Addictive Digital-Content Consumption and Strategic Self-Control: An Empirical Study

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Abstract

This paper studies how consumers are addicted to digital-content consumption and how they may self-control their consumption. We focus on web-fiction reading, which is a prevalent phenomenon among Asian consumers. We use a unique dataset obtained from a major digital book platform in China where consumers can either pay by monthly subscription or per chapter, and find that one third of consumers consistently choose to pay per chapter even though a monthly subscription would significantly reduce the monetary cost. We propose a dynamic structural model that incorporates addictive consumption and strategic self-control behaviors to rationalize the overpaying behavior. We first demonstrate from an analytical model the existence of a uniqueness equilibrium, and show how under steady states, overpaying for reading may be optimal for consumers. We then estimate an econometric model from the data. Results show a large consumer segment with high price sensitivity consistently overpays by choosing to pay per chapter. Other segments are more likely to choose a monthly subscription and thus are more addicted. We then use counterfactuals to show that eliminating the pay-per-chapter plan would hurt not only consumer welfare, but also the company's profit. Eliminating the monthly subscription plan, however, would significantly increase the company's profit while only slightly decreasing consumer welfare. Finally, adding a hybrid pricing plan would not significantly improve the company's profit or consumer welfare.

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

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 growth is facilitated by the improved download speed from the Internet and the penetration of smartphones, which allows consumers to gain access almost anywhere and anytime.[2]

The rapid growth in the consumption of digital content has raised concerns that users may become addicted, which can have a detrimental effect on their physical, mental, social, or financial well-being. Medical and psychological research has identified internet usage as one type of potential addictive behavior, similar to gambling, use of drugs, alcohol and tobacco consumption, sexual intercourse, and playing video games (e.g., Kuss and Lopez-Fernandez, 2016). In China, internet addiction has been officially acknowledged as a clinical disorder since 2008.[3] Addictive consumption is traditionally viewed as an irrational behavior under loss of control. Becker and Murphy (1988), however, argue that individuals evaluate the monetary and non-monetary benefits and costs when deciding the optimal level of consumption. They will curb their

[1] Source: https://www.emarketer.com/content/us-time-spent-with-media-2018.
[2] Source: https://newzoo.com/insights/rankings/top-50-countries-by-smartphone-penetration-and-users.
[3] Source: https://www.theguardian.com/news/blog/2008/nov/11/china-internet.

current consumption levels if the cost of the increased future consumption due to addiction is high.

The goal of this study is to understand and quantify how consumers are addicted to digital content and how they may control their consumption. We focus on a specific type of digital 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. In China, for example, more than 400 million unique readers pay for some form of web fiction. 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. Several data features suggest reading web fiction may be associated with addiction. First, our data show that 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 reading web fiction as on other major 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, because payment to authors is linked to how many chapters an individual reads, authors have an incentive to include plot twists to keep readers

[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

following their books every day. These features can lead to addictive consumption behaviors, as identified in the medical research. Finally, we observe an interesting overpaying phenomenon among consumers in our data: An individual can purchase either a pay-per-chapter plan (0.1 RMB each 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 whereas 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. The reading amount of most switchers from the monthly subscription (including those who do not overpay) remains so high that the monetary cost would have been significantly lower had they stayed with the original plan. We argue these overpaying behaviors are consistent with the idea that consumers use strategic self-control measures to curb their addictive consumption of web fiction.

To formalize the idea, we propose a dynamic structural model that incorporates addictive consumption and strategic self-control behaviors. The model explicitly accounts for two features that characterize addiction in the medical research (Nestler 2013). First, high past consumption can reinforce the propensity of future consumption. Second, a biologically intrinsic rewarding mechanism during consumption increases the desire to consume more during addiction, making individuals under-evaluate the short- and long-term monetary and non-monetary costs. These two features apply to not only digital content, but also other types of addictive consumption. Anticipating that they will be under the influence of addiction, consumers impose strategic self-control when deciding the pricing plan for reading web fiction. They may choose a plan that will help curb their reading level, even if 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, addictive self during consumption.

We first use an analytical model to illustrate this argument. We show that, given a set of model parameters and state of addiction, 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 state of addiction; (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-inconsistency behaviors.

We then construct an econometric model for the empirical analysis by incorporating unobservables and individual heterogeneous preferences. Estimation results show that, out of the three latent segments of consumers, the first segment is more price sensitive and less prone to become addicted than the other two segments. The non-monetary cost of excessive consumption is also higher for this segment. 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 has a small proportion of consumers with extremely high reading amounts and therefore is most likely to choose monthly subscription.

The findings of this study can have important substantive implications not only for public policymakers, but also for producers and distributors of digital content. As an illustration, we use counterfactuals to study the impacts of pricing plans on consumer welfare and platform profit. We find that if the platform were to eliminate the pay-per-chapter plan that helps curb addictive consumption, not only would consumer welfare be hurt, but the platform's profit would also drop by 68%. By contrast, if the platform were to eliminate the monthly subscription plan that encourages more consumption, its profit would increase by 35%, whereas consumer welfare remains almost intact. Finally, we find that adding a hybrid pricing plan to the current plans would not help improve consumer welfare or the platform's profit. Firms may be tempted to choose a pricing plan (e.g. monthly subscription only) that encourages consumption; however, our study shows that, accounting for consumers' motive of self-control, offering a pricing plan (e.g. paid-by-chapter) that helps curb the consumption may be profitable. This type of pricing plan will also benefit consumers.

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

Our study is related to the literature on addictive 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. The addictive behaviors thus can be optimal. 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] With the prevalence of digital media usage, researchers have also investigated the consumption of social media and internet browsing (e.g. Young, 1998; Pelling and White, 2009; Wan, 2009; Kuss and Griffiths, 2011). Consistent with the rational addiction theory, Kwon et al. (2016) find consumers adjust their effort and time spent on mobile apps, based on their addiction level in a forward-looking manner. Our model differs from the above literature because we allow consumers to make plan-choice and consumption decisions in two separate stages. Consumers during the consumption stage can be truly "addicted" as defined in the medical literature (e.g., Nestler, 2013). Because consumption is intrinsically rewarding,

[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.

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 the addictive consumption; therefore, they will take actions to control the behavior when choosing a pricing plan.

Because consumer preferences during the pricing-plan choice and consumption can be different in our model, 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).

Given the ubiquitous evidence for time-inconsistent behaviors, theoretical and empirical researchers have further studied to what extent consumers use self-control strategies to deal with time inconsistency, 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 rationalize individual self-control problems with time-inconsistent preferences when the cost and reward of consumer decisions does not come into realization in the same time period. 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 understand various types of consumer behaviors that classical economics theory fails to explain. 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 gym memberships. 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 the consumption level, which results in utility loss in the long run. Gruber and Köszegi (2001) develop a utility function with time inconsistency, embedded in a framework of addictive 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 rational addiction assumption. Our paper makes both methodological and substantive contributions to this stream of literature. On the methodological side, Caplin and Leahy (2006) show the standard recursive iteration method cannot be applied to time-inconsistency models when more than three time periods exist. Caplin and Leahy (2006) further suggest that equilibrium solutions may not exist and that estimating such models can be difficult. Our paper shows that by specifying time inconsistency as an addictive behavior, consistent with the medical and psychological literature, a unique equilibrium exists in the infinite-horizon model and can be computed using the recursive method. Future researchers could use our method to study consumer addiction and time-inconsistency decisions in a wide range of industries including other digital content and traditional product categories (e.g., tobacco, alcohol, and drugs). For the substantive contribution, we show both addictive consumption behaviors and strategic self-control exist in a digital-content market, and use counterfactuals to study the impacts of marketing actions that affect addictive consumption. The results have a direct impact on consumer welfare and firm profit. Without considering the consumer strategic self-control induced by time-inconsistent preferences, researchers may reach to misleading results.

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 for six months from January to June in 2017. The individuals in the sample are randomly selected from among existing subscribers to the platform. The platform offers a rich collection of web fiction for consumers to read online. Unlike online books provided by Amazon Kindle, web fiction is 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 fiction, which usually refers to fiction with literary merit, web fiction is classified by genres such as fantasy, romance, and science. Readers follow web fiction for entertainment, for a riveting story, and for escape from reality.

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] For the pay-per-chapter plan, readers swipe a bar on their mobile phones to confirm the payment before reading each chapter. For 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 will automatically be switched to pay-per-chapter.

Each period is a month in our analysis. We calculate the number of chapters an individual reads in a month to represent the 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

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

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]

3.1 Addictive Consumption and Self-Control Behaviors in Data

The key premises in our model are that for a significant proportion of consumers, reading web fiction is an addictive consumption behavior, characterized by the following: (1) Past consumption enhances the propensity for current consumption, and (2) due to the intrinsic rewarding mechanism, consumers do not sufficiently consider the costs during consumption, implying time-inconsistent preferences in the consumption and plan-choice stages. Furthermore, our model assumes consumers are aware of the time inconsistency; therefore, when choosing a pricing plan, they will use strategic self-control to curb their consumption.

[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 hoursa month, or almost two hours each day. If the average work day is eight hours, the above

[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 different cutoff dates does not affect the results.

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 on life) of reading could be very significant. A report from eMarketer shows that US adults, on average, spent 379 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 fiction is as "addictive" as consuming other digital contents.

We test whether increasing exposure from past consumption will increase current consumption in our data. Following the addiction model in Becker et al. (1994), we specify the state of addiction 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 state of addiction evolves as the following:

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

To test the relationship between the addiction state and consumption, we run an OLS regression with the reading amount (from second to the last month) as the dependent variable and the addiction state in the previous month as an independent variable. Because the addiction state 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 a

[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

zero-addiction state 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 0.31 and 1. They are all significant at the 0.001 significance level. The results suggest past consumption is positively correlated with future consumption.

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 consumption of a significant proportion 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 do not sufficiently take account of the costs during consumption, they will have incentive to take actions to curb future consumption. The most notable data pattern is the proportion of consumers who overpay under the pay-per-chapter plan and monthly subscriptions, 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 the argument of self-control to work, consumption has to be responsive to the monetary cost. 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 the change in consumption in the six months of the sample period into 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 (1994). Their model does not allow for time-inconsistent preferences. Without the time inconsistency, 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.

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. However, this explanation still cannot address the asymmetric overpay patterns. Indeed, this explanation contradicts the fact that a larger proportion of consumers will overpay for pay-per-chapter. 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.

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 pay-per-chapter, the switching probabilities are consistently higher for 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.[13]

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. The inattention cannot explain such an 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

[13] An alternative explanation similar to the learning story is that consumers are *overoptimistic about their ability* to control their reading amount, or they *underestimate the extent of addiction*, during the consumption stage. The lack of learning as we have demonstrated suggests this is unlikely the case

pricing plan.

Transaction cost as an alternative explanation for the asymmetric overpay patterns suggests 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.

Transaction costs may be 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 reread the chapter, whereas that option is not available for monthly subscription once she stops the subscription. This argument is not true in our data context. Once the consumer pays for one chapter, she can only read it for 30 days. This restriction makes access to any chapter under monthly subscription identical to pay-per-chapter.

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 addictive consumption 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 addictive consumption 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 addiction.

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 state of addiction, 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 state of addiction 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

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

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 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 considering the cost $\gamma \cdot c$. Furthermore, she is forward-looking as she considers how her current consumption can affect her future state of addiction and thus future 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 state of addiction 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:

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

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

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

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.[14]

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

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

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:

Lemma: Based on Proposition 1, with any initial addiction state 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 addiction state, and the y-axis denotes the next-period addiction state. The black solid line is the addiction state, with arrows indicating how it evolves. The steady states are located at the intersection of the path and the 45-degree line, on which the next-period addiction state is the same as the current period's. Under the condition in 1A in the top panel, if the addiction state 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 addiction 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 addiction 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 the addiction and time-inconsistent preferences 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 addiction 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, unobserved factors may exist, and thus the observed data will not be perfectly aligned with model predictions. 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. 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

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

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

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:

$$V_{it}(h_{it}, e_{it}^{0}, e_{it}^{1}) = \max_{s_{it}=\{0,1\}} E_{\omega} u_{it}(c_{it}^{*}(s_{it}, h_{it}), s_{it}, h_{it}) - \mu_i \cdot p_s \cdot 1\{s_{it} = 1\} - \gamma_i \cdot c^{*}(s_{it}, h_{it})$$

$$+e_{it}^{0} \cdot 1\{s_{it} = 0\} + e_{it}^{1} \cdot 1\{s_{it} = 1\}$$

$$+\beta \cdot E_{\omega} E_e V_{i,t+1}\left(h_{i,t+1}, e_{i,t+1}^{0}, e_{i,t+1}^{1}\right), \quad (9)$$

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

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

(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 $k\in\{1,\ldots,N\}$. Based on the distribution assumption of ω_{it} and our model setting, we can derive that given the plan choice s_{it} and current addiction 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 $\frac{\sigma_{w}^{2}}{4a_{i,cc}}$. 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

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

where p is the probability of choosing a pricing plan. The probability of an addiction state 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 $p^s_{mn}(\theta)$ 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 addiction state. That is,* $\lim_{s\to\infty} p^s_{mn}(\theta) = p_n(\theta)$ *exists for any m, n = 1, 2, ..., N.* Let $p(\theta) = (p_1(\theta), p_2(\theta), \ldots, p_N(\theta))$, 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

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

where r is the Euler constant, and

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

(13)

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

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

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:

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

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 addiction state 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 addiction 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 addiction state 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

[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.

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

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

(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, $\{\alpha_c, \alpha_{cc}, \alpha_{ch}, \gamma, \mu, \tau, \sigma_\omega\}$.

Two additional parameters, $\{\beta, \delta\}$, represent the discounting factor and the depreciation rate of the addiction 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 addiction 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 addiction 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 from excessive consumption, γ, is identified by the proportion of consumers who overpay for pay-per-chapter, relative to the proportion of consumers who overpay under monthly subscription. In other words, the identification comes from the asymmetric overpay pattern. The larger the proportion of consumers who read more than 120 chapters per month and do not choose monthly subscription, the larger γ 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 model-estimation results and, based on the results, demonstrate how the reading behavior and pricing-plan choice are heterogeneous across consumers. Next, we use counterfactuals to show how changing the pricing-plan options available to consumers would affect consumer welfare and the platform's profit. The findings help shed light on firms' pricing strategies for product or service categories for which addictive consumption and consumers' strategic self-control behaviors are important.

5.1 Estimation Results

[Table 4 here]

We use latent class analysis 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 class size reaches four. However, the size of the additional consumer segment from a three- to a four-class model is only 0.8%. It does not generate meaningful economic implications. Table 4 reports the estimation results from one-class to three-class models for comparison. All model parameters are statistically significant. Based on the AIC and BIC criteria, we only focus on the estimation results from the three-class model, which are reported in the last panel of the table.

Consumer segments 1 and 2 are similar in size (50% vs. 48%), whereas segment 3 is far smaller (2.5%). 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 segment 2 is positive, implying the addiction state will enhance consumers' marginal utility for consumption. The coefficients for segments 1 and especially segment 3 are also positive, but they are not statistically significant. The coefficient μ for segment 1 is the largest among the three segments, suggesting consumers of this segment are highly price sensitive. The coefficients for segments 2 and 3 are far smaller in magnitude, indicating consumers of these segments pay less attention to the monetary cost during consumption. This finding implies not only that consumers are willing to pay more for reading, but also that the difference in reading amount under the two pricing plans is small. Therefore, choosing pay-per-chapter would curb consumption only minimally. Strategic self-control by choosing pay-per-chapter, therefore, is more effective for consumers of segment 1. Note that μ represents the price sensitivity during consumption, which can be lower than in the pricing-plan-choice stage. In our model, γ captures the difference in a reduced-form way. The larger the difference in the price sensitivity, the higher the estimated γ. Table 4 shows the estimated γ's are very large in magnitude across the three segments, suggesting time-inconsistent preferences exist between the pricing-plan choice and consumption stages, giving consumers a strong incentive to curb their consumption.[16]

Based on the results, we quantify how the three consumer segments differ in the reading behavior and pricing-plan choice. Assuming the addiction state is 0, the average reading amount of segment 1 under pay-per-chapter is 161.1 chapters per month, with a 61% chance of no reading. Under monthly subscription, the reading amount would increase to 216.3 chapters, with a 52% of no reading. This finding indicates the pricing-plan choice strongly influences consumption levels. For segment 2, the reading amount under pay-per-chapter is 219.2 chapters per month, with a 53% chance of no reading. For segment 3, it is about 734 chapters per month, with an 11.2% chance of no reading. Switching to the monthly subscription would not significantly increase consumers' reading amount. In terms of the reading level, consumers in segment 3 are heavy users, whereas the reading amount of segment 1 is the lowest. Regarding the pricing-plan choice, the choice probability of pay-per-chapter of segment 1 is close to 100% under different addiction states. The choice probability of pay-per-chapter among consumers

[16] Note we cannot use γ divided by μ to calculate the dollar amount of the marginal disutility of reading., because μ does not represent the true price coefficient when consumers choose the pricing plan. If the difference in the price sensitivity between the pricing-plan choice and consumption-choice stages contributes $\pi\%$ of γ, for example, the true dollar amount should be $\gamma/(\mu + \pi\% \cdot \gamma)$.

of segment 2 is 48%, whereas that for segment 3 is about 52%. Although overpaying for pay-per-chapter is not very effective for reducing consumption, many consumers in these two segments would still choose the costlier pricing plan because of the large disutility of reading web fiction.

To test the model fitness, we simulate the plan choice and reading amount for each individual in the data for six time periods. We repeat the simulation process with 50 different draws from the stationary distribution and compare the results with data in Figure 3. The upper panel shows 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 average probability of choosing pay-per-chapter in the simulation is 74.74% across six months, whereas it is 74.51% in the data. These comparisons indicate our model predictions fit the actual data pattern very well.

[Figure 3 here]

Our model can also replicate the unique data features we discuss in section 2. Through the simulation, for example, our model predicts that around 6.4% of consumers read less than 120 chapters under monthly subscription, and 45.8% consumers read more than 120 chapters under pay-per-chapter. In the data, the overpaying proportions are 6.6% under monthly subscription and 34.2% under pay-per-chapter. Although our model over-predicts the overpaying ratio for consumers under pay-per-chapter, it replicates the asymmetrical overpay pattern. Furthermore, our model can explain why consumers who overpay for pay-per-chapter are less likely to switch plans than those who overpay under the monthly subscription.

We further test the robustness of the estimation results under various model specifications. We vary the value of δ, the depreciation rate of the addiction state, from 0.1 to 0.9 and re-estimate the 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.

To conclude, our model-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 all consumers in segment 1 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 addictive consumption. By contrast, the strategy is less effective for the other two segments who do not care much about the monetary cost during 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 Counterfactuals

To illustrate the substantive implications from our study, we investigate three counterfactual scenarios. The first two scenarios restrict the pricing plans that consumers can choose, and the last scenario increases consumers' options by introducing a new hybrid plan. We use random draws from stationary distribution calculated from our estimation result as the initial addiction state. In each scenario, we simulate the plan and reading choices of 5,673 (50%) consumers from segment 1, 5,390 (47.5%) from segment 2, and 283 from segment 3, until the reading distribution becomes stable after the policy change.[17] We then compare the change in the monthly average reading amount, consumer welfare (measured by the utility in each month divided by the discount rate), and the platform's profit (measured by the revenue). The results are summarized in Table 5. For easier comparison, we report the percentage changes in each scenario in comparison with that in the original case with both pricing plans.

[Table 5]

We first study how consumers make their reading decisions when their only option is monthly subscription. This scenario is reminiscent of the practice of Netflix,

[17] In practice, we find the reading-amount distribution typically stabilizes after 2~4 time periods. We simulate the data for 12 periods under all scenarios and use the last six months for comparison.

which only offers the monthly subscription plan for watching videos. Consumers can choose to either not read any chapters or to pay for the monthly subscription. The results are in the first panel in Table 5. As expected, consumers under subscription read more. On average, the reading amount for segment 1 increases by 160% per month per consumer. Because the price coefficients of the other two segments are very small, consumers do not vary their reading amount significantly. Across all three segments, the reading amount increases by 63%. Although the fact that consumers read more may look good for the platform, the consumer-welfare and profit analyses tell another story: Without pay-per-chapter, consumers lose a means of strategic self-control. Consumer welfare for segment 1 decreases 43.58%. The decrease in the platform's profit is 68%. The reason that higher reading amounts generate much less revenue is that consumers of all three segments who used to read around 600 to 700 chapters a month and still pay per chapter now have to switch to subscription. As a result, the average revenue per consumer drops from 60~70 RMB to 12 RMB each month.

Next, we study the scenario in which 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 middle panel of Table 5 report the results of this scenario. Because almost all of the consumers in segment 1 choose pay-per-chapter, the policy change has a very limited effect on them. Segments 2 and 3 are more affected, because many of the consumers are forced to switch. However, due to the low price coefficients, their reading amount and consumer welfare do not change much. The profit of the platform increases significantly. Most of the increase comes from segment 2, which is the largest in segment size. Overall, taking away the monthly subscription plan in our counterfactual increases profits by about 35%, whereas removing it has little impact on consumer welfare.

This finding is very surprising. Taking away the monthly subscription option implies the firm forces consumers to impose self-control and thus restricts demand. Our results show, however, that consumers who would have chosen monthly subscription are already very addicted. They will still read a lot and thus overpay under the pay-per-chapter plan; therefore, choosing a pricing strategy that helps prevent addictive consumption can benefit the platform. Not considering addictive behavior can result in the misleading implication that consumers will decrease their reading significantly without the monthly subscription. The difference in managerial implications highlights the importance of time-inconsistent preferences in our study.

In the last counterfactual, the platform introduces a new hybrid price plan, under which consumers would pay a fixed fee and get a discounted unit price for consumption. Such plans are becoming increasingly popular among digital-content providers. For example, Amazon charges an annual fee for Prime membership. Its members then have to pay to rent or purchase most Prime Video movies. The hybrid plan in our counterfactual charges 6 RMB each month and then a discounted price of 0.05 RMB per chapter. We assume the original pay-per-chapter and monthly subscription plans remain unchanged. Therefore, consumers have more choice options in this scenario.

We start from the same stationary distribution and solve the consumer dynamic programming with three options. Results are reported in the last three rows of Table 5.

We find that all consumers in segment 1 stay with the pay-per-chapter plan. To them, the new plan is not attractive because it would undermine their ability to constrain consumption. In our counterfactual, the new plan draws 34% from segment 2 and 31% from segment 3, which adds up to around 17% of the total sample size. However, due to the low price sensitivity, consumers who make the switch do not significantly change the reading amount. The profit of the platform slightly improves by 0.03% and the consumer welfare by 0.18%, mostly coming from consumers in segment 3. Overall, the impact of introducing the new hybrid plan is very limited.

[Table 6 here]

Results reported in Table 5 are based on the latent classes that we do not observe from the data. To demonstrate the impact of the counterfactual policies on different types of consumers, Table 6 reports the results based on their reading amount, which, under the stationary distribution assumption, is close to their addiction state. Overall, the table shows that if the platform were to remove the pay-per-chapter option, the reading amount of light readers would significantly increase. Their welfare would be reduced, and the decrease in the platform's profit would come from heavy users. By contrast, if the platform were to remove monthly subscription, neither the reading amount nor the welfare across consumer types would change significantly. The increase in the platform's profit would mainly come from heavy users. Finally, adding the hybrid plan would have little impact across consumer types.

6. Conclusion

In this paper, we study how consumers overpay for reading web fiction as a means of strategic self-control in the context of addictive digital-content 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 addictive consumption and time-inconsistent preferences, in which 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, with one segment being more price sensitive than the others. This segment overpays for pay-per-chapter because the high cost of reading can effectively work as a "commitment device" to restrict future consumption. In the counterfactuals, we show that offering only pay-per-chapter would have little impact on consumer welfare but would vastly improve the platform's profit. Switching to a subscription-only pricing model would significantly decrease consumer welfare and the platform's profit. Introducing a hybrid plan with a lower subscription fee and unit price for each chapter would have a limited.

Our study contributes both theoretically and empirically to the literature for studying consumer addictive consumption 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 the monthly subscription and pay-per-chapter plans. The data limitation also makes it difficult to separately identify the monetary and non-monetary costs due to the excessive consumption, when consumers are making the pricing-plan choice. Currently, both costs are aggregated in a reduced-form way. 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. To test the model assumptions, one can use survey data to investigate what underlying mechanisms are driving 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: Estimation Results

beta=0.98 Observation=68,706

		Segment 1	s.e.				
	a_c	-44.88	0.25				
	a_{ch}	0.76	3.22E-03				
	μ	5.51	3.97E-03				
	γ	2425.35	5.53				
1-Class	$log\sigma_w$	6.62	2.04E-03				
	$log\sigma_e$	8.24	2.16E-03				
	Class size	1.00	NA				
	Log likelihood	-440288.20	AIC	880598.4	BIC	880698	
		Segment 1	s.e.	Segment 2	s.e.		
	a_c	-154.26	6.93	-125.97	2.31		
	a_{ch}	0.70	3.12E-03	0.97	3.06E-03		
	μ	9.36	0.25	1.60E-03	4.40E-04		
	γ	2483.56	147.91	1625.41	73.98		
2-Class	$log\sigma_w$	6.52	0.00				
	$log\sigma_e$	8.55	0.05				
	Class size	0.54	2.57E-03	0.46	NA		
	Log likelihood	-430661.70	AIC	861355.4	BIC	861501.454	
3-Class		Segment 1	s.e.	Segment 2	s.e.	Segment 3	s.e.
	a_c	-44.37	16.80	-38.2	3.72	719.34	0.04

a_{ch}	0.79	15.93	0.78	0.2	1.40	8.83
μ	127.74	0.18	0.04	6.41E-05	0.19	0.89
γ	2345.88	238.00	2269.98	219.38	2673.24	1239.77
$log\sigma_w$	6.84	3.18E-03				
$log\sigma_e$	8.53	0.58				
Class size	0.50	4.78E-03	0.48	4.83E-03	0.03	NA
Log likelihood	-425141.30	AIC	850324.6	BIC	850516	

Table 5: Counterfactual Results

	Monthly Subscription Only			
	Segment 1	Segment 2	Segment 3	Overall
Reading amount (chapter per month)	160.37%	0.02%	7.15E-06%	63.36%
Firm revenue	-59.79%	-77.23%	-85.68%	-68.17%
Consumer welfare	-43.58%	-0.32%	-0.02%	-21.51%
	Paid-by-chapter only			
	Segment 1	Segment 2	Segment 3	Overall
Reading amount (chapter per month)	0.00%	-0.02%	-5.60E-03%*	-0.01%
Firm revenue	0.00%	68.65%	90.78%	34.99%
Consumer welfare	0.00%	0.00%	-0.24%	-0.005%
	Adding a Hybrid plan			
	Segment 1	Segment 2	Segment 3	Overall
Reading amount (chapter per month)	0.00%	7.08E-5%	-2.68E-05%*	3.61E-05%
Firm revenue	0.00%	-0.04%*	0.86%	0.03%*
Consumer welfare	0.00%	0.19%	2.90%	0.18%

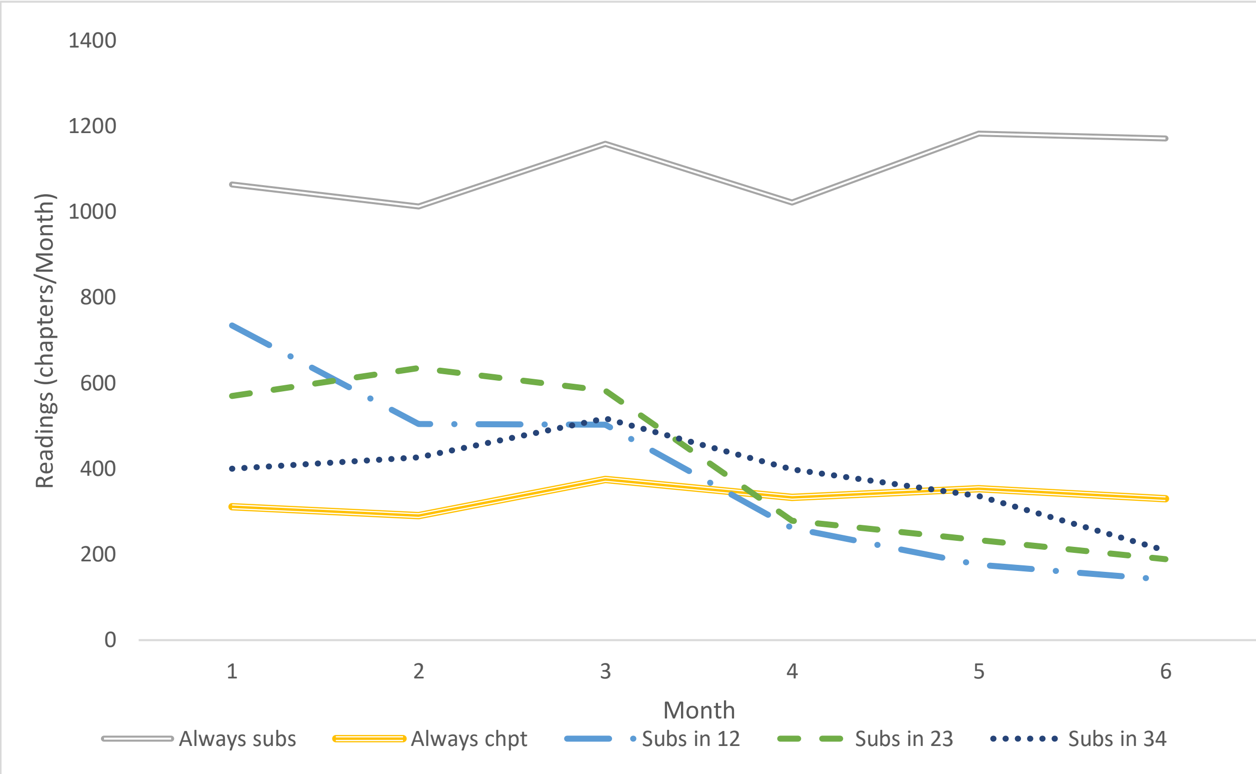
*:Not significant with 95% CI

Table 6: Counterfactual Results by Reading Quantiles

	Monthly Subscription Only		
Quantile	Reading	Welfare	Revenue
0~20%	117.7200%	-104.5300%	54.5700%
20%~40%	67.3900%	-54.2900%	-44.3800%
40% ~60%	40.6400%	-30.2600%	-68.5900%
60%~80%	17.2800%	-10.4200%	-80.2500%
80%~100%	3.1400%	-0.3500%	-86.0800%
	Pay-per-Chapter Only		
Quantile	Reading	Welfare	Revenue
0~20%	-0.0050%	0.0050%	-7.8300%
20%~40%	-0.0040%	0.0040%	10.6100%
40% ~60%	-0.0050%	0.0040%	21.1800%
60%~80%	-0.0050%	0.0030%	33.0000%
80%~100%	-0.0020%	0.0020%	53.3500%
	Adding Hybrid Plan		
Quantile	Reading	Welfare	Revenue
0~20%	-0.0001%	0.0001%	-0.1100%*
20%~40%	2.28E-06%*	0.0000%	-0.0600%*
40% ~60%	3.40E-05%*	-1.82E-05%*	0.07%*
60%~80%	2.06E-05%*	-1.22E-05%*	0.0900%
80%~100%	0.0000%	0.0000%	0.2240%

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

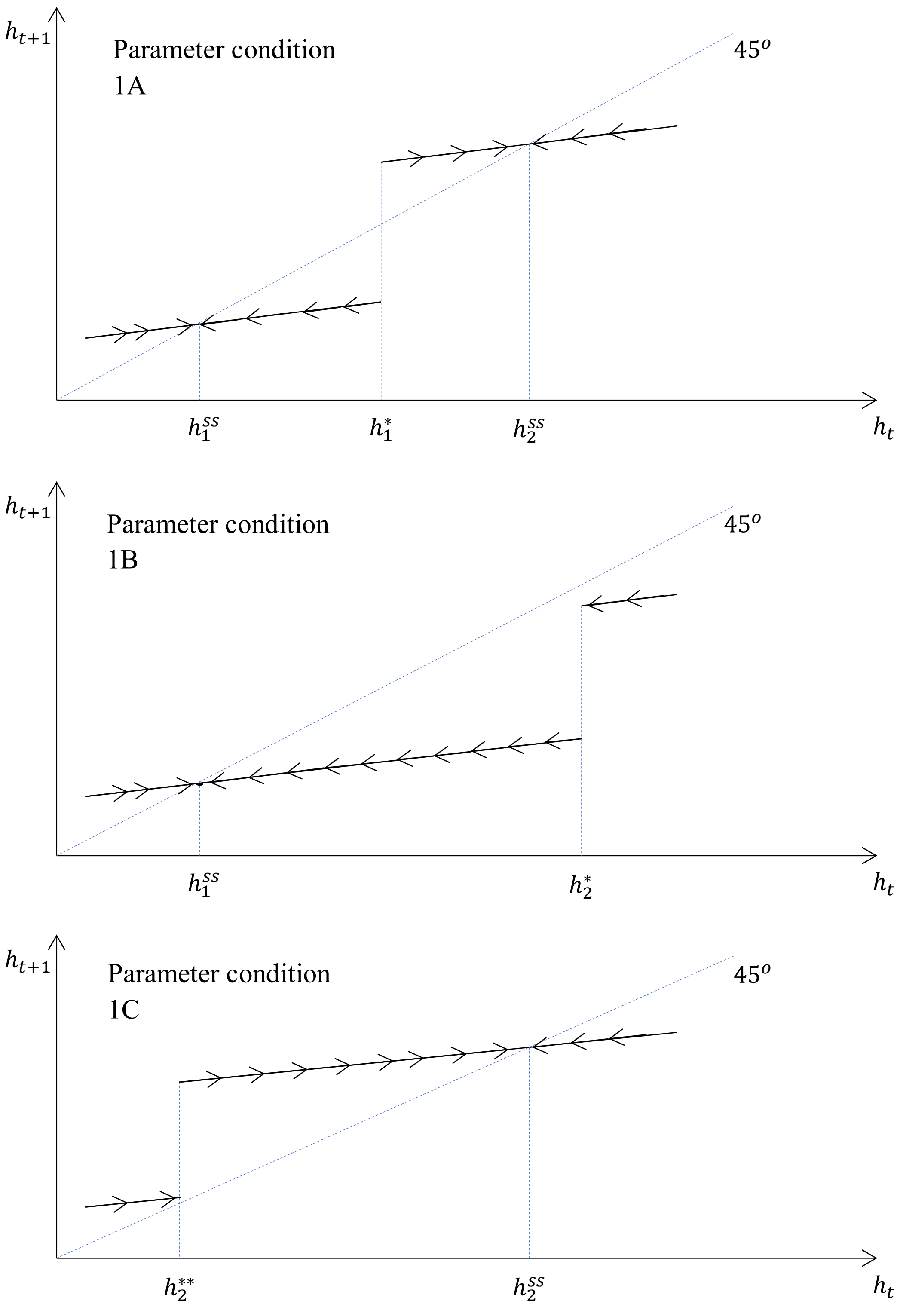
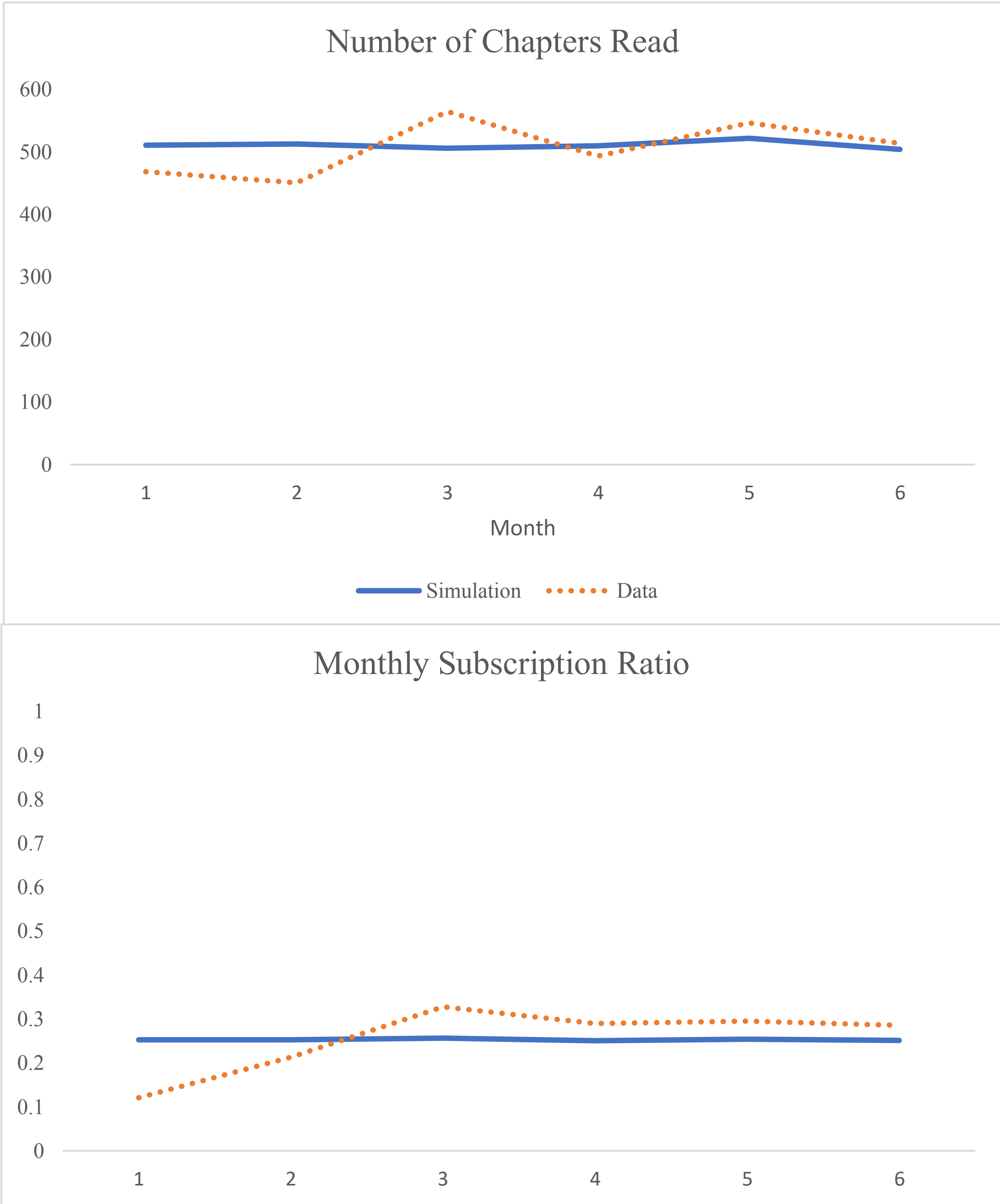


Figure 3: Model Fit



Appendix

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 $u_s(h) \equiv u_p(c^*(s,h),s,h) \; - \mu p_s 1\{s=1\}$

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

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

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

[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 $c^* > 0$

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

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

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

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

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

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

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

$$W_0(h) = a_0 h^2 + b_0 h + c_0 \qquad [9]$$

$$W_1(h) = a_1 h^2 + b_1 h + c_1.$$

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

$$u_0(h) = Ah^2 + B_0 h + C_0 \qquad [10]$$

$$u_1(h) = Ah^2 + B_1 h + C_1$$

$$h' = eh + f_0$$

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

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

$$a_0 h^2 + b_0 h + c_0 = Ah^2 + B_0 h + C_0 + \beta[a_0(eh + f_0)^2 + b_0(eh + f_0) + c_0], \forall h.$$

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 initial addiction 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-period addiction 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 $h_1^* > h_2^{ss} > h_1^{ss}$,

$$V(h) = \begin{cases} \sum_{t=0}^{T_h} \beta^t u_1(h_t) + \beta^{T_h+1}(a_0 h_{T_h+1}^2 + b_0 h_{T_h+1} + c_0) & if\ h \geq h_2^* \\ a_0 h^2 + b_0 h + c_0 & Otherwise \end{cases},$$

where

$$h_0 = h$$

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

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

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

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 initial addiction 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,

$$u_1(h) + \beta(a_0h_2^2 + b_0h_2 + c_0) = u_1(h) + \beta w_0(h'') \geq \ w_0(h) = a_0h^2 + b_0h + c_{0.}$$

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 any addiction 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-period addiction states will be h'', again we discuss two cases in which $h'' \geq h_2^*$ and $h'' < h_2^*$:

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

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

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

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

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

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 $i, j = 1,2,, \ldots, H, \exists\, n_0$ 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 of addiction 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.