Time-inconsistent Preferences and Strategic Self-Control in Digital-Content Consumption

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Abstract

This paper studies consumers' time-inconsistent preferences in digital-content consumption and their strategic self-control behaviors. We use a unique dataset obtained from a major digital book platform, where consumers can pay either by chapters or by monthly subscription, in China. One third of consumers in data consistently choose to pay by chapters even though monthly subscription would significantly reduce the monetary cost. We propose a dynamic structural model that incorporates time-inconsistent preferences and strategic self-control behaviors to rationalize the overpaying behavior. We first demonstrate analytically the existence of the unique equilibrium, and show how, under steady states, overpaying for reading may be optimal for consumers. We then estimate the model from the data. Results show that there is a large segment of consumers who are highly price sensitive. They are also willing to overpay in order to curb future consumption. Our counterfactuals show that eliminating the pay-per-chapter plan would hurt the consumer welfare and the platform's profit. Eliminating the monthly subscription plan, however, would increase the platform's profit but reduce the consumer welfare. We introduce a novel non-linear pricing plan with volume surcharge and show how it can simultaneously improve the platform's profit and the consumer welfare.

Keywords: Digital-content consumption, consumption stock, time inconsistency, strategic self-control, pricing plans

1. Introduction

Consumers widely embrace digital content such as social media, videos, music, and books. According to a report from eMarketer,[1] US adults on average spent 6 hours and 19 minutes per day on digital media in 2018, overtaking the time spent on traditional media for the first time. Online video has been the main driver of this phenomenon. Netflix, for example, gained more than 700 million subscribers in just four years from 2013 to 2017. Demand for other content has also significantly increased. The rapid growth in the consumption of digital content has raised concerns for the mental and physical well-being for consumers. Research on consumer digital content consumption decisions (e.g. Zhang et al 2012, Boumosleh and Jaalouk, 2017) has shown that when consumers indulge themselves inside the fantasy world created by video games, online videos and web fictions, they can lose self-control and spend more time and money than they originally intended to. Other consequences include various mental and physical problems. Such over-consumption behavior has been categorized as a clinical disorder in China since 2008.[2] Being aware of the negative consequences of over-consumption, however, consumers may conduct self-control strategies in advance. Wertenbroch (1998), for example, documents that smokers may purchase small cigarette packets, with the goal of curbing future smoking. This strategy may also be used to control over-consumption in the digital content.

The goal of our study is to study consumers' digital-content consumption behaviors and their self-control strategies. We focus on a specific type of digital

[1] Source: https://www.emarketer.com/content/us-time-spent-with-media-2018.
[2] Source: https://www.theguardian.com/news/blog/2008/nov/11/china-internet.

content—web fiction. Web fiction is available primarily on the internet, usually released serially by chapters on a daily basis. Reading web fiction is prevalent among Asian consumers: according to a report, more than 400 million unique readers in China pay for some form of web fiction. A successful web fiction writer can earn more than 16 million dollars.[3] The market size reached 18 billion RMB[4] in 2018.[5] We use a unique dataset obtained from a major digital book platform in China that provides content to service subscribers. We observe several unique data features that are related to our research goal. First, individual consumers on average read about 500 chapters per month, with one-fourth reading more than 1,500 chapters. Assuming one chapter takes five minutes to read,[6] reading time per month is 42 hours for an average consumer and 125 hours for the top one-fourth, indicating individuals spend as much time on web fictions as on other digital media. Second, web fiction is different from literary fiction. It enables readers to immerse themselves in "fantasy pleasure" and can cause withdrawal symptoms when they try to stop reading.[7] Also, as payment from the platform to authors is linked to how many chapters an individual reads, authors have an incentive to include plot twists to keep readers following their books every day. These features may cause consumers to read more than they intend to on a regular basis. Finally, we observe an interesting overpaying phenomenon among consumers: to read web fictions an individual can choose either a pay-per-chapter plan (0.1 RMB for each

[3] Source: https://www.nytimes.com/2016/11/01/world/asia/china-online-literature-zhang-wei.html
[4] One RMB is about 0.15 US dollar.
[5] Source: "2018 China Digital Reading Market Industry Report" by ASKCI Consulting, 2018. Another article from Forbes described the rapid growth of web fictions in China that challenges Amazon's Kindle (see https://www.forbes.com/sites/jinshanhong/2017/07/17/chinas-online-reading-craze-is-so-big-its-challenging-amazons-kindle/#7c48709f4a8c).
[6] A chapter contains about 1,000 Chinese characters
[7] Source: http://www.cnki.com.cn/Article/CJFDTotal-DDWT201701036.htm

chapter) or a monthly subscription plan (12 RMB each month). Anyone who reads more than 120 chapters under the former plan or fewer than 120 chapters under the latter plan will overpay for the reading. We find that, while only 6% of consumers overpay by choosing the monthly subscription, one third of them consistently overpay by choosing the pay-per-chapter plan. Among consumers who overpay, 60% switch plans later if they are under the monthly subscription, but only 20% switch under the pay-per-chapter plan. Furthermore, most switchers from the monthly subscription (including those who do not overpay) continue to read a lot after switching, as such the monetary cost would have been significantly lower if they did not switch. We argue that these overpaying behaviors are consistent with the idea that consumers use strategic self-control measures to curb over-consumption which can have negative long-term consequences.

To formalize the idea, we propose a dynamic structural model that allows consumers to have different consumption preferences during the reading plan choice and consumption choice stages. This characterizes a type of "time-inconsistent" preferences which can lead to the over-consumption behavior. Such time-inconsistent preferences apply to not only digital content consumption but also other types of behaviors such as gambling, use of drugs, alcohol and tobacco. Furthermore, the model allows for habit formation, as reading more today may increase the reading preference (and thus read even more) in the future. Anticipating the potential downsides of the time-inconsistent preferences and habit formation, rational consumers will impose strategic self-controls. One of the strategies is to choose a reading plan that will help curb their future reading, even doing so could incur a higher monetary cost. This decision implies that a forward-looking consumer, when choosing the plan, plays a game against the myopic self during the consumption stage.

We first use an analytical model to illustrate this argument. We show that, given a set of model parameters and state of reading preference, a unique equilibrium exists. We also show that, under reasonable assumptions, the equilibrium will converge globally to one of the three steady states: (1) Consumers choose the pay-per-chapter plan, and stay at a low reading preference; (2) consumers choose the pay-per-chapter plan and remain at a medium state; and (3) consumers pay by monthly subscription and stay at a high state. Depending on the utility parameters, we show that overpaying by choosing the pay-per-chapter plan can be optimal. We further show the standard recursive method that solves the optimal policy function in the dynamic programming literature can be used in our model, even though the agent exhibits time-inconsistent preferences.

We then construct an econometric model for the empirical analysis by incorporating unobservable and individual heterogeneities. Estimation results show that, out of the three latent segments of consumers, the first segment is more price sensitive and has a higher non-monetary cost of over-consumption. Interestingly, despite being more price sensitive, this segment actually overpays for the consumption due to the self-control reason. By contrast, segment 2 is less likely to overpay, and about half of the segment chooses the monthly subscription. Segment 3 is small in size; it has the highest reading preference and is most likely to choose the monthly subscription.

The findings of this study can have substantive implications not only for public policymakers but also for producers and distributors of digital content. We use counterfactuals to study the impacts of pricing plans on consumer welfare and the platform's profit. We find that if the platform were to eliminate the pay-per-chapter plan that helps curb consumption, not only would consumer welfare be hurt, but its profit would also drop by 76%. On the other hand, if the platform were to eliminate the monthly subscription that encourages more consumption, its profit would increase by 46%, whereas consumer welfare only decreases by 4.5%. Finally, we find that introducing a new nonlinear pricing plan with volume surcharge can simultaneously improve the platform's profit by 46% (almost the same as eliminating the monthly subscription) and the consumer welfare by 2.5%. It also dominates another nonlinear pricing plan with volume discount on both dimensions. Overall, our results show that, in contrast to the common belief that firms should offer pricing plans that encourages consumption (e.g. monthly subscription only), offering a plan that helps curb the consumption (e.g. paid-by-chapter and volume surcharge) can increase the firm profit when consumers have the motivation of self-control. This highlights the necessity of considering consumers' self-control behaviors when marketing managers design the pricing structure for digital content distribution.

The rest of the paper is organized as follows: Section 2 reviews the related literature. We describe the data and present some empirical data patterns in section 3 to motivate our modeling approach. Section 4 describes our structural model and estimation strategy. Section 5 presents the estimation results and counterfactual results. Finally, section 6 concludes.

2. Literature

This paper is related to the literature on time inconsistency, a concept first formally introduced by Strotz (1956). Because preferences evolve over time, the optimal choice today may not be the best in the future. Since Strotz (1956), numerous experimental and empirical studies have shown different forms of time inconsistency (see Loewenstein and O'donoghue, 2002 for a summary). An example of time inconsistency is hyperbolic discounting, that is, the discounting rate is much higher for future outcomes. Hyperbolic discounting has found support in numerous studies using experiment or field data (e.g., Thaler, 1981; Benzion et al., 1989; Redelmeier and Heller, 1993; Chapman and Elstein, 1995; Chapman, 1996; Pender, 1996). Previous literature has also shown other forms of time inconsistency, for example, the "sign effect," whereby consumers value future loss more than gains (Mischel et al., 1969; Yates and Watts, 1975; Loewenstein, 1987; Benzion et al., 1989; MacKeigan et al., 1993; Redelmeier and Heller, 1993), and the "magnitude effect," whereby consumers discount small numbers more than large numbers (Thaler, 1981; Ainslie and Haendel, 1983; Kirby and Loewenstein, 1987; Benzion et al., 1989; Green et al., 1994a, 1994b; Kirby and Marakovic, 1995; Kirby, 1997). We model how individuals may ignore the consumption cost during the consumption stage yet they are fully rational when choosing the price plan. This is consistent with the general definition of time-inconsistency in Strotz (1956), but it is different from a typical hyperbolic discounting model setting.

Given the ubiquitous evidence for time-inconsistent behaviors, theoretical and empirical researchers have further studied to what extent consumers use self-control strategies to solve this problem, mostly in the form of hyperbolic discounting. Laibson (1997), for example, constructs a theory to show how dynamically inconsistent preferences could incentivize consumers to constrain their future choice. O'Donoghue and Rabin (1999) also use theoretical models to study how individual's self-control when the cost and reward of consumer decisions do not realize at the same time. Other works also study how consumers can achieve self-control by restricting the opportunity for additional purchases (Rachlin, 1995), or reducing temptation through substitution (Hoch and Loewenstein, 1991). The concept of time inconsistency has also been adopted in empirical studies to explain various types of consumer behaviors that seem to be inconsistent with classical economics theories. Wertenbroch (1998), for example, uses both experiment and field data to show how consumers strategically ration the purchase quantity to restrict excessive consumption. DellaVigna and Malmendier (2006) find from data that individuals overpay for the gym membership. They argue this overpaying is a strategy to increase future gym use. We study a similar behavior; however, we show that consumers overpay to curb over-consumption that will result in future utility loss. Gruber and Köszegi (2001) develop a utility function with time inconsistency and addictive consumption behaviors. Due to the technical barrier of estimating such a dynamic model, they calibrate model parameters to show that, due to smokers' time-inconsistent preferences, the optimal cigarette tax should be higher than under the time consistent assumption. Our paper makes both methodological and substantive contributions to this stream of literature. On the methodological side, Caplin and Leahy (2006) have shown that the standard recursive iteration method cannot be applied to time-inconsistency models when more than three time periods exist. They further suggest that equilibrium may not exist. We show that a unique equilibrium exists in our model setting and can be computed using the recursive method. Future researchers could use our method to study other types of time-inconsistency consumer behaviors in a wide range of markets including other digital contents and traditional product categories (e.g., tobacco, alcohol, and drugs). For the substantive contribution, we use counterfactuals to study the impacts of marketing actions on firm profit and consumer welfare. The implications will be entirely different without considering the consumer strategic self-control induced by time-inconsistent preferences.

The reason behind time-inconsistent preferences can be related to additive consumption. The theory of rational addiction in Becker and Murphy (1988) is based on the assumption that consumers can evaluate the monetary and non-monetary benefits and costs from consumption. This theory has been adopted in later empirical research studying different consumption behaviors including cigarettes (Chaloupka, 1991; Becker et al., 1994), alcohol (Baltagi and Griffin, 2002), drugs (Grossman and Chaloupka, 1998; Liu et al., 1999; Olekalns and Bardsley, 1996), and gambling (Mobilia, 1993). Arcidiacono et al. (2007) study how forward-looking consumers make decisions for consuming alcohol and tobacco.[8] Researchers have also investigated

[8] In marketing, researchers have documented addictive cigarette consumption and the consequences of a cigarette tax on demand (Chen, Sun, and Singh, 2009; Wang et al., 2015). Gordon and Sun (2015) use a dynamic model of rational addiction to study the impacts of a permanent price shift induced by a new cigarette tax on the demand for cigarettes.

addiction in social media consumption, internet browsing, and mobile apps usage (e.g. Young, 1998; Pelling and White, 2009; Wan, 2009; Kuss and Griffiths, 2011; Kwon et al. 2016). Our model differs from the rational addiction literature, as we allow consumers during the consumption stage to be myopic and ignorant of the cost of over-consumption. This is consistent with the medical literature (e.g., Nestler, 2013) which argues that, since consumption is intrinsically rewarding, consumers may not properly evaluate the short- and long-term costs during consumption. A recent study on addictive usage of smartphones by Boumosleh and Jaalouk (2017) also finds users usually do not consider health consequences during usage. However, like Becker and Murphy (1988) we allow consumers to form expectations of their future consumption when choosing the price plan.

3 Data

Our data come from a major digital-book platform in China. The data sample includes the reading activity from 11,346 unique consumers, randomly selected among the existing subscribers of the platform, for six months from January to June 2017. The platform offers a rich collection of web fictions. Unlike online books provided by Amazon Kindle, web fictions are mostly written by amateurs. They are primarily published online, updated daily by chapters. The length of each book varies depending on whether it attracts readership. A complete one could easily exceed a thousand chapters. Each chapter is usually about 1,000 to 5,000 Chinese characters, requiring a few minutes of reading time. Distinct from literary fictions, which usually refer to fictions with literary merit, web fictions are classified by genres such as fantasy, romance, and science. Readers follow web fictions for entertainment, for a riveting story, and for escape from reality. Since each chapter is short, consumers often read multiple books each day. This is different from the "binge watch" behavior, of which consumers spend a short period of time on intensively watching a whole season of TV series and then stop.

The platform offers two pricing plans for readers: pay-per-chapter and monthly subscription. The prices are 0.1 RMB for each chapter under the former plan, and 12 RMB under the latter.[9] Under the pay-per-chapter plan, readers have to swipe a bar on their mobile phones to confirm the payment before reading each chapter. Under the monthly subscription, readers receive a text reminder for the payment due a few days before the subscription expires. If readers stop the subscription, they are automatically switched to the pay-per-chapter plan.

Each period is a month in our analysis. The number of chapters an individual reads in a month represents her consumption level. Because readers start and end monthly subscriptions at different times, we make an assumption when constructing the dataset: If a reader starts a subscription before the 15th of a month, we assume she starts the subscription at the beginning of this month; otherwise, her subscription starts at the beginning of next month. We tried different data-construction methods and find robust results.[10]

9 These prices are equivalent to US $0.015 for each chapter and $1.80 for each month.

10 For example, we change the date to the 7th or 23rd in each month, and find the data patterns that we present below remain similar. In the data, 84% of consumers change plans in the first or last week of a month; therefore, using

3.1 Consumption Behaviors in Data

We use the data to examine consumers' reading behaviors. We first present an overview of the reading amount, then look at whether there is a habit formation that is well-known in the marketing literature. Habit formation is characterized as past consumption enhancing the current consumption preference, thus creating dynamics in reading behaviors. Next, we investigate possible time-inconsistent preferences exhibited from the consumption and plan-choice stages. Finally, we examine evidence that consumers use self-control strategies. These are the two important components in our structural dynamic model.

[Table 1 here]

Table 1 presents a glimpse of the consumption level. The first row shows that an average consumer reads about 500 chapters per month. Assuming consumers spend five minutes reading each chapter, this amount represents spending 2,500 minutes per month reading web fiction, or 83 minutes per day. Furthermore, 25% of consumers in the data read more than 700 chapters in a month, implying they spend about 60 hours a month, or almost two hours each day. If the average work day is eight hours, the above statistics suggest that in a month, the reading time is equivalent to 5.2 working days for an average consumer, and 7.5 working days for the top 25%. These suggest the non-monetary costs (e.g., time cost and other adverse consequences) of reading could be very significant. A report from eMarketer shows that US adults, on average, spent 379

different cutoff dates does not affect the results.

minutes per day on digital media in 2018. Broken down by format, consumers spend 51 minutes per day on video games [11] and 135 minutes on social media. [12] The comparison suggests reading web fictions is as time-consuming as other digital contents.

We test whether increasing exposure from past consumption will increase the current consumption in our data. Following the model in Becker and Murphy (1994), we specify the habit stock as an accumulation of past consumption under depreciation. Denoting the state of individual i in month t as h_{it}, the depreciation rate as δ, and the consumption as c_{it}, the habit stock evolves as the following:

$$h_{i,t+1} = (1 - \delta)h_{it} + c_{it}. \tag{1}$$

To test the relationship between the habit stock and consumption, we run an OLS regression with the reading amount (from second to the last month) as the dependent variable and the habit stock in the previous month as an independent variable. Because the habit stock cannot be directly observed in the data, we calculate it in equation (1), restricting the value of δ with a lower bound at 0.36, as suggested by Becker and Murphy (1990). We also assume every consumer starts at $h_{i1} = 0$ in the first month. To control for the heterogeneity in reading preferences across consumers, we include individual fixed effects in the regression.

Regression results show the coefficients for h_{it} range from 0.05 to 0.005, for δ within the range of 0.36 and 1. They are all significant at the 0.001 significance level. The results suggest past consumption is positively correlated with future consumption.

[11] Source: https://www.limelight.com/resources/white-paper/state-of-online-gaming-2018/#spend
[12] Source: https://www.statista.com/statistics/433871/daily-social-media-usage-worldwide

To show evidence of time-inconsistent preferences is less straightforward, because we do not observe consumers' utility during the plan-choice and consumption stages. Our strategy is to show inconsistencies between the pricing plan consumers choose and their reading amount, as an indirect support of the assumption. The second and third rows of Table 1 show the majority (three fourths) of consumers choose the pay-per-chapter plan and, as expected, the number of chapters these consumers read is lower than the number of chapters consumers who choose the monthly subscription read. What is surprising is that the average number of chapters read by the consumers is 392, significantly higher than the 120 chapters over which the optimal plan choice should be monthly subscription. Furthermore, the last two rows of Table 1 show the majority of consumers who overpay choose the pay-per-chapter plan. Their average reading amount is 836 chapters, similar to consumers who choose the monthly subscription. All of these numbers suggest the reading amount of the majority of consumers who choose the pay-per-chapter plan is not consistent with their choice, indicating possible time-inconsistent preferences in the two stages.

Finally, we look for supportive evidence for the strategic self-control assumption. Assuming consumers know that during consumption they will not sufficiently take account of the costs, they will have incentive to take actions during the plan choice stage to curb future consumption. The most notable data pattern is the proportion of consumers who overpay under the pay-per-chapter plan and monthly subscription, as shown in Table 1. Over one third of consumers overpay by reading too much under the pay-per-chapter plan, whereas only 6.6% consumers overpay by reading too little under the monthly subscription. For the former consumers, the reading amount is 836 chapters, far higher than the 120 chapters over which they should choose monthly subscription. The asymmetric overpay ratios of consumers under the two pricing plans are consistent with the assumption that consumers strategically choose the pay-per-chapter plan in order to curb their future consumption.

[Table 2 here]

Table 2 offers further evidence in support of the strategic self-control assumption. The first column reports the probabilities that consumers switch away from the plan they chose last month. The proportion of consumers who switch away from monthly subscription is far larger than those who switch away from pay-per-chapter. The next column shows that for consumers who overpay for pay-per-chapter (by reading too much), only 22.7% switch to monthly subscription, whereas the switching probability for those who overpay for monthly subscription (by reading too little) is 58.4%. The high switch probability for monthly subscription suggests consumers pay attention to the monetary cost and adjust the pricing plan accordingly. The low switch probability for pay-per-chapter, on the other hand, implies consumers are willing to incur a higher monetary cost to curb future consumption.

[Figure 1 here]

For self-control to work, one necessary assumption is that consumers are responsive to the monetary cost during the consumption stage. We find from data that after a consumer switches to pay-per-chapter, the average reading amount drops from 794 to 395 chapters per month. Figure 1 breaks down reading amount in the six months of the sample period by consumers who always choose monthly subscription, always choose pay-per-chapter, and subscribe in months 1 and 2, 2 and 3, and 3 and 4, before they switch to pay-per-chapter. The figure shows the consumption level of consumers who always choose monthly subscription increases over time (from 1,063 to 1,171 chapters). The consumption level of consumers who always choose pay-per-chapter is steady between 200 and 300 chapters a month. The consumption level of consumers who switch from monthly subscription to pay-per-chapter drops significantly after the switch. These data patterns suggest switching to pay-per-chapter helps curb consumption. Interestingly, we find these consumers still overpay for their reading after they switch.

3.2 Alternative Explanations

In this subsection, we examine whether several alternative explanations adopted from the past literature can explain the data patterns presented above. The first one is the *rational addiction* theory developed by Becker and Murphy (1988). The habit formation specification we presented above is based on their work. However, they do not consider time-inconsistent preferences. Consequently, the consumption is optimal and consumers will choose the pricing plan consistent with their consumption level. In this case, the asymmetrical pattern of overpaying we show in Table 1 should not exist. Therefore, we conclude the rational addiction theory cannot explain why overpaying predominantly comes from pay-per-chapter. Later in the model estimation we further show that without time inconsistency, the model fails to predict the asymmetric overpaying behavior where a large proportion of consumers stay with their pay-per-chapter plan and keep overpaying their readings.

Another alternative explanation is that because consumers first make the plan choice and then go through the consumption process, their reading preferences can experience *random shocks* in the second stage. This explanation still cannot explain the asymmetric overpay patterns. We use a simulation exercise for illustration. For each individual, we assume the reading amount follows an individual-specific normal distribution. Before making the pricing-plan decision, the individual knows the distribution of her reading amount in the next period but not the exact amount, and makes the plan choice that minimizes the expected cost based on the information. We run the simulation that draws from the empirical distribution of the reading amount for each individual. We find that for consumers who choose pay-per-chapter, the average overpay ratio is about 11.7%, whereas that for those who choose monthly subscription is significantly higher at 17.9%. Overpaying for monthly subscription is higher because the plan puts an upper bound on the monetary cost if a positive shock occurs in reading preferences. The result contradicts the empirical data pattern. The data pattern also rejects the *risk aversion* or *option value* explanation for consumers who choose not to switch to monthly subscription. This is because the likelihood that a consumer reads fewer than 120 chapters per month is very small, but the chance that she reads a large amount is very substantial. A consumer should choose the monthly subscription if she is averse to overpaying. Likewise, choosing monthly subscription will have a higher option value (in the case she reads a lot in a month) than the pay-per-chapter plan.

Consumer learning is another explanation. It argues that the overpaying behavior can be a result of people learning about their true preferences over time. To test this explanation, we repeat the simulation described above, allowing each individual to update her belief of the mean reading amount in each month based on the reading amount in the previous month. With the learning, the proportion of consumers overpaying is reduced under the two pricing plans; however, the overpaying ratio under monthly subscription is still higher than that under the pay-per-chapter.

[Table 3 here]

Another way to test the learning story is to see how consumers adjust their pricing plans after overpaying. We calculate the average switch probabilities for consumers who overpay for one, two, and three months. The results are reported in Table 3. Despite the fact that overpaying predominantly comes from consumers who choose pay-per-chapter, their switching probabilities are consistently lower than those who choose the monthly subscription. Furthermore, the switch probabilities actually decline for those who overpay for a longer period. This clearly contradicts the learning story, which predicts consumers will adjust their choices accordingly over time.

As another alternative explanation, *consumer inattention* suggests consumers are not aware they are overpaying. Table 2 shows the switching probability is high (58.4%) when consumers overpay under monthly subscription for the previous month. Only consumers who overpay under paid-by-chapter plan do not switch. Consumer inattention cannot explain this asymmetric switching pattern. Furthermore, in our empirical context, consumers under pay-per-chapter have to agree to pay 0.1 RMB each time they read a new chapter. Because they are constantly reminded of the payment, inattention does not seem to be the main reason behind the massive scale of overpaying for such a pricing plan.

Transaction cost or *consumer inertia* as an alternative explanation for the asymmetric overpay patterns suggests that consumers find switching from pay-per-chapter to monthly subscription to be too costly. We do not have direct evidence to rule out such an explanation. In our empirical context, however, consumers are already registered users of the platform. Because they do not have to provide any personal information or change their payment method, consumers can switch with just one click. Given the average overpaying amount is more than four times the cost of a monthly subscription, transaction costs are unlikely to be the reason for not switching.

One may argue that the costs are not about registration but are related to the effort of making payment. However, under the pay-per-chapter plan, consumers need to swipe the bar on their smartphones to pay for each chapter they read. Such effort is costlier than making one upfront payment for a monthly subscription. Again, the transaction-cost explanation does not seem to hold in our empirical context.

The asymmetric overpay pattern may be explained by the *non-monetary benefit of pay-per-chapter*. For example, once a consumer pays for a chapter, she can always re-read the chapter, whereas that option is not available for monthly subscription once she stops the subscription. This is not true in our context. Once the consumer pays for one chapter, she can only read it within 30 days. This restriction makes access to any chapter under pay-per-chapter identical to monthly subscription. Another potential non-monetary benefit of pay-per-chapter for consumers lie in its option value in the sense that consumers can always switch from pay-per-chapter to monthly subscription but cannot freely switch back to pay-per-chapter within one subscription cycle (30 days). There can be psychological benefit due to the payment flexibility. We find from data that consumers who pay by chapters read on average 800 chapters per month, and more than 80% of them never read below 120 chapters. Given the consistently high reading amount, consumers have to have exceedingly large psychological benefit for the pay-per-use plan for them not to switch.

Another alternative explanation, *over-confidence,* suggest that consumers overestimate their self-control ability in the future and thus underestimate the future reading amount. The assumption behind is that they are *naïve time-inconsistent* consumers who are not aware how they will make choices during the consumption stage. Although this explanation cannot be completely ruled out, we find it is not likely to be the main reason consumers overpay for their reading. The majority of those who overpay with pay-per-chapter keep their plan for more than four months. It is unreasonable to assume that, after such a long time, consumers still believe that they can keep their reading amount below 120 chapters, when the actual average reading amount is consistently far higher than that. We should observe consumers to eventually switch to monthly subscription. The same argument is made in DellaVigna and Malmendier (2006). As a more formal test, we estimate a model with naïve time-inconsistent consumers. Estimation results suggest that consumers would need to underestimate future reading by an unreasonably large amount. Details are in the next section.

The last potential explanation is that *consumers do not care about the small price* of 0.1 RMB under pay-per-chapter and end up overpaying. In this case, we should not find consumers reduce their consumption after they switch from monthly subscription to pay-per-chapter. In our data, however, the average reading amount after consumers switch to pay-per-chapter drops from 794 to 395 chapters per month, suggesting their consumption is responsive to the price of each additional chapter they read.

To conclude, although the alternative explanations we list above may explain some of the data patterns, they are inconsistent with either the asymmetric overpaying and switching patterns or the change in consumption behaviors in the data. We acknowledge that time-inconsistent preference and strategic self-control may not be the only mechanism driving the data observations; other potential behavioral explanations that we have not examined may still exist.

4. The Model and its Estimation

In this section, we first use an analytical model to demonstrate under what conditions consumers will overpay as an optimal behavior. We then develop an econometric model with stochastic components and estimate the model from data. We discuss the estimation method and the model identification.

4.1 An Analytical Model and Its Equilibrium

In the dynamic programming literature, the recursive method has proved to be a useful tool to solve dynamic problems. When agents have time-inconsistent preferences, however, equilibrium may not be computed using the solution concept (e.g., Peleg and Yaari, 1973; Caplin and Leathy, 2006), because value-function iteration may not converge, and thus the optimal policy function does not exist. Our model features both habit formation and time-inconsistent preferences under rational agent behavior. We show a unique equilibrium exists in the model. We further show the existence of a unique steady-state equilibrium. We characterize how the equilibrium varies depending on model parameters and the state of consumption stock.

In the model, a consumer chooses either pay-per-chapter ($s = 0$) or monthly subscription ($s = 1$) at the beginning of each period, then decides the level of consumption conditional on the chosen plan. The price for each chapter is p_c under pay-per-chapter, and p_s for the monthly subscription. The consumption utility is influenced by the habit stock, h. The utility during the consumption process is different from the utility when the consumer makes the pricing-plan choice.

Starting with the utility function during consumption, we specify a quadratic utility function as follows:

$$u_c(c, s, h) = (\alpha_c + \alpha_{ch} \cdot h) \cdot c - \alpha_{cc} \cdot c^2 - \mu \cdot p_c \cdot 1\{s = 0\} \cdot c \,, \quad (2)$$

where a_{ch} captures how the habit stock h may change the marginal utility of consumption, and μ is the price coefficient representing the marginal disutility of the monetary cost during the consumption stage. It only occurs if the consumer chooses pay-per-chapter; otherwise, the price of reading a chapter is zero. Given s and h, the consumer chooses the optimal $c^*(s, h)$. It is straightforward to derive that

$$c^*(s, h) = \frac{a_c + a_{ch} \cdot h - \mu \cdot p_c \cdot 1\{s=0\}}{2 \cdot a_{cc}} \text{ if } c^* \geq 0, \text{and 0 otherwise.} \quad (3)$$

Suppose μ is positive. The optimal c^* when *s=0* is lower than that when *s=1*.

Time inconsistency in our model comes from consumers who, when choosing the pricing plan, consider the non-monetary costs of consumption (e.g., time, negative health impact from excessive smartphone usage) that they do not fully take into account in $u_c(c, s, h)$. A difference in the monetary cost between the consumption stage and plan-choice stage can also exist (e.g., the consumer may care less about price once she has indulged in reading). We use γ to represent the total difference in the marginal cost for reading each chapter. The utility function when the consumer chooses the pricing plan is specified as follows:

$$u_p(c, s, h) = u_c(c, s, h) - \gamma \cdot c. \quad (4)$$

We assume the consumer is a "sophisticated" type, as proposed by Strotz (1956). That is, the consumer is aware that during consumption her choice is $c^*(s, h)$ in equation (3) without the cost $\gamma \cdot c$. Furthermore, she is forward-looking as she considers how her current consumption can affect her future habit and thus the consumption. Formally, the consumer chooses a pricing plan by solving the following value function:

$$V(h) = \max_s u_p(c, s, h) - \mu \cdot p_s \cdot 1\{s = 1\} + \beta V(h'), \quad (5)$$

where

$$h' = (1 - \delta)h + c \quad (6)$$

Equation (6) illustrates how the habit stock in the next period will evolve following the current consumption *c*.

Because the utility function is continuous under either pricing plan, value function *V* is continuous in state space h. Assuming h is a compact set bounded above, for any parameter set, the contraction mapping theorem will hold so that the dynamic programming problem is guaranteed to have a unique fixed point for *V*. Therefore, for any h, a unique equilibrium exists in our model. This finding is different from other studies of time inconsistency in preferences, because we assume the consumer is myopic during the consumption stage. The optimal consumption thus can be solved as in equation (3) and, as a result, the optimal plan choice in equation (5) is reduced to a standard dynamic programming problem.

The unique optimal policy function that solves the dynamic problem in equation (5) is a function of h and model parameters. First, define the following variables:

$A = \frac{\alpha_{ch}^2}{4\alpha_{cc}}$; $e = (1-\delta) + \frac{\alpha_{ch}}{2\alpha_{cc}}$;

$B_0 = \frac{(\alpha_c - \mu p_c - \gamma)\cdot\alpha_{ch}}{2\alpha_{cc}}$; $C_0 = \frac{(\alpha_c - \mu p_c)\cdot(\alpha_c - \mu p_c - 2\gamma)}{4\alpha_{cc}}$; $f_0 = \frac{\alpha_c - \mu p_c}{2\alpha_{cc}}$;

$B_1 = \frac{(a_c - \gamma)\cdot a_{ch}}{2a_{cc}}$; $C_1 = \frac{a_c\cdot(a_c - 2\gamma)}{4a_{cc}} - \mu p_s$; $f_1 = \frac{a_c}{2a_{cc}}$.

Let

$$\begin{cases} a_0 = \frac{A}{1-\beta e^2}, \\ b_0 = \frac{B_0 + 2\beta e f_0 a_0}{1-\beta e}, \\ c_0 = \frac{C_0 + \beta a_0 f_0^2 + \beta b_0 f_0}{1-\beta}, \end{cases}$$

and

$$\begin{cases} a_1 = \frac{A}{1-\beta e^2}, \\ b_1 = \frac{B_1 + 2\beta e f_1 a_1}{1-\beta e}, \\ c_1 = \frac{C_1 + \beta a_1 f_1^2 + \beta b_1 f_1}{1-\beta}. \end{cases}$$

Finally, define the "cutoffs" as

$h_1^{ss} = \frac{\alpha_c - \mu p_c}{2\delta\alpha_{cc} - \alpha_{ch}}$, $h_2^{ss} = \frac{\alpha_c}{2\delta\alpha_{cc} - \alpha_{ch}}$, and

$h_1^* = (c_0 - c_1)/(b_1 - b_0)$; $h_2^* = \frac{(1-\beta)(c_0 - c_1) + \beta(b_1 - b_0)f_1}{(1-\beta e)(b_1 - b_0)}$, $h_2^{**} = \frac{(1-\beta)(c_1 - c_0) + \beta(b_1 - b_0)f_0}{(1-\beta e)(b_1 - b_0)}$.

We use the standard recursive method to solve for the value function and the optimal policy function, and obtain the following proposition:

Proposition 1: *Assuming parameters* $\alpha_c, \alpha_{ch}, and\ \lambda$ *are nonnegative, the following unique equilibrium exists:*

1A. If $h_1^{ss} \leq h_1^* < h_2^{ss}$,

$$s^*(h) = \begin{cases} 1\ for\ h > h_1^* \\ 0\ for\ h \leq h_1^* \end{cases}$$

1B. If $h_2^{ss} \leq h_1^*$,

$$s^*(h) = \begin{cases} 1\ for\ h > h_2^* \\ 0\ for\ h \leq h_2^* \end{cases}$$

1C. If $h_1^* < h_1^{ss}$,

$$s^*(h) = \begin{cases} 1\ for\ h > h_2^{**} \\ 0\ for\ h \leq h_2^{**} \end{cases}.$$

Proof: See Appendix 1.[13]

Proposition 1 establishes that a unique equilibrium always exists. Depending on the parameter condition listed in 1A, 1B, and 1C, the cutoff points h_1^*, h_2^*, and h_2^{**} will vary, and thus the optimal plan choice will be different. Following the equilibrium plan choice, the consumption level follows equation (3). Because now we have an analytical solution to our model, given an initial value *h*, we can predict how it will evolve and where the steady state is. Based on Proposition 1, we can derive how the plan choice and consumption level will converge to the steady-state equilibrium as follows:

[13] We require steady states to be nonnegative in the proof. This requirement is not necessary for the general setup.

Lemma: Based on Proposition 1, with any initial habit stock h_0, the following steady-state equilibria exist:

i) if the condition in 1A is satisfied,

$$\lim_{t\to\infty} h_t = h_1^{ss} \cdot \{h_0 < h_1^*\} + h_2^{ss} \cdot \{h_0 \geq h_1^*\};$$

ii) if the condition in 1B is satisfied,

$$\lim_{t\to\infty} h_t = h_1^{ss}$$

iii) if the condition in 1C is satisfied,

$$\lim_{t\to\infty} h_t = h_2^{ss}$$

[Figure 2]

The lemma essentially guarantees all steady states are globally convergent steady states. Figure 2 provides a graphic illustration. In each panel of the figure, the x-axis denotes the current-period habit stock, and the y-axis the next-period habit stock. The black solid line is the policy function which returns a unique value of next-period given current habit stock level, with arrows indicating how it evolves over time. The steady states are located at the intersection of the path and the 45-degree line, on which the state in the next period is the same as the current period. Under the condition in 1A in the top panel, if the habit stock starts below h_1^*, consumers will always choose pay-per-chapter, and h will converge to the "low" steady state h_1^{ss}; otherwise, they will choose the monthly subscription, and h will converge to the "high" steady state h_2^{ss}. In the second panel, when the condition in 1B is satisfied, h will converge to the steady state h_1^{ss}, regardless of where the initial consumption stock state is. If the initial state h_0 is very high ($> h_2^*$), consumers first choose monthly subscription, then switch to pay-per-chapter *when* h drops below h_2^*. The gap on h_2^* indicates the change in consumption level when they switch plans. The last panel in the figure demonstrates when the condition in 1C is satisfied. Regardless of where the initial consumption stock state is, consumers will eventually choose monthly subscription and converge to the high steady state h_2^{ss}.

When no time inconsistency exists (either $\gamma = 0$ or $\gamma \cdot c$ also affects the utility function in the consumption stage), overpaying can never be the optimal choice. For any consumption amount above p_s/p_c chapters, consumers should always choose the monthly subscription. Under time-inconsistent preferences, however, consumers may overpay by choosing pay-per-chapter to prevent excessive consumption. The equilibrium characterized in proposition 1 provides a clear illustration on how time-inconsistent preferences and strategic self-control together can explain the unique data features we observe in section 3:

1. Consumers overpay by consistently choosing pay-per-chapter: In the first two panels of Figure 2, consumers choose the plan at the steady-state equilibrium even though h_1^{ss} can be at a level that is costlier for pay-per-chapter.
2. Consumers switch to pay-per-chapter but still overpay: The second panel indicates consumers in a high state will switch from subscription to pay-per-chapter and decrease their consumption toward h_1^{ss}. During the process, consumers may overpay for pay-per-chapter. They may still overpay at the steady state h_1^{ss}.
3. Asymmetric overpay patterns: We have shown consumers have incentive to

overpay under pay-per-chapter. It is easy to show that when consumers choose the monthly subscription (i.e., $s^*(h) = 1$ in Proposition 1), their reading amount will never be below p_s/p_c chapters a month.

4.2 An Econometric Model

In the analytical model, the plan choice and consumption level are deterministic. In reality, however, observed data will not be perfectly aligned with model predictions due to unobserved factors. To explain fluctuations in the plan choice and consumption across and within individuals, we construct an econometric model so that such fluctuations can be estimated from data. The model is similar to the analytical model, but it incorporates stochastic components in the utility functions. Furthermore, we allow heterogeneous model parameters across consumers to capture the fact that some consumers' reading preferences can be systematically different from the others. And we also allow the non-monetary cost of reading web fiction to change given different level of habit stock h.[14] For individual *i* in period *t*, the utility function during the consumption stage that corresponds to equation (2) is modified as follows:

$$u_{it}(c_{it}, s_{it}, h_{it}) = \left(\alpha_{ic} + \omega_{it} + \alpha_{i,ch} \cdot h_{it}\right) \cdot c_{it} - \alpha_{i,cc} \cdot c_{it}^2 - \mu_i \cdot p_c \cdot 1\{s_{it} = 0\} \cdot c_{it} \quad (7)$$

In this function, ω_{it} represents the unobserved factors that may affect the marginal utility of consumption in each period. The individual-specific model parameters capture the heterogeneity across consumers.

The consumption level that corresponds to equation (3) therefore is

[14] Since such change of model setting do not affect the consumption stage decisions when compared to the baseline model, it is straightforward to see all essential model properties and proof are unaffected even if we apply such change into the analytical model we discussed in the last section.

$$c_{it}^{*}(s_{it}, h_{it}) = max\left\{\frac{\alpha_{ic} + \alpha_{i,ch} \cdot h_{it} - \mu_i \cdot p_c \cdot 1\{s_{it} = 0\}}{2 \cdot \alpha_{i,cc}} + \frac{\omega_{it}}{2 \cdot \alpha_{i,cc}}, 0\right\}. \quad (8)$$

Note the consumption level cannot be negative; therefore, $c_{it}^{*}(s_{it}, h_{it})$ in equation (8) is bounded below by 0.

For the marginal cost of reading each chapter, we allow γ (see equation 4) to be heterogeneous among consumers. In addition, we allow the cost to change as the habit state increases. That is, $\gamma_{it} = \gamma_{i0} + \gamma_{i1} \cdot h_{it}$. This setting implies that an individual's time-inconsistency in terms of plan and consumption choices can be dynamically evolving.

We assume that when making the plan choice, the consumer only knows the distribution of ω_{it} and not the exact value. The consumer will choose a plan that maximizes the expected value function. Two additional stochastic terms, e_{it}^{0} and e_{it}^{1}, will affect the utility of choosing pay-per-chapter and monthly subscription, respectively. Corresponding to equations (5) and (6), the consumer's dynamic problem of plan choice is specified as follows:

$$\begin{aligned} V_{it}(h_{it}, e_{it}^{0}, e_{it}^{1}) = \max_{s_{it}=\{0,1\}} & E_\omega u_{it}(c_{it}^{*}(s_{it}, h_{it}), s_{it}, h_{it}) - \mu_i \cdot p_s \cdot 1\{s_{it} = 1\} \\ & -(\gamma_{i0} + \gamma_{i1} \cdot h_{it}) \cdot c^{*}(s_{it}, h_{it}) \\ & +e_{it}^{0} \cdot 1\{s_{it} = 0\} + e_{it}^{1} \cdot 1\{s_{it} = 1\} \\ & +\beta \cdot E_\omega E_e V_{i,t+1}\left(h_{i,t+1}, e_{i,t+1}^{0}, e_{i,t+1}^{1}\right), \end{aligned} \quad (9)$$

where

$$h_{i,t+1} = (1 - \delta)h_{it} + c^{*}(s_{it}, h_{it}). \quad (10)$$

The expectation operator E_ω in equation (9) integrates over ω_{it} and another E_e

integrates over $e_{i,t+1}^0$ and $e_{i,t+1}^1$ in the next period. Given ω_{it}, the expected value function in the third line of equation (9) can be specified as

$$E_e V_{i,t+1}\left(h_{i,t+1}, e_{i,t+1}^0, e_{i,t+1}^1\right) = E_e max\left\{V_{i,t+1}^0\left(h_{i,t+1}, e_{i,t+1}^0\right), V_{i,t+1}^1\left(h_{i,t+1}, e_{i,t+1}^1\right)\right\}, \quad (11)$$

where $V_{i,t+1}^0$ and $V_{i,t+1}^1$ represent the value function conditional on choosing pay-per-chapter and monthly subscription, respectively. In the empirical application, we assume ω_{it} is distributed as $N(0, \sigma_\omega^2)$, where σ_ω^2 is the variance, and is i.i.d. across consumers and periods. Furthermore, e_{it}^0 and e_{it}^1 are extreme-value type I distributed with zero location parameter and a scale parameter τ.

In the value function, the state variable is h_{it}. Suppose the state space is a closed interval on $\mathcal{R}^1$ denoted by *[0, H]*. We discretized the state space into *N* grid points, and assume h_{it} is constant within an interval $[\frac{(k-1)H}{N}, \frac{kH}{N}]$, where $k \in \{1, \dots, N\}$. Based on the distribution assumption of ω_{it} and our model setting, we can derive that given the plan choice s_{it} and current state h_{it}, the conditional distribution of $h_{i,t+1}$ follows a truncated normal distribution g with support on [0,H], with mean $\mu(h_{it}, s_{it}) = (1-\delta)h_{it} + \frac{\alpha_{ic}+\alpha_{i,ch}\cdot h_{it}-\mu_i\cdot p_c\cdot 1\{s_{it}=0\}}{2\cdot\alpha_{i,cc}}$ and variance equal to $\frac{\sigma_w^2}{4\alpha_{i,cc}}$. The distribution satisfies the Markov property of "memorylessness." Let θ be the collection of model parameters. The distribution function of $h_{i,t+1}$, unconditional on s_{it}, is

$$f\left(h_{i,t+1}\middle|h_{it}, \theta\right) \sim p(s_{it} = 0|h_{it}, \theta)\mathrm{g}\left(\mu(h_{it}, 0|\theta), \frac{\sigma_w^2}{4\alpha_{i,cc}}\right) +$$
$$p(s_{it} = 1|h_{it}, \theta)\mathrm{g}\left(\mu(h_{it}, 1|\ \theta\ ), \frac{\sigma_w^2}{4\alpha_{i,cc}}\right),$$

where p is the probability of choosing a pricing plan. The probability of *h* in interval *m* falling into another interval *n* in the next period therefore is

$$p_{mn}^{1}(\theta) = \int_{\frac{(n-1)H}{N}}^{\frac{nH}{N}} f(h'|h \in m, \theta)dh'.$$

Denote the transition matrix

$$M^{1}(\theta) = \begin{bmatrix} {p^{1}}_{11}(\theta) & \cdots & {p^{1}}_{1,N}(\theta) \\ \vdots & \ddots & \vdots \\ {p^{1}}_{N,1}(\theta) & \cdots & {p^{1}}_{N,N}(\theta) \end{bmatrix}.$$

Similarly, denote the transition probability from state *m* to state *n* after *s* periods as $p_{mn}^{s}(\theta)$ and similarly the transition matrix as $M^{s}(\theta)$. We have the following proposition:

Proposition 2: *For any model parameters* θ, *there exists a unique stationary distribution (or limiting distribution) equilibrium for the state. That is,* $\lim_{s\to\infty} p_{mn}^{s}(\theta) = p_n(\theta)$ *exists for any m, n = 1, 2, ..., N. Let* $p(\theta) = (p_1(\theta), p_2(\theta), \dots, p_N(\theta))$, *where* $p_n(\theta) \geq 0$, $\sum_{n=1}^{N} p_n(\theta) = 1$, *under the stationary distribution equilibrium, we have* $p(\theta)M^{1}(\theta) = p(\theta)$. *This implies*

$$\lim_{s\to\infty} M^{s}(\theta) = \begin{bmatrix} p_1(\theta) & p_2(\theta) & \cdots & p_N(\theta) \\ & \vdots & & \vdots \\ p_1(\theta) & p_2(\theta) & \cdots & p_N(\theta) \end{bmatrix}.$$

Proof: See Appendix A2.

Proposition 2 guarantees that, for any set of model parameters, a unique stationary distribution for *h* exists. Therefore, regardless of the initial distribution, a unique distribution of *h* will exist under a sufficiently large number of iterations. This property helps us solve the initial value problem in the model estimation.

4.3 Model Estimation

Based on the assumption that e_{it}^{0} and e_{it}^{1} are extreme-value type I distributed with zero location parameter and a scale parameter τ, we can rewrite

$$E_e V_{i,t+1}\left(h_{i,t+1}, e_{i,t+1}^{0}, e_{i,t+1}^{1}\right) = \tau \cdot r + \tau \cdot \ln\left(\sum_{s=\{0,1\}} \exp\left(\frac{\bar{V}_i^{s}\left(h_{i,t+1}\right)}{\tau}\right)\right), \qquad (12)$$

where r is the Euler constant, and

$$\begin{aligned}\bar{V}_i^{s}\left(h_{i,t+1}\right) = {} & E_\omega u_{it}\left(c_{i,t+1}^{*}\left(s_{i,t+1} = s, h_{i,t+1}\right), s_{i,t+1} = s, h_{i,t+1}\right) \\ & -(\gamma_{i0} + \gamma_{i1} \cdot h_{it}) \cdot c_{i,t+1}^{*}\left(s_{i,t+1} = s, h_{i,t+1}\right) \\ & +\beta \cdot E_\omega\left(\tau \cdot r + \tau \cdot \ln\left(\sum_{s'=\{0,1\}} \exp\left(\frac{\bar{V}_i^{s'}\left(h_{i,t+2}\right)}{\tau}\right)\right)\right). \qquad (13)\end{aligned}$$

Substitute equation (12) into equation (9), we can rewrite the dynamic plan-choice problem as

$$V_{it}(h_{it}, e_{it}^{0}, e_{it}^{1}) = \max\{\bar{V}_i^{0}(h_{it}) + e_{it}^{0}, \bar{V}_i^{1}(h_{it}) + e_{it}^{1}\}, \qquad (14)$$

where

$$\begin{aligned}\bar{V}_i^{s}(h_{it}) = {} & E_\omega u_{it}(c_{it}^{*}(s_{it} = s, h_{it}), s_{it} = s, h_{it}) - (\gamma_{i0} + \gamma_{i1} \cdot h_{it}) \cdot c^{*}(s_{it} = s, h_{it}) \\ & +\beta \cdot E_\omega\left(\tau \cdot r + \tau \cdot \ln\left(\sum_{s'=\{0,1\}} \exp\left(\frac{\bar{V}_i^{s'}\left(h_{i,t+1}\right)}{\tau}\right)\right)\right).\end{aligned}$$

Proposition 1 shows that for the analytical model, a unique equilibrium exists; therefore, the value function $\bar{V}_i^{s}(h_{it})$ can be solved through the iteration method. For the econometric model, however, the existence of the unique equilibrium is difficult to prove. For each h_{it} in the state space, we use different initial values for $\bar{V}_i^{s}(h_{it})$ in the model estimation, and find the iteration method always converges to the same value. Therefore, we assume $\bar{V}_i^{s}(h_{it})$ will converge to the unique equilibrium in practice even with the stochastic components.

Given the distribution assumption for e_{it}^{0} and e_{it}^{1}, Rust (1987) shows the plan-choice probability has the following analytical expression:

$$P_{it}^{s}(h_{it}) = \frac{\exp(\bar{V}_i^{s}(h_{it})/\tau)}{\exp(\bar{V}_i^{0}(h_{it})/\tau)+\exp(\bar{V}_i^{1}(h_{it})/\tau)} \tag{15}$$

Let c_{it} be the observed consumption level that is bounded below by zero. Conditional on the plan choice s_{it} and the assumption that ω_{it} is distributed as $N(0,\sigma_\omega^2)$, the likelihood of observing c_{it} can be derived from equation (8) as follows:

$$P_{it}^{c|s}(c_{it}|s_{it},h_{it})$$
$$= \begin{cases} 1-\Phi\left(\alpha_{ic}+\alpha_{i,ch}\cdot h_{it}-\mu_i\cdot p_c\cdot 1\{s_{it}=0\}\right), & if\ c_{it}=0 \\ \phi\left(2\cdot c_{it}\cdot \alpha_{i,cc}-\dfrac{\alpha_{ic}+\alpha_{i,ch}\cdot h_{it}-\mu_i\cdot p_c\cdot 1\{s_{it}=0\}}{2\cdot a_{i,cc}}\right), & if\ c_{it}>0 \end{cases}, \tag{16}$$

where ϕ and Φ are the p.d.f and c.d.f of the normal distribution with mean zero and variance σ_ω^2.

Combining the likelihoods in (15) and (16), the full likelihood function for observation (c_{it}, s_{it}), conditional on the habit stock h_{it} and individual-specific model parameters θ_i, is

$$L(c_{it},s_{it}|h_{it},\theta_i) = P_{it}^{1}(h_{it},\theta_i)^{s_{it}=1}\cdot P_{it}^{0}(h_{it},\theta_i)^{s_{it}=0}\cdot P_{it}^{c|s}(c_{it}|s_{it},h_{it},\theta_i). \tag{17}$$

To evaluate the likelihood function, however, we need to solve an initial value problem, because the consumption stock state when the sample period starts, h_{i0}, is unobserved in the data. Given individual-specific model parameters, h_{i0} can be systematically different across consumers. Ignoring this problem can lead to biased model estimates. To deal with the problem, recall that Proposition 2 guarantees the existence of a stationary distribution of h. We assume at the beginning of period 1 the state variable h_{i0} of each individual comes from the stationary distribution. We simulate the stationary distribution as a function of the individual-specific model parameters, and draw h_{i0} multiple times from this distribution. We then calculate the likelihood function conditional on the simulated h_{i0}, and finally take the average of the likelihoods across draws to obtain the simulated likelihood. Given a trial value θ, the detailed estimation procedure is as follows:

1. We first numerically solve the value function $V_{it}(h_{it}, e_{it}^0, e_{it}^1)$ defined in equation (14). We set the state space for habit stock h_{it} as [0,2000].[15] We discretize the state space into grids with length of 10, and linearly interpolate the value function within the range.
2. Next, we calculate the stationary distribution of the state variable h. With the numerical solution of the value function, we can calculate the value of the plan-choice probability $P^s(h)$ with equation (15) for any given h_{it}. Define interval [10(m-1), 10m] as state m for h. Starting from any value of h_m with state *m*, the probability for *h* to transfer from state *m* to state *n*, $p_{mn}(\theta)$, can be calculated by

$$p_{mn}(\theta) = \sum_{s\in\{0,1\}} P^s(h_m) \int_{10(n-1)}^{10n} \mathrm{g}\left(\mu(h_\mathrm{n}, s|\theta), \frac{\sigma_w^2}{4a_{i,cc}}\right) dh_n.$$

   Define the transfer matrix as

$$M^1(\theta) = \begin{bmatrix} p_{11}(\theta) & \cdots & p_{1,200}(\theta) \\ \vdots & \ddots & \vdots \\ p_{200,1}(\theta) & \cdots & p_{200,200}(\theta) \end{bmatrix}.$$

   Proposition 2 shows a unique nonnegative vector $\mathrm{P}(\theta) = (p_1(\theta), p_2(\theta), \dots, p_{200}(\theta))$ exists such that

[15] We choose the maximum state space as 2,000 because it covers most of the data range (95%). We have also tried other values as large as 10,000 and the estimation results are robust.

(1) $\sum_{n=1}^{200} p_n(\theta) = 1$

(2) $\lim_{n\to\infty} (M(\theta))^n = \begin{bmatrix} P(\theta) \\ \vdots \\ P(\theta) \end{bmatrix}$.

To compute the limit, we calculate $(M(\theta))^n$ recursively until $|M(\theta)^{n+1} - M(\theta)^n| < 0.01$, and obtain the stationary distribution $\mathrm{P}(\theta)$.

3. Finally, we take 50 draws of the initial value $\{h_{i0}^n\}$ for each individual. With an initial h_{i0}^n, h_{it} can be computed from the monthly reading amount. This approach enables us to calculate the simulated maximum likelihood function as

$$L(\widehat{c_{it}}, \widehat{s_{it}}, h_{it}) = \prod_i \frac{1}{50} \sum_{n=1}^{50} \prod_t P_{i1t}^{\widehat{s_{it}}}(h_{it}^n) P_{i0t}^{1-\widehat{s_{it}}}(h_{it}^n) P_{ict}(\widehat{c_{it}}, \widehat{s_{it}}, h_{it}^n).$$

During the parameter search, we use the gradient optimization method (BFGS). After it converges, we then switch to the Nelder-Meade numerical optimization. We repeat the procedure until the increase in the log likelihood becomes trivial (<1e-2). From different start points, we find such an algorithm can effectively reach the same global optimum without falling into some local optimum when we only use one method.

4.4 Identification

For ease of discussion, we ignore the heterogeneity in model parameters across consumers. The parameters in the model include all parameters in the utility functions, and the variance for ω's and the scale parameter for *e*'s, that is, $\{\alpha_c, \alpha_{cc}, \alpha_{ch}, \gamma_0, \gamma_1, \mu, \tau, \sigma_\omega\}$. Two additional parameters, $\{\beta, \delta\}$, represent the discounting factor and the depreciation rate of the consumption stock state. Following the previous literature, we fix $\beta = 0.98$ as the monthly discounting factor. This value is equivalent to the daily discounting factor 0.998, as suggested in DellaVigna and

Malmendier (2006). For the depreciation rate δ, we find from practice that it is difficult to be separately identified from α_{ch}, the parameter that captures the effect of the consumption stock state on the marginal utility of consumption. During the estimation, we vary δ from 0.1 to 0.9, and choose the one ($\delta = 0.8$) that maximizes the likelihood function. We test the robustness by varying the value of the two parameters, and find the main results remain unchanged.

Parameters in the consumption utility function, including $\{\alpha_c, \alpha_{cc}, \alpha_{ch}, \sigma_\omega\}$, are identified from the data on monthly reading amounts. For those who choose monthly subscription, equation (8) shows that multiplying a constant on α_c, α_{cc}, and α_{ch} will not change the consumption level. Therefore, we normalize $a_{cc} = 0.5$. The optimal consumption level thus is $c_{it} = max\{\alpha_c + \alpha_{ch}h_{it} + \omega_{it}, 0\}$. Given the consumption states across consumers, we can identify parameters α_c, α_{ch}, and the variance σ_ω.

The price coefficient μ is identified from the difference in the reading amount for the same individual after she switches pricing plans. Suppose the consumer switches from monthly subscription to pay-per-chapter and the reading amount significantly drops. This finding would suggest she has a higher value of μ. Given the parameters in the consumption utility, the disutility parameters from excessive consumption, (γ_0, γ_1), are identified by the proportion of consumers who overpay for pay-per-chapter, relative to the proportion of consumers who overpay under monthly subscription across different level of habit stock. In other words, the identification comes from the asymmetric overpay pattern across consumers with different consumption pattern history. The larger the proportion of consumers who read more than 120 chapters per month and do not choose monthly subscription, the larger γ_0 is among consumers. And the larger overpay amount for consumers who have higher habit stock after controlling for the effect of γ_0, the larger γ_1 is among consumers.

Finally, the scale parameter τ is identified from the plan choice and the corresponding reading amount. Suppose, given all other model parameters, the expected value from one pricing plan is higher than the other. If the probability that consumers choose the high-valued plan is not much higher than the low-valued plan, this scenario implies a large τ. Note that τ cannot be identified if we only observe the plan choice. We need the reading amount together with the plan choice to pin down the parameter.

5. Results

In this section, we first discuss the estimation results of the proposed model. We will then discuss the estimation results from an alternative model under which there are no time-inconsistent preferences and another model assuming consumers are naïve in forming expectation about their consumption choice. Based on the proposed model, we use counterfactuals to show how changing the pricing plan options available to consumers would affect the consumer welfare and the platform's profit. Finally, we show that a new nonlinear pricing plan with volume surcharge could simultaneously improve the consumer welfare and the platform's profit. Our findings help shed light on firms' pricing strategies for product or service categories for which consumers' strategic self-control behaviors are prevalent.

5.1 Estimation Results

[Table 4 here]

We use latent class approach to model the individual heterogeneity in the utility function. We start from a one-class model and keep increasing the number of classes. We find the BIC stops increasing when the number of classes reaches three. Furthermore, the size of the third class has become very small (only about 3%). Therefore, we choose the three-class specification as our main results. For comparison Table 4 reports the estimation results from one- to three-class specifications, but we will focus the discussion based on the three-class model.

Based on the plan choice and consumption behavior of the three segments implied from the estimation results, we name these three consumer segments as *self-controllers, powerless relapsers* and *enthusiastic readers*.

There are two large latent segments, 1 and 2, that are similar in size (49% and 47%, respectively), and another very small segment 3 (3%). The plan choice and consumption behaviors are significantly different among the three segments. The coefficient α_c for segment 3 is the largest, indicating consumers of this segment have the highest reading preference. The coefficient α_{ch} for all three segments is positive, implying the habit stock will enhance consumers' marginal utility for consumption. The magnitude is also the highest for segment 3.

The price coefficient μ is positively significant for all three segments; however, segment 1 is much more price sensitive than the other two segments. This implies that the reading amount of consumers in this segment will decrease much more than that of other two segments when facing a plan with a high marginal cost (e.g. pay-per-chapter). Note that μ represents the price sensitivity during consumption, which can be lower than that in the pricing-plan-choice stage. The difference if it exists will be captured in a reduced-form way by γ_0 and γ_1. The larger the difference in the price sensitivity across different habit stock levels, the higher the value of γ_0 and γ_1. In Table 4, the large estimated γ_0 across all three segments suggests that the true monetary or non-monetary cost of reading web fictions has been seriously under-evaluated by all consumers during the consumption stage. Worse still, the positive estimated γ_1 suggests that, as the habit stock increases, the cost will be under-evaluated even more. Therefore, consumers during the pricing plan choice stage have an incentive to self-control their future consumption.

How can they control the consumption level? Obviously choosing the pay-per-chapter plan is a feasible option, yet this option works differently across consumers. For consumers of segment 1, because of their high price sensitivity, the reading amount will be significantly drop if they switch from the monthly subscription to the pay-per-chapter plan. For consumers of other two segments, however, their much smaller price sensitivities imply that their reading amount will not change much after the switch. As an illustration, we assume that for every consumer the habit stock is at zero level, and calculate the predicted reading amount of each segment. The average reading amount of a consumer in segment 1 is 173.2 chapters, with a 53% chance of no reading, under the monthly subscription. It will drop to 133.5 chapters per month, with a 59% chance of no reading, under the pay-per-chapter plan. In contrast, for a consumer of segment

2, the reading amount under the monthly subscription is 175.7 chapters per month, with a 52.5% chance of no reading. Switching to the pay-per-chapter plan will only marginally reduce the reading amount.

The difference in how much reading amount can be reduced will have a main impact on the pricing-plan choice. We find that the probability of choosing the pay-per-chapter plan is close to 100% among consumers of segment 1. The reading amount is 631 chapters under the monthly subscription, and 435 chapters under the pay-per-chapter, across consumers under different levels of habit stock in our data. With the 0.1RMB/chapter price under pay-per-chapter, an average consumer in segment 1 pays 43.5RMB for their monthly reading, while the monthly subscription would cost them 12 RMB. This suggests that an average consumer in segment 1 is willing to pay 31.5 RMB (about 4.6 U.S. dollars) more to reduce their monthly reading amount by 196 chapters. Assuming it takes five minutes to read one chapter, our results imply that consumers of this segment are willing to pay about a little more than four dollars per month to cut their time with web fiction by about 16 hours per month (or about half an hour per day). In contrast, the probability of choosing the pay-per-chapter plan among consumers of segment 2 however gradually drops from 55% to 29%, as the habit stock increases from 0 to 2000 (this is the range among the majority of consumers estimated from the model), indicating a much weaker willingness to conduct self-control. Since these consumers are incapable of controlling the reading amount, we find that, assuming their habit stock starts from zero, it will increase rapidly each month and eventually will stabilize at a level much higher than that of consumers of segment 1.

Consequently, their consumption level will also stabilize at a much higher level.

Because of the differences in consumption behaviors and pricing plan choices, and the subsequent changes in the habit stock, between the two segments, we call consumers of segment 1 *self-controllers*, and consumers of segment 2 *powerless relapsers*. Due to their large size, these two segments are the most important consumers from the platform's profit perspective.

To conclude, our estimation results show a large cost is associated with reading books, which consumers in the consumption stage do not consider. This leads to the time-inconsistency problem that incentivizes consumers to use self-control strategies when they make the plan choice. We find almost about half consumers are self-controllers. They choose pay-per-chapter, and most of them overpay. The reason is that this segment is price sensitive during consumption; therefore, paying for each chapter as a self-control strategy would be effective in curbing future consumption. Consequently, the price-sensitive consumers are more likely to overpay. This result is counter-intuitive, because previous economic and marketing studies have found that, all else being equal, price-sensitive consumers will engage in more cost-saving purchase and consumption strategies (e.g., taking advantage of price promotions, searching more for price information). However, we show that when strategic self-control is an important goal in the purchase decision, the result can be reversed.

5.2 Model Fit and Alternative Model Specifications

To investigate the model fit, we simulate the plan choice and reading amount for each individual in the data for six time periods, using the estimation results from the proposed model. We repeat the simulation process with 50 different draws from the stationary distribution.

The upper panel of Figure 3 shows that the simulated average reading amount for all readers is 512.1 chapters per month, whereas it is 506.4 chapters in the actual data. The lower panel shows that the average probability of choosing pay-per-chapter in the simulation is 73.38% across six months, whereas it is 74.51% in the data. These comparisons indicate that our model predictions fit the actual data pattern very well.

[Figure 3 here]

Our model can also replicate the unique overpaying data patterns we discuss in section 2. Figure 4 compares the overpaying probability under each pricing plan predicted by the model and the data. Our model predicts that around 6.4% of consumers overpay under the monthly subscription by reading less than 120 chapters, and 45.8% consumers overpay under the pay-per-chapter plan by reading more than 120 chapters. In the data, the overpaying proportions are 6.6% under monthly subscription and 34.2% under pay-per-chapter. Our model replicates the asymmetrical overpay pattern.

[Figure 4 here]

For comparison purpose, we estimate two alternative models. The first assumes time-consistent agents, i.e. consumers' reading amount choice during the consumption stage is consistent with the choice during the pricing plan choice stage. This is similar with the empirical implementation of the rational addiction theory proposed in Becker, Grossman and Murphy (1994). The second one is a model with naïve time-inconsistent consumers, i.e. during the pricing plan choice stage they assume their choice during the consumption stage does not deviate (but indeed it does). Estimation results for time-consistent consumers and naïve time-inconsistent consumers are reported in the Appendix B (Table B1 and Table B2).

We first look at the predictions from the rational model with time consistent consumers. This model shows worse performance in terms of likelihood and AIC/BIC criterion compared to our main estimation results. The parameters and the estimation procedure are the same except that there is no time-inconsistent parameters (γ_0, γ_1 in our full model). The estimation also gives us three consumer segments. However, this time 94% of the total population has a very low price coefficient of 0.34 in consumer segment 1, while the other two segments with higher price sensitivity only account for 3% of the consumers. Such results are significantly different from our main estimation results where almost half of the consumers have relative high price sensitivity and thus willing to conduct self-control. Without time-inconsistent preference, there is no incentive for consumers to choose the more costly pricing plan to curb future consumption. Essentially, this estimation results attribute the reason why consumers overpay for their reading to very low price sensitivity, which cannot explain the asymmetry overpaying pattern presented in previous section. With 94% consumers caring very little about the monetary cost, this model predicts that the average choice probability of the monthly subscription is 62.5%, far higher than 25.5% in the data. The model also predicts the average monthly reading amount to be 743 chapters, well beyond the 506.4 chapters in data. Finally, the predicted proportions of overpaying under the pay-per-chapter plan and monthly subscription are 23% and 16%, respectively. It fails to replicate the high overpaying ratio for the former pricing plan data. These results show that, without accounting for the time-inconsistent preferences, a standard rational economic model cannot explain the unique behavioral patterns we observe from data.

For the model with naïve consumers, we find that the three-class model has a slightly higher log likelihood value or lower BIC in comparison with the proposed model. Although the model fit is better, we believe this is unlikely to be the true model that explains the unique behavioral patterns in data. For example, estimation results show a large consumer segment similar to the self-controllers in our proposed model. Using simulations, we find that consumers of this segment when making the pricing plan choice expect to read 220 chapters in each month, but in reality they consistently read more than 800 chapters. Such under-prediction bias also exists for the other two segments. Overall, the model attributes the overpaying pattern to the fact that more than 60% consumers systematically underestimate their monthly reading amount by 300 to 800 chapters a month. Given the consistently high consumption level across individuals, and the easiness to keep track of the reading history, such a large underestimation persisting over many months is unlikely to happen in our data.

We further test the robustness of the estimation results under other model specifications. We vary the value of δ, the depreciation rate in the habit formation, from 0.1 to 0.9 and re-estimate the proposed model. Though other parameters and model implications remain the same, we find the lower the value of δ, the larger the estimated value of α_{ch}. However, the multiplication $\delta \cdot \alpha_{ch}$ remains stable. We also test different values for the time discounting factor β, and extend the range of the state space to [0, 10,000], which covers 99.9% of the data. All of the results are similar to the results reported in Table 4.

5.3 Counterfactuals

To illustrate the substantive implications from our study, we investigate four counterfactual scenarios. The first two scenarios restrict the pricing plans that consumers can choose, and the last two scenarios increase consumers' options by separately introducing a nonlinear pricing plan with volume discount and another with volume surcharge. We use random draws from the stationary distribution calculated from our estimation result as the initial consumption stock state. In each scenario, we simulate the plan and reading choices of consumers from each segment, until the reading distribution becomes stable after the policy change.[16] We then compare the change in the monthly average reading amount, consumer welfare, and the platform's profit (measured by the revenue). It is straightforward to measure the change of reading amount and revenue under new pricing policies. To measure the consumer welfare, we follow the "dictator of the present" method (see Cropper and Laibson 1998, Caplin and Leahy (2000), Gruber and Koszegi 2001). We measure a consumer's welfare as the discounted value of his life-time utility flow under the model equilibrium. Since a unique stationary distribution exists in our model, for each consumer segment we randomly draw the initial state from the stationary distribution for 50 times and

[16] We simulate the data for 12 periods under all scenarios and use the last six months for comparison. We find the reading-amount distribution typically stabilizes after 2 to 4 months.

calculate the average of the value functions. To compute the overall consumer welfare change across different consumer segments, we calculate the weighted average of the percentage change for each consumer segments.

[Table 5 here]

The first counterfactual restricts consumers' option to monthly subscription only. This scenario is reminiscent of the practice of Netflix, which only offers the monthly subscription plan for watching movies. Consumers choose whether to subscribe or not. The results are in the first panel in Table 5. As expected, the reading amount of self-controllers will increase by 44.41% (from 441 chapters to 637 chapters) per month, when they can do not have the option of choosing the pay-per-chapter plan to curb consumption. Across all three segments, the reading amount increases by 16.82%. Without the pay-per-chapter plan, the welfare of self-controllers decreases 76.06%. The platform's profit from this segment also drops by 79.52%. Overall, the consumer welfare drops by 40.54% and the platform's profit drops by 76.95%. The reason that higher reading amounts generate much less profit for the platform is that consumers who used to read around 600 to 700 chapters a month and still pay by chapters now have to switch to monthly subscription. As a result, the average revenue per consumer drops from 60~70 RMB to 12 RMB each month.

In the second counterfactual, the platform only offers the pay-per-chapter plan. This scenario mimics the video game market, in which players have to pay for each game title. The second panel of Table 5 reports the results. Because almost all self-controllers choose pay-per-chapter, the policy change has a very limited effect on them.

Powerless relapsers and enthusiastic readers are more affected. Since consumers of these two segments are less price sensitive, they will continue to maintain the high consumption under the pay-per-chapter plan and therefore will pay significantly more to the platform. Consequently, the consumer welfare of powerless relapsers will decrease by 9.74%.[17] Overall, the consumer welfare will decrease by 4.51%. The profit of the platform will significantly increase by 46.35%, mostly from the powerless relapsers.

The above two counterfactuals suggest that taking away options from consumers will result in a decrease in consumer welfare. We further investigate if there exists a pricing policy that could improve both firm's profit and consumers' well-being. In the next two counterfactuals, we introduce a step-wise pay-per-chapter pricing structure where price is a nonlinear function of the reading amount. In the third counterfactual, we introduce a novel volume discount plan with a nonlinear structure. Under this plan, which consumers pay for 0.12 RMB for the first 400 chapters in each month, and the price will decrease by 0.04 RMB after that. The 400 chapter threshold is chosen based on the median reading amount under the pay-per-chapter scenario. As the pay-per-chapter plan charges 0.1 RMB, the new plan is more expensive if a consumer reads below 400 chapters, and it becomes cheaper after. The third panel of Table 5 reports the results. Offering the additional pricing plan, the platform's profit will decrease by 45.48%. This is because consumers are able to switch from the pay-

[17] For enthusiastic readers, they are very price insensitive and have a high reading preference, so their welfare is not much affected.

per-chapter plan to the volume discount plan and pay less for reading. Though consumers are paying less, the consumer welfare will reduce by 17.54%. The welfare decrease is due to the higher non-monetary cost as they consume more.

Finally, we introduce a novel volume surcharge plan. Under this plan, consumers are charged 0.08 RMB for the first 400 chapters they read, and 0.12 RMB afterward. Such a pricing scheme is similar to the anti-addiction law for minors playing video games in China, where when a player reaches to a certain amount of time playing video games, the reward from the game (such as virtual coins) will be decreased or forfeited by the system. If the player keeps playing, he/she will be forced to quit the game for a certain time period (usually 24 hours) before logging back into the game. Under such pricing scheme, our results are reported in the bottom panel of Table 5. With this additional pricing plan, self-controllers' welfare will increase by 14.47%, as many of these consumers will switch from the pay-per-chapter plan to the new plan, and thus significantly reduce their reading amount by 7.48%. The welfare of powerless relapsers on the other hand will decrease because they pay more for reading (though their reading amount will marginally reduce). Overall, the aggregate consumer welfare will increase by 2.48%, while the platform's profit is also increase by 46.02%. This profit increase is only 0.33% less than the profit increase generated when the platform only offers pay-per-chapter plan in the second counterfactual.

The findings from the four counterfactuals are very surprising. Taking away the monthly subscription option in the second counterfactual implies the platform forces consumers to restrict their consumption. Our results show that consumers who would have chosen monthly subscription will still read a lot and thus overpay under the pay-per-chapter plan. Therefore, choosing a pricing strategy that helps prevent consumption in this empirical setting can benefit the platform. A pricing plan with volume surcharge, which will restrict consumers' overall consumption, can simultaneously improve the platform's profit and the consumer welfare. By charging a higher price when reading above certain level, the plan helps self-controllers to further control their consumption and also generate more revenue for the platform from powerless relapsers who already have a strong habit of reading web fictions. In contrast, pricing strategies that encourage more consumption, such as offering the monthly subscription only, will hurt not only the consumer welfare but also the platform's profit. The managerial implications will be completely the opposite if one does not take time-inconsistent preferences and consumers' strategic self-control into account. This highlights the substantive contribution of our study.

6. Conclusion

In this paper, we study how consumers overpay for reading web fiction as a means of strategic self-control when time-inconsistent preferences exist during consumption. Using data from one of China's largest digital-book platforms, we find a large percentage of consumers consistently choose pay-per-chapter even when the monthly subscription plan would be less costly. To explain this behavior, we construct a dynamic structural model featuring habit formation and time-inconsistent preferences, as such choosing a costlier pricing plan in order to curb consumption can be optimal for consumers. We apply our model to the data. Estimation results suggest the market has three segments of consumers. Self-controllers overpay for the pay-per-chapter plan because the high cost of reading can effectively work as a “commitment device” to restrict future consumption. In the counterfactuals, we show that eliminating the pay-per-chapter plan would hurt the consumer welfare and the platform’s profit. Eliminating the monthly subscription plan, however, would increase the platform’s profit but reduce the consumer welfare. We introduce a novel non-linear pricing plan with volume surcharge and show how it can simultaneously improve the platform’s profit and the consumer welfare.

Our study contributes both theoretically and empirically to the literature for studying consumer time-inconsistent preferences and strategic self-control behaviors. Findings from our structural model help shed light on firms’ pricing strategies in the digital-content market. Despite its contributions, this research has limitations that call for future study. First, the lack of price variation in our data limits our ability to investigate the optimal prices the platform should charge for various pricing plans. Second, due to the lack of data, our study abstracts away from platform competition, which may bias our counterfactual results. For example, if removing the monthly subscription would push heavy readers to switch to another competing platform, the increase in the focal platform’s profit would be more limited. Finally, we acknowledge that strategic self-control may not be the only mechanism that can explain the overpaying behavior. One can use surveys to test what is the underlying mechanism that drives the observed consumer behaviors.

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Tables:

Table 1: Reading Amount

Reader group	Monthly reading (chapter)	Percentage of Population
Overall	506.4	100.00%
Pay-per-Chapter	392.19	74.51%
Monthly Subscription	827.06	25.49%
Overpay for Monthly Subscription	45.92	6.60%
Overpay for Paid-per--by-Chapter	836.03	34.16%

Table 2: Probability of Switching Plans

Switching from	Overall	Overpay	No overpay
Pay-per-Chapter	17.55%	22.65%	12.45%
Monthly Subscription	46.43%	58.44%	34.41%

Table 3: Switching Probability after Overpay

Consumer group	Switch probability		
	Overpay for 1 months	Overpay for 2 months	Overpay for 3 months
Overpay for Pay-per-Chapter	22.65%	16.03%	4.95%
Overpay for Monthly Subscription	58.44%	52.64%	27.64%

Table 4: Main Estimation Results

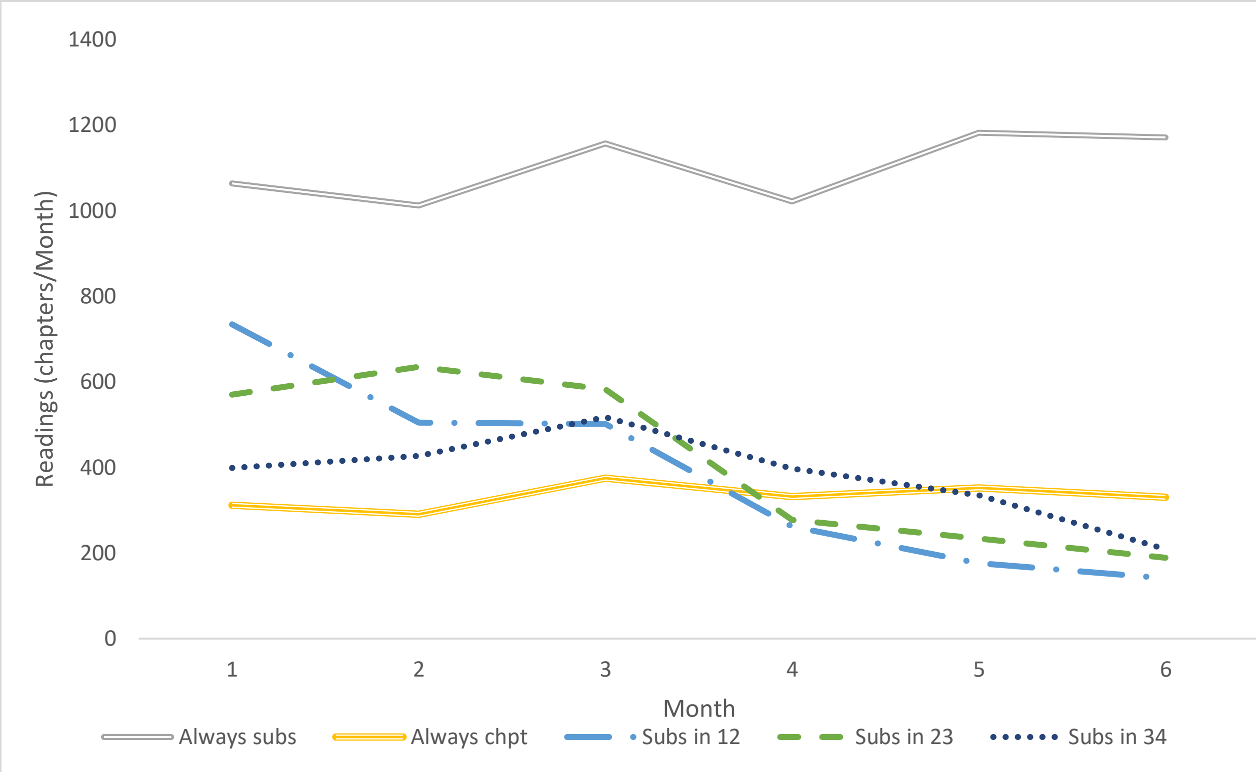
beta= 0.98	Observation=68,7068						
		Segment 1	s.e.				
1-class	a_c	-124.20	1.13				
	a_{ch}	0.86	0.00				
	μ	7.61	0.44				
	γ_0	124.36	33.49				
	γ_1	0.57	0.02				
	$log\sigma_w$	6.57	0.00				
	$log\sigma_e$	8.24	0.03				
	Log likelihood	-439259	AIC	878532	BIC	878595	
		Segment 1	s.e.	Segment 2	s.e.		
2-class	a_c	-124.33	2.29	0.06	11.31		
	a_{ch}	0.68	0.01	0.87	0.01		
	μ	9.31	1.72	0.57	0.13		
	γ_0	124.38	88.71	124.32	153.87		
	γ_1	2.08	0.21	0.29	0.10		
	$log\sigma_w$	6.52	0.00				
	$log\sigma_e$	8.24	0.24				
	Class size	0.54		0.46			
	Log likelihood	-430996	AIC	862019	BIC	862138	
		Segment 1	s.e.	Segment 2	s.e.	Segment 3	s.e.
		(self-controllers)		(powerless relapsers)		(enthusiastic readers)	
3-class	a_c	-44.97	3.88	-37.93	4.49	627.21	34.27
	a_{ch}	0.76	0.01	0.79	0.01	1.46	0.02
	μ	100.82	4.29	3.78	0.39	0.16	0.01
	γ_0	100.05	6.26	99.89	40.1	100.01	159.42
	γ_1	0.58	0.02	0.38	0.02	12.90	1.13
	$log\sigma_w$	6.39	0.00				
	$log\sigma_e$	8.49	0.07				
	Class size	0.49		0.47		0.03	
	Log likelihood	-424730	AIC	849498	BIC	849671	

Table 5: Counterfactual Results

Monthly Subscription Only				
	Self-controller	Powerless relapsers	Enthusiastic reader	Overall
Reading amount	44.41%	0.51%	0.00%	16.82%
Firm revenue	-79.52%	-71.91%	-85.77%	-76.95%
Consumer welfare	-76.06%	-6.96%	-0.01%	-40.54%
Pay-per-chapter only (Linear Pricing)				
	Self-controller	Powerless relapser	Enthusiastic reader	Overall
Reading amount	0.00%	-0.69%	0.00%	-0.38%
Firm revenue	0.00%	102.87%	96.82%	46.35%
Consumer welfare	0.15%	-9.74%	-0.01%	-4.51%
Pay-per-chapter only (Volume Discount)				
	Self-controller	Powerless relapser	Enthusiastic reader	Overall
Reading amount	9.02%	-0.42%	0.00%	3.13%
Firm revenue	6.51%	95.79%	70.74%	45.48%
Consumer welfare	-26.14%	-10.05%	-0.01%	-17.54%
Pay-per-chapter only (Volume Surcharge)				
	Self-controller	Powerless relapser	Enthusiastic reader	Overall
Reading amount	-7.48%	-0.94%	0.00%	-3.30%
Firm revenue	-6.98%	109.84%	108.68%	46.02%
Consumer welfare	14.47%	-9.81%	-0.01%	2.48%

Figures

Figure 1: Number of Chapters Read after Switching to Pay-per-Chapter



Variables	Meaning
Always subs:	Consumers who always purchase monthly subscription during the data time period
Always chpt:	Consumers who never purchase monthly subscription during the data time period
Subs in xy:	Consumers who purchase monthly subscription from month x to month y and then quit

Figure 2: Dynamics of the Steady States

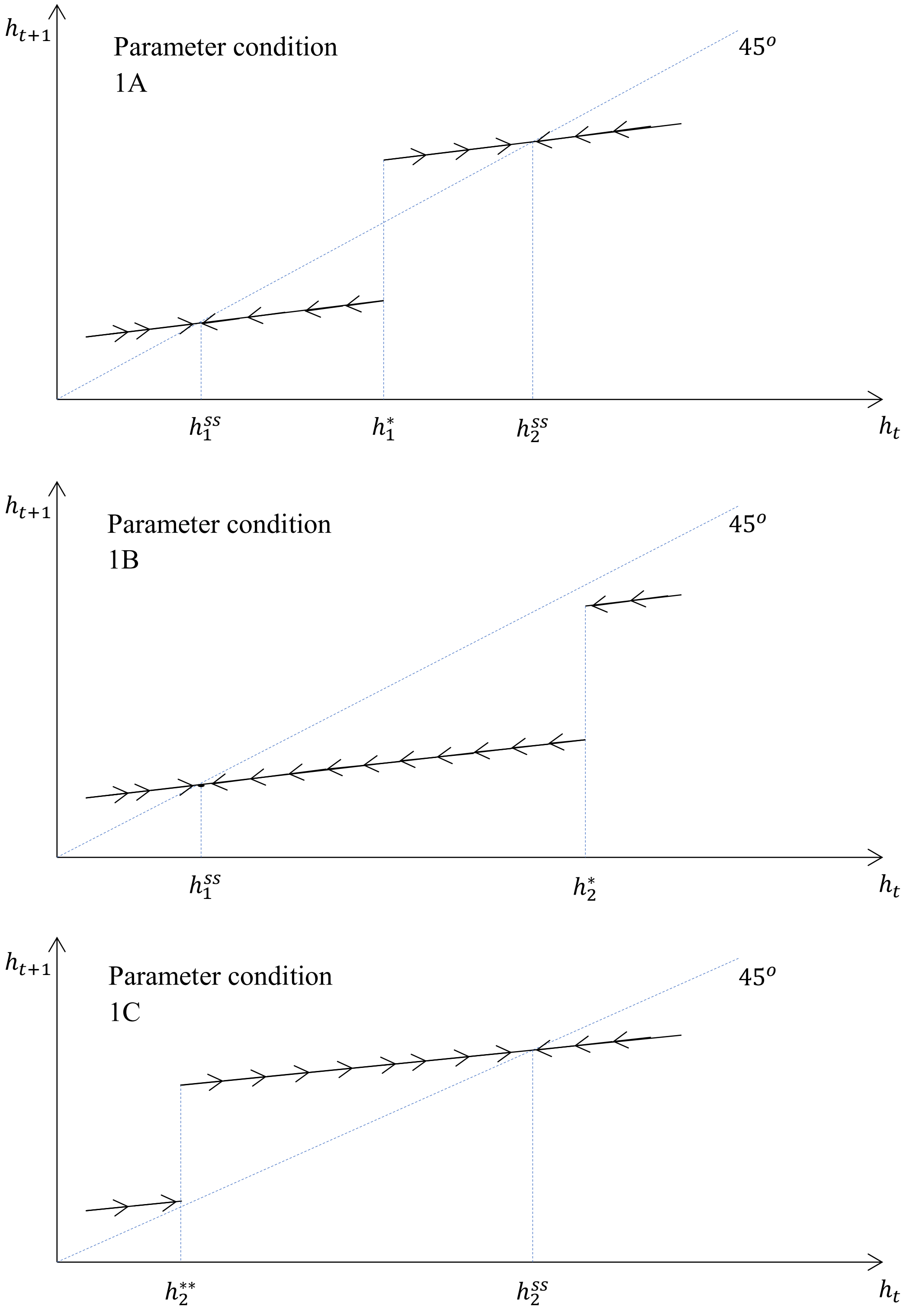
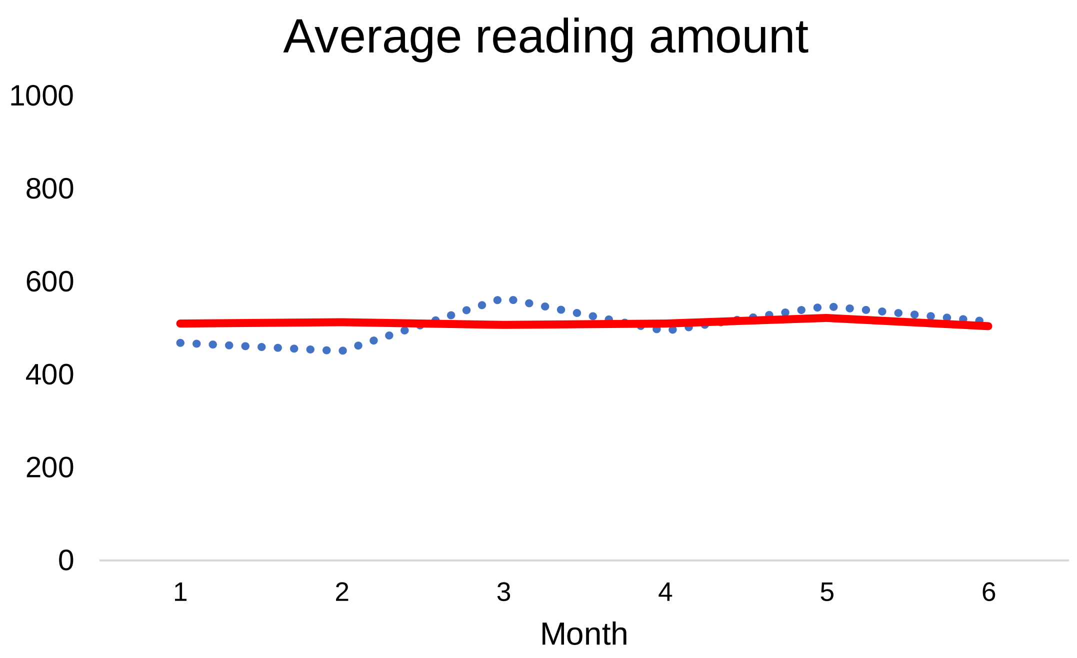


Figure 3: Model Fit: reading and plan choice



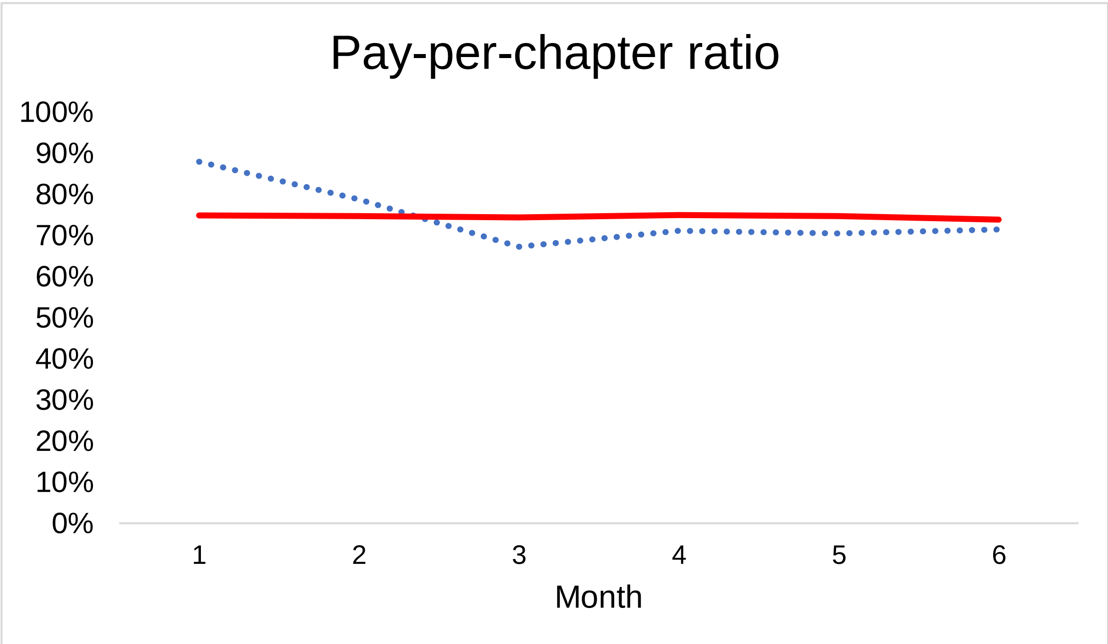
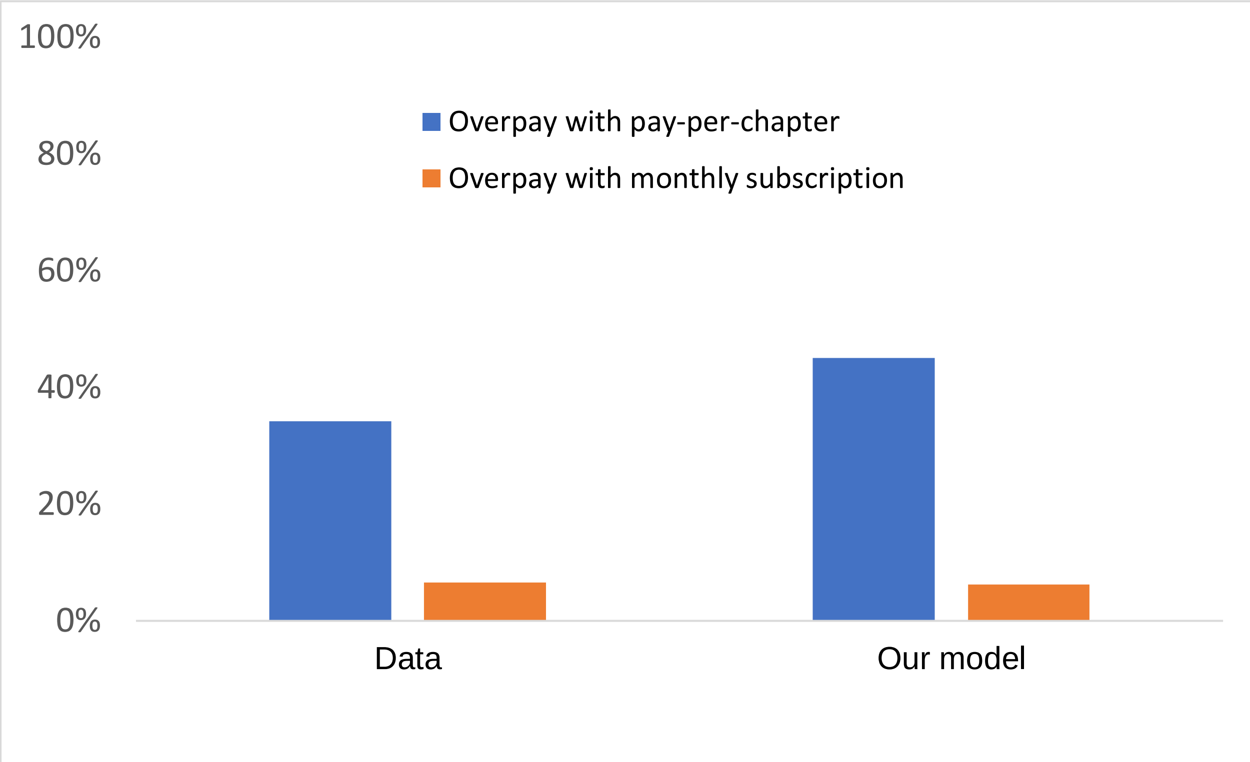


Figure 4: Model Fit: overpaying ratio



Appendix A

A1. Proof of proposition 1

In this section, we provide the detailed proof of proposition 1, showing the analytical solution to our baseline model. Before we start the formal proof, we first restate the problems to be solved:

$$V(h) = \max_{s} u_p(c,s,h) - \mu p_s 1\{s=1\} + \beta V(h') \quad [1]$$

$$u_p(c,s,h) = (\alpha_c + \alpha_{ch}h)c - \alpha_{cc}c^2 - \mu p_c 1\{s=0\}c - \gamma c \quad [2]$$

$$h' = (1-\delta)h + c \quad [3]$$

$$c^*(s,h) \equiv \frac{\alpha_c + \alpha_{ch}h - \mu p_c 1\{s=0\}}{2\alpha_{cc}} \, if\ c^* \geq 0, and\ 0\ otherwise, \quad [4]$$

where equation 4 is easily derived from the maximization of the utility function in equation 2 in terms of consumption c. [18] For notation simplicity, let $u_s(h) \equiv u_p(c^*(s,h),s,h) \ - \mu p_s 1\{s=1\}$

$$V(h) = \max_{s}\{V_0(h), V_1(h)\} \quad [5]$$

$$V_0(h) = u_0(h) + \beta * \max\{V_0(h'), V_1(h')\}$$

$$V_1(h) = u_1(h) + \beta * \max\{V_0(h''), V_1(h'')\}.$$

$$h' = \left[(1-\delta) + \frac{a_{ch}}{2a_{cc}}\right]h + \frac{a_c - \mu p_c}{2a_{cc}}$$
$$h'' = \left[(1-\delta) + \frac{a_{ch}}{2a_{cc}}\right]h + \frac{a_c}{2a_{cc}}. \quad [6]$$

[18] It is straightforward to see that if $s = 1$, $c^* > 0$; if s=0, then if c^*=0 at time t, all consumers' future decisions will be reduced to the trivial equilibrium where s=0 and c^*=0 for all future periods. So we focus on the case where $c^* > 0$

Notice that for a given plan choice s, the value function V is continuous in terms of the state variable h. Given the state space is a compact set (a closed interval on $\mathcal{R}^1$), the contraction mapping theorem holds and there exists a unique fixed point for value function V for any h.

From equation 6, we can solve for two candidate steady states:

$$h_1^{ss} = \frac{\alpha_c - \mu p_c}{2\delta\alpha_{cc} - \alpha_{ch}}, h_2^{ss} = \frac{\alpha_c}{2\delta\alpha_{cc} - \alpha_{ch}}.$$

Because consumption is nonnegative, h is also nonnegative. So we further impose an additional assumption.

Assumption I

$$2\delta\alpha_{cc} - \alpha_{ch} > 0 \quad [7]$$

Assumption I guarantees at least one of the steady states is positive. This assumption also give us an ideal property of the model: The "slope" in the linear equation 6 is strictly less than 1 under assumption I, which ensures both steady states as convergent steady state for the model. Before we prove the existence of the equilibria, we first consider a simple case in which the consumers always choose s=1 or s=0. Denote the value under these scenarios as $W_s(h)$, we have

$$W_0(h) = u_0(h) + \beta W_0(h')$$

$$W_1(h) = u_1(h) + \beta W_1(h''). \quad [8]$$

Because $u_s(h)$ is a quadratic form in h and equation 6 is linear in h, we know W must also be quadratic functions of h. Plugging equation 2 and 6 into equation 8, we can solve for the $W_s(h)$.

Assume

$$W_0(h) = a_0h^2 + b_0h + c_0 \quad [9]$$

$$W_1(h) = a_1h^2 + b_1h + c_1.$$

To keep the notation from being overcomplicated, we introduce a new set of utility parameter notations such that

$$u_0(h) = Ah^2 + B_0h + C_0 \quad [10]$$

$$u_1(h) = Ah^2 + B_1h + C_1$$

$$h' = eh + f_0$$

$$h'' = eh + f_1.$$

Now, we can use equation 8 to solve for the parameters in equation 9 in terms of these simplified notations for utility parameters:

$$a_0h^2 + b_0h + c_0 = Ah^2 + B_0h + C_0 + \beta[a_0(eh + f_0)^2 + b_0(eh + f_0) + c_0], \forall h.$$

We get

$$\begin{cases} a_0 = \frac{A}{1-\beta e^2} \\ b_0 = \frac{B_0+2\beta e f_0 a_0}{1-\beta e} \\ c_0 = \frac{C_0+\beta a_0 f_0^2+\beta b_0 f_0}{1-\beta} \end{cases}.$$

Similarly, we can solve for $W_1(h)$ in the same way and get

$$\begin{cases} a_1 = \frac{A}{1-\beta e^2} \\ b_1 = \frac{B_1+2\beta e f_1 a_1}{1-\beta e} \\ c_1 = \frac{C_1+\beta a_1 f_1^2+\beta b_1 f_1}{1-\beta} \end{cases},$$

where

$$A = \frac{\alpha_{ch}^2}{4\alpha_{cc}}; e = (1-\delta) + \frac{\alpha_{ch}}{2\alpha_{cc}};$$

$B_0 = \frac{(\alpha_c - \mu p_c - \gamma)\alpha_{ch}}{2\alpha_{cc}}; C_0 = \frac{(\alpha_c - \mu p_c)(\alpha_c - \mu p_c - 2\gamma)}{4\alpha_{cc}}; f_0 = \frac{\alpha_c - \mu p_c}{2\alpha_{cc}};$

$B_1 = \frac{(\alpha_c - \gamma)\alpha_{ch}}{2\alpha_{cc}}; C_1 = \frac{\alpha_c(\alpha_c - 2\gamma)}{4\alpha_{cc}} - \mu p_s; f_1 = \frac{\alpha_c}{2\alpha_{cc}}.$

Notice $a_1 = a_0$, so $W_1(h) - W_0(h) = (b_1 - b_0)h - (c_0 - c_1)$, which is linear in *h* and thus guarantees the "single-crossing" property of $W_1(h)$ and $W_0(h)$. Equipped with these results, we start the formal proof of proposition 1. Our method is by guess and verify of the value function and then solve for the policy function.

1. When $h_2^{ss} > h_1^* > h_1^{ss}$

$$V = \begin{cases} ah^2 + b_0 h + c_0, h < h_1^* \\ ah^2 + b_1 h + c_1, h \geq h_1^* \end{cases}$$

$$h_1^* = \frac{c_0 - c_1}{b_1 - b_0}.$$

Without loss of generosity, assume the consumer starts with some initialconsumption stock state $h > h_1^*$. If the above value function is correct, after one iteration, *V* will remain identical. In other words, because $h > h_1^*$, we need to show that for any *h* after the consumer makes the optimal plan-choice decision to maximize the value function, *V* will still be equal to $ah^2 + b_1 h + c_1$ after it is plugged into equation 5. Given assumption I, we know that if the consumer chooses monthly subscription s=1, h_1^* is lower than her next-periodconsumption stock state, h''. However, it is undetermined whether $h' > h_1^*$. So, we discuss two cases here.

Case I $h' < h_1^*$

$$V(h) = \max\,(V_0(h), V_1(h))$$

$$= \max\{Ah^2 + B_0h + C_0 + \beta(ah'^2 + b_0h' + c_0), Ah^2 + B_1h + C_1$$

$$+ \beta(ah''^2 + b_1h'' + c_1)\}$$

$$= \max\{ah^2 + b_0h + c_0, ah^2 + b_1h + c_1\}$$

$$= ah^2 + b_1h + c_{1,}$$

where the second equation utilizes the "fixed-point" property of W_1 and W_2, and the third equation is simply algebra with the fact the $b_1 > b_0$ and $ah^2 + b_1h + c_1 > ah^2 + b_0h + c_0$ with any $h > h_1^* = (c_0 - c_1)/(b_1 - b_0)$.

Case II $h' \geq h_1^*$

$$V(h) = \max\begin{Bmatrix} Ah^2 + B_0h + C_0 + \beta(ah'^2 + b_1h' + c_1), \\ Ah^2 + B_1h + C_1 + \beta(ah''^2 + b_1h'' + c_1) \end{Bmatrix}$$

$$= \max\begin{Bmatrix} ah^2 + b_0h + c_0 + \beta[(b_1 - b_0)h' + (c_1 - c_0)], \\ ah^2 + b_1h + c_1 \end{Bmatrix}$$

$$= \max\{ ah^2 + b_0h + c_0 + \beta[(b_1 - b_0)h' + (c_1 - c_0)],$$

$$ah^2 + b_0h + c_0 + [(b_1 - b_0)h + (c_1 - c_0)]\}.$$

Because $h > h_1^* > h_1^{ss}$, by equation 6, we know that $h > h'$, so we have

$$[(b_1 - b_0)h + (c_1 - c_0)] > \beta[(b_1 - b_0)h + (c_1 - c_0)]$$

$$> \beta[(b_1 - b_0)h' + (c_1 - c_0)],$$

and $$V(h) = ah^2 + b_1h + c_1.$$

Similarly, we can prove that for any $h < h_1^*$, $V(h) = ah^2 + b_0h + c_0$.

Given the functional form of the value function, it is straightforward to solve for the optimal policy function $s(h) = 1 * 1(h > h_1^*) + 0 * 1(h < h_1^*)$.

2. When $h_1^* > h_2^{ss} > h_1^{ss}$,

$$V(h) = \begin{cases} \sum_{t=0}^{T_h} \beta^t u_1(h_t) + \beta^{T_h+1}(a_0h_{T_h+1}^2 + b_0h_{T_h+1} + c_0) & if\ h \geq h_2^*, \\ a_0h^2 + b_0h + c_0 & Otherwise \end{cases}$$

where

$$h_0 = h$$

$$h_{t+1} = eh_t + f_1; t = 0,1,2, \dots, T_h$$

$$T_h = \lfloor \frac{\log \frac{(1-\mathrm{e})\mathrm{h}_2^* - \mathrm{f}_1}{(1-\mathrm{e})\mathrm{h} - \mathrm{f}_1}}{\log \mathrm{e}} \rfloor$$

$$h_2^* = \frac{(c_0 - c_1) + \beta[(b_1 - b_0)f_1 + c_1 - c_0]}{(1-\beta e)(b_1 - b_0)}.$$

Proof:

First, we define the "difference function" Z(h) as

$$Z(h) \equiv u_1(h) + \beta W_0(h'') - W_0(h) = u_1(h) + \beta W_0(eh + f_1) - W_0(h).$$

Z(h) measures the lifetime utility difference between when consumers always choose to pay per chapter and when consumers purchase monthly subscription in the current period and choose to pay-per-chapter starting next period. When Z(h)=0, the consumer receives same utility value no matter what price plan he chooses in the next time period, given that he keep pay-per-chapter since the third time period. With some algebra, we can show

$$Z(h) = (B_1 + \beta(2aef_1 + b_0 e) - b_0)h + (1-\beta)(c_0 - c_1) + \beta(b_1 - b_0)f_1$$

$$= (B_1 - B_0 + \beta(2ae(f_1 - f_0)))h + (1-\beta)(c_0 - c_1) + \beta(b_1 - b_0)f_1,$$

where the second equation uses the fixed-point property of $W_0(h)$. Because $B_1 > B_0$

and $f_1 > f_0$ (the utility for monetary cost is always negative), Z(h) is a linear monotone increasing function in h, and h_2^* is the unique solution to Z(h)=0. So,

$$u_1(h) + \beta w_0(h'') \geq w_0(h) \; \forall h \geq h_2^* \quad [11]$$

$$u_1(h) + \beta w_0(h'') < w_0(h) \; \forall h < h_2^*, \quad [12]$$

and vice versa.

Next, we show that if h_1^*>h_2^{ss}, then h_2^*>h_2^{ss};

$$\begin{aligned} h_2^* &= \frac{\frac{(1-\beta)(c_0-c_1)}{b_1-b_0} + \beta f_1}{1-\beta e} \\ &= \frac{(1-\beta)h_1^* + \beta f_1}{1-\beta e} \\ &> \frac{(1-\beta)h_2^{ss} + \beta f_1}{1-\beta e} \\ &= \frac{\frac{(1-\beta)f_1}{1-e} + \beta f_1}{1-\beta e} \\ &= \frac{f_1}{1-e} = h_2^{ss}, \end{aligned}$$

where the third equation is derived from the expression of h_2^{ss} in the form of f_1 and e.

Finally, we show the value function above is the fixed point of equation 5. Without loss of generosity, assume some consumer with initialconsumption stock state $h > h_2^*$ at the initial period t=0. We first show by induction that for any T (for any h),

by equation 11, we know that for T_h=0,

$$u_1(h) + \beta(a_0 h_2^2 + b_0 h_2 + c_0) = u_1(h) + \beta w_0(h'') \geq w_0(h) = a_0 h^2 + b_0 h + c_{0.}$$

If for $T_h = n$, the following inequality holds:

$$\sum_{t=0}^{n} \beta^t u_1(h_t) + \beta^{n+1} w_0(h_{n+1}) \geq w_0(h_1).$$

Then, for $T_h = n + 1$, the following also holds:

$$\sum_{t=0}^{n+1} \beta^t u_1(h_t) + \beta^{n+2} w_0(h_{n+2})$$

$$= \sum_{t=0}^{n} \beta^t u_1(h_t) + \beta^{n+1} u_1(h_{n+1}) + \beta^{n+2} w_0(h_{n+2})$$

$$= \sum_{t=0}^{n} \beta^t u_1(h_t) + \beta^{n+1}\big(u_1(h_{n+1}) + \beta w_0(h_{n+2})\big)$$

$$\geq \sum_{t=0}^{n} \beta^t u_1(h_t) + \beta^{n+1} w_0(h_{n+1})$$

$$\geq w_0(h).$$

The proof above establishes that when the consumer starts with anyconsumption stock state $h \geq h_2^*$, the optimal plan choice is always s=1. We now show that after one iteration, the value function remains the same functional form. Because the next-periodconsumption stock states will be h'', again we discuss two cases in which $h'' \geq h_2^*$ and $h'' < h_2^*$:

Case I. $h'' \geq h_2^*$

$$V(h) = u_1(h) + \beta V(h'')$$

$$= u_1(h) + \beta(\sum_{t=0}^{T_{h''}} \beta^t u_1(h_{t+1}) + \beta^{T_{h''}+1}(a_0 h_{T_{h''}+2}^2 + b_0 h_{T_{h''}+2} + c_0)$$

Because $h'' = eh + f_1, T_{h''} = T_h - 1$,

$$= \sum_{t=0}^{T_h} \beta^t u_1(h_t) + \beta^{T_h+1}\big(a_0 h_{T_h+1}^2 + b_0 h_{T_h+1} + c_0\big).$$

Case I. $h'' < h_2^*$

When $h'' < h_2^*$, it is straightforward to see $T_h = 0$ and T_ by its specification:

$$V(h) = u_1(h) + \beta V(h'')$$

$$= u_1(h) + \beta(a_0 h''^2 + b_0 h'' + c_0)$$

$$= \sum_{t=0}^{T_h} \beta^t u_1(h_t) + \beta^{T_h+1}\left(a_0 h_{T_h+1}^2 + b_0 h_{T_h+1} + c_0\right).$$

Use equation 12 instead of equation 11, we can repeat the same proof above and show for any $h < h_2^*$,$V(h) = a_0 h^2 + b_0 h + c_0$.

Thus, we have proved that for any h when h_1^*>h_2^{ss}>h_1^{ss}, the policy function is

$$s(h) = 1 * (h > h_2^*) + 0 * (h < h_2^*).$$

Symmetrically, when h_2^{ss}>h_1^{ss}>h_1^{ss}, we can show $s(h) = 1 * (h > h_2^{**}) + 0 * (h < h_2^{**})$, where h_2^{**} is the unique solution to

$$u_0(h) + \beta w_1(h') - w_1(h) = 0.$$

Solving the equation above gives us $h_2^{**} = \frac{(1-\beta)(c_1-c_0)+\beta(b_1-b_0)f_0}{(1-\beta e)(b_1-b_0)}$. Q.E.D.

A2. Proof of Proposition 2

Because it is obvious that all states for h are aperiodic given $p_{m,m'}(\theta) > 0$ for any m. To prove the existence of the limiting distribution, we only need to show that all states for h are irreducible, which means for any state $i, j = 1,2,, \dots, H, \exists\, n_0$ s.t. $p_{ij}^{n_0} > 0$. Together with aperiodic and irreducible states, the Markov chain for *h* is ergodic. Thus, the ergodicity theorem guarantees the existence of the limiting distribution for *h* specified in proposition 2.

For any *i*, we first show that if $j \geq i$, then $\exists\, n_0 = 1$ s.t. p_{ij}^1>0: without loss of generosity, we start from any h in state i, which means $h \in \left[\frac{i-1}{N}H, \frac{i}{N}H\right)$. The c.d.f. for the next period ofconsumption stock state h' follows the c.d.f $f(h'|h, \theta)$, which is specified in the main text right before the proposition 2. Because the consumption is nonnegative, it is straightforward to see that $f(h'|h,\theta)$>0 on the support of $[(1-\delta)h, H]$. Also, we have $\frac{j}{N}H > \frac{j-1}{N}H > h > (1-\delta)h$, so $p_{ij}^1 = \int_{\frac{i}{N}H}^{\frac{i-1}{N}H} f(h'|h \in i, \theta)dh' > 0$.

Similarly, we can show that for any j that $\frac{j-1}{N}H \geq (1-\delta)h$, $p_{ij}^1 > 0$. Because $\lim_{n\to\infty}(1-\delta)^n h = 0$, for any j that $\frac{j-1}{N}H \geq 0$, there always exists a finite n_0 so that $p_{ij}^{n_0} > 0$.

Now that we have established that any i,j=1,2,..,N, $\exists\, n_0$ s.t. $p_{ij}^{n_0} > 0$, together with the facts that the Markov chain is aperiodic, we have proved the $\{h_t\}$ is an ergodic Markov chain that has a unique stationary distribution. Q.E.D.

Appendix B

Table B1 Estimation results (time-consistent consumers)

beta=0.98 Observation=68,706

		Segment 1	s.e.	Segment 2	s.e.	Segment 3	s.e.
3-Class	a_c	-113.41	0.41	-25.16	0.84	760.39	31.25
	a_{ch}	0.34	37.56	557.86	0.69	0.63	0.02
	μ	0.88	418.03	0.65	623.96	1.52	2.23
	$\log\sigma_w$	6.38	3.63				
	$\log\sigma_e$	8.49	0.02				
	Class size	0.94		0.03		0.03	
	Log likelihood	-439711.00	AIC	848697	BIC	848870	

Table B2 Estimation results (Naïve time-inconsistent consumers)

beta=0.98 Observation=68,706

		Segment 1	s.e.	Segment 2	s.e.	Segment 3	s.e.
3-Class	a_c	-37.17	6.61	-32.78	6.25	627.14	31.25
	a_{ch}	0.82	0.01	0.79	2.43 E-04	1.47	0.02
	μ	160.37	5.49	1.40	0.08	0.07	2.23
	γ_0	649.33	72.65	20.52	0.30	100.30	31.82
	γ_1	63.27	57.33	0.09	7.81 E-04	14.30	0.05
	$\log\sigma_w$	8.54	3.19E-02				
	$\log\sigma_e$	6.39	1.38E-04				
	Class size	0.44		0.41		0.15	
	Log likelihood	-424329.50	AIC	848697	BIC	848870.44	