. For the hyperpriors, we set $\bar{\zeta}$ and $\bar{\mu}$ to zero vectors, A_ζ to an identity matrix times 0.05, a_μ to 0.05; ν to 14; V to an identity matrix; and α_k's to 1.

We then use the Markov Chain Monte Carlo (MCMC) chain to alternatingly draw the unit-level parameters and hyperparameters:

$$\Theta_i | ind_i, \Delta' Z_i, \mu_{ind_i}, \Sigma_{ind_i}, \tag{1}$$

$$\rho, \{ind_i\}, \Delta, \{\mu_k, \Sigma_k\} | \{\Theta_i\}, \tag{2}$$

where the posterior in (1) is proportional to the product of the likelihood in the text and the multivariate normal prior. Here, we use a Random-Walk Metropolis algorithm to draw Θ_i, where acceptance in each iteration is relative to a uniform random number, and then an unconstrained Gibbs sampler to draw the hyperparameters in (2) in the following steps:

$$\{ind_i\} | \rho, \{Z_i\}, \Delta, \{\mu_k, \Sigma_k\}, \{\Theta_i\}, \tag{3}$$

$$\rho | \{ind_i\}, \tag{4}$$

$$\{\mu_k, \Sigma_k\} | \{ind_i\}, \{Z_i\}, \Delta, \{\Theta_i\}, \tag{5}$$

$$\Delta | \{ind_i\}, \{Z_i\}, \{\mu_k, \Sigma_k\}, \{\Theta_i\}, \tag{6}$$

where $\{ind_i\}$ in (3) is a draw from the product of the probability distribution of ρ and the multivariate normal density of $\Theta_i - \Delta' Z_i$ conditional on $\{\mu_k, \Sigma_k\}$; ρ in (4) is a gamma draw based on the sum of the vector α and bin counts in $\{ind_i\}$; μ_k and Σ_k in (5) are draws from the multivariate regression for each mixture component k; and Δ in (6) is derived from a pooled regression using vec operation across the K components. For space consideration, we refer the reader to Rossi et al. (2005) for more details.

Table 7 describes the hyperparameters in Δ, which reports the means of the MCMC draws along with the 90% highest density intervals in square brackets. While the goal of Bayesian inference lies in the posterior distribution rather than a test of statistical significance, the table can be interpreted in a similar fashion. For instance, age is positively correlated with choice-specific intercepts for all three e-book devices, whereas the association is only marginally more positive than negative for the hard copy option. Males tend to have lower choice intercepts for all four inside options than females do.

In terms of the association with the (untransformed) DRM coefficient δ_i, age is on average positively associated with the coefficient, meaning that older people tend to care less about DRM. Males mostly have a negative association with the DRM coefficient, meaning that they have a larger disutility from having a DRM system than females do. Income is on average neutral with a small variation; and education is negatively associated with the DRM coefficient, suggesting that those with a higher education dislike DRM more.

Those who said that they read e-books on average have a higher DRM coefficient, although the association can be negative for a minority of draws; that is, for the majority of draws, those who read e-books care less about DRM. On the other hand, those who said that they have downloaded a pirated e-book have a lower DRM coefficient in all the posterior draws, suggesting that they do dislike DRM. Similar to income, the imputed budget for books and devices has an insignificant association with the DRM coefficient, or is split between the positive and the negative ranges with a somewhat larger variation.

Table 7
Estimation of Hyperparameters Δ.

	γ_{Kindle}	γ_{Nook}	γ_{iPad}	$\gamma_{\text{Hard Copies}}$	$\gamma_{\text{Touch Screen}}$	$\gamma_{\text{Screen Size}}$
Age	0.67	0.51	0.54	0.12	0.09	-0.05
	[0.18,1.2]	[-0.07,1.0]	[0.01,1.1]	[-0.66,0.84]	[-0.04,0.21]	[-0.09,-0.01]
Male	-2.1	-2.3	-1.8	-1.2	-0.46	0.05
	[-3.1,-1.2]	[-3.2,-1.3]	[-2.8,-0.78]	[-2.0,-0.41]	[-0.69,-0.21]	[-0.04,0.13]
Income	-0.02	-0.03	-0.04	-0.00	-0.01	-0.00
	[-0.04,0.01]	[-0.05,-0.01]	[-0.06,-0.02]	[-0.02,0.02]	[-0.01,-0.01]	[-0.00,0.00]
Education	-0.23	-0.26	-0.04	0.40	-0.33	0.04
	[-0.80,0.33]	[-0.84,0.27]	[-0.64,0.53]	[-0.05,0.91]	[-0.43,-0.22]	[0.01,0.08]
Reading	-0.22	-0.34	-0.36	-0.73	-0.01	0.03
Habit	[-0.42,-0.03]	[-0.55,-0.16]	[-0.56,-0.17]	[-0.94,-0.47]	[-0.06,0.04]	[0.02,0.05]
Piracy	-0.00	0.09	0.03	0.28	0.07	0.00
Experience	[-0.17,0.16]	[-0.07,0.29]	[-0.12,0.18]	[0.11,0.46]	[0.03,0.12]	[-0.01,0.02]
Imputed	0.09	0.10	0.20	0.52	-0.01	0.00
Budget	[-0.12,0.35]	[-0.13,0.31]	[-0.03,0.44]	[0.27,0.75]	[-0.07,0.05]	[-0.02,0.02]
	δ_{DRM}	β_{Kindle}	β_{Nook}	β_{iPad}	$\beta_{\text{Hard Copies}}$	
Age	0.43	0.27	0.09	0.10	-0.66	
	[-0.59,1.5]	[0.15,0.38]	[-0.03,0.22]	[-0.01,0.21]	[-0.94,-0.36]	
Male	-1.1	-0.05	0.06	-0.34	-0.16	
	[-2.3,0.14]	[-0.27,0.16]	[-0.17,0.26]	[-0.56,-0.08]	[-0.52,0.15]	
Income	0.00	-0.05	-0.04	-0.03	-0.04	
	[-0.03,0.04]	[-0.05,-0.04]	[-0.05,-0.04]	[-0.03,-0.02]	[-0.05,-0.03]	
Education	-0.97	0.09	0.03	0.10	-0.35	
	[-1.4,-0.44]	[-0.01,0.19]	[-0.07,0.14]	[0.02,0.20]	[-0.54,-0.13]	
Reading	0.11	-0.09	-0.07	-0.09	-0.02	
Habit	[-0.24,0.44]	[-0.13,-0.03]	[-0.12,-0.02]	[-0.14,-0.05]	[-0.10,0.07]	
Piracy	-0.60	0.05	0.03	0.04	-0.08	
Experience	[-0.87,-0.37]	[-0.00,0.10]	[-0.01,0.07]	[0.01,0.08]	[-0.15,0.01]	
Imputed	0.02	0.13	0.12	0.08	0.02	
Budget	[-0.34,0.33]	[0.07,0.20]	[0.06,0.18]	[0.02,0.13]	[-0.06,0.10]	

These are the posterior means of the hyperparameters Δ, based on 30,000 draws. The first 10,000 draws are dropped as burn-ins, and every 10th draw thereafter is saved. 90% highest density intervals are shown in square brackets.

Overall, we find the Δ estimates plausible and the respondent characteristics Z_i reasonably informative as covariates of the parameters in Θ_i.

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