DYNAMIC PRICING STRATEGY FOR NEW PRODUCTS IN THE PRESENCE OF CONSUMER-TO-CONSUMER RESALE MARKET

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Dynamic Pricing Strategy for New Products in the Presence of Consumer-to-Consumer Resale Market

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CERTIFICATE OF ORIGINALITY

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Abstract

As one of the fastest-growing segments in retail industry, consumer-to-consumer (C2C) resale markets stand out to become a mainstream online shopping experience. One report reveals that 64% of shoppers shift spending away from purchasing new items to look for used ones, and 82% of consumers weigh the resale value of an item before purchasing it. The presence of C2C resale markets expands the purchase options for consumers, granting them the liberty of deciding when to purchase, what to purchase, and where to purchase, forcing enterprises to adjust their selling strategies for new products to suit the market change thus occurs. In practice, enterprises are adapting to the rise of C2C resale markets by aiming to provide consumers with resale revenue, entice them to make repeat purchases, and generate profits. Simultaneously, consumers face uncertainty about the value of used products in C2C resale transactions. They strategically act as individual suppliers, postponed demanders, or repeat purchasers. These behaviors interactively influence the demand for both new and used products, thereby affecting the role of the C2C resale platform (CRP) in the marketplace. However, existing literature suggests that enterprises should discourage consumers from purchasing on CRPs, as these platforms expose enterprises to direct competition and cannibalize new-product demand. In addition, the lack of exploration into the product and consumer characteristics specific to the C2C resale market makes it challenging to provide clear theoretical guidance for business practices. Therefore, addressing the gap between theoretical research and practical businesses regarding the prevalence of C2C resale markets is essential.

This thesis analytically develops a series of two-period game-theoretical models to investigate the optimal dynamic pricing strategy for new products. We explore how product and consumer characteristics in the C2C resale market influence the transactions of new and used products. Additionally, we examine the impacts of the C2C resale market on enterprises, consumers, platforms, society and the environment. The objective is to tackle the operational challenges that C2C resale markets pose to enterprises within the supply chain and to optimize their marketing strategies. The innovative contributions, primary findings, and managerial implications of this thesis are as follows:

1. This study proposes the optimal dynamic pricing strategy for new products considering product characteristic in the presence of C2C resale markets. We demonstrate that the C2C resale market leads to an expansion in total new-product demand. Moreover, we identify the conditions under which retailers can profit from C2C resale transactions and clarify how C2C resale markets negatively affect the environment. The findings are as follows: (a) The intertemporal price discrimination adopted by retailers for new products is influenced by the extent of heterogeneity in used products. When the heterogeneity of used products is high, retailers tend to exacerbate intertemporal price discrimination; (b) The existence of C2C resale transactions results in an increase in the total demand for new products, referred to as the demand-expansion effect. The demand-expansion effect aggravates the environmental impact brought by C2C resale markets, counteracting the original intention of creating an efficient and sustainable consumption mode to eliminate negative environmental impacts; (c) Retailers can benefit when consumers perceive certain discrepancies in the values of new and used products, whereas they may experience revenue loss if the CRP charges a high commission rate; (d) The availability of the disposal option with positive salvage value causes the retailer to benefit less from CRP, due to the competition between the disposal channel and the C2C resale channel for

consumers to deal with used products. Contrasting with extant literature, our research incorporates consumers' heterogeneities in their valuations of both new and used products. We emphasize the relationship between secondhand product heterogeneity and intertemporal price discrimination for new products. The result suggests that enterprises can profit from managing new-product selling over periods in parallel to support used-product transactions on CRPs, rather than competing with the platform for demand. Additionally, we find that enterprises can exacerbate intertemporal price discrimination for new products to encourage consumers' strategic waiting in the presence of C2C resale markets. These findings enrich the literature on optimal dynamic pricing strategy for new products by offering novel insights.

2. This study proposes the optimal dynamic pricing strategy for new products considering consumers' utility dependence in the presence of C2C resale markets. We reveal the impact of consumers' utility dependence in shaping market segmentation. Moreover, we identify the conditions under which CRPs can create a win-win situation for all market participants. We also provide theoretical guidance for retailers on collaborating with CRPs. Utility dependence refers to an additional utility experienced by consumers due to their reliance on retailers' products. It may lead consumers to repurchase new products from retailers after ridding of their used items on CRPs. The findings are as follows: (a) As a result of enhanced demand management, consumers' utility dependence mitigates the direct competition posed by CRPs to retailers. By leveraging the heterogeneities in consumers' utility dependence and perceived quality levels of used products, retailers can effectively exacerbate intertemporal price discrimination. This pricing strategy allows retailers to alternate and balance the demands for new and used products, producing an enhancement effect and a cannibalization effect on revenue; (b) Retailers and consumers are likely to either benefit or get worse simultaneously from the rise of the C2C resale market, thus to have

aligned preferences over the establishment of this new market entity. Whenever both retailers and consumers are better off, the commission revenue reaped by CRPs strengthens the gain in social welfare, leading to a win-win situation for all market participants. Additionally, the rise of CRP is more likely to benefit the society than individual consumers and the retailer; (c) Retailers can benefit from self-managing a CRP when the marginal operating cost is low. However, offering price discounts to consumers who participate in C2C resale transactions is not an efficient revenue-enhancement strategy, as it reduces new product sales and negatively affects retailers' revenue. Contrasting with extant literature, this study uncovers the strategic role of consumers' utility dependence in the context of C2C resale markets. We clarify the intricate impacts of C2C resale markets on consumers, enterprises, platforms, and society. Our work contributes to the literature on secondary markets by conducting a comprehensive investigation into the C2C mode and providing theoretical guidance for enterprises on adjusting prices in response to consumers' utility dependence.

3. This study proposes the optimal dynamic pricing strategy for new products considering consumers' time inconsistency in the presence of C2C resale markets. We construct a dynamic pricing model that incorporates consumers' time-inconsistent behavior and sequential product upgrades. Moreover, we examine the impacts of time inconsistency on the demands for both new and used products across periods. We also identify an assistant effect and a deterrent effect brought by consumers' time inconsistency on the optimal release strategy for product upgrades by manufacturers in the existence of C2C resale markets. Consumers' time-inconsistency arises from the temporal disparity between immediate payments and delayed payoffs, leading to misestimations of their intertemporal utilities. The findings are as follows: (a) Despite consumers' time-inconsistent behavior may intensify the competition brought by CRPs, manufacturers can still profit by leveraging C2C resale markets to alle-

viate the negative impact of consumers' misestimation of intertemporal utilities; (b) The presence of time inconsistency generates three distinct demand effects on market segmentation: demand vanishing, demand expansion, and demand migration; (c) Manufacturers need to carefully evaluate the differentiation level between product versions to determine whether to release the upgraded version. Specifically, if the upgraded version closely resembles the original version in experiential features, manufacturers can profit from releasing product upgrades in the existence of time inconsistency. Contrasting with extant literature, this research incorporates consumers' time-inconsistent behavior into the theoretical framework of C2C resale markets. Our results emphasize the significant impacts of time inconsistency on enterprises' dynamic pricing strategy for new products and optimal release strategy for product upgrades in the presence of C2C resale markets. The findings offer valuable insights for enterprises to strategically navigate their decisions in response to the challenges posed by consumers' time inconsistency.

Publications Arising from the Thesis

1. **Pang Chen**, Li Gang, Jiang Li. (2023). "Leveraging Strategic Consumer Behavior in Consumer-to-Consumer Resale: From Economic and Environmental Perspectives", *Omega (Oxford), 120,* 102924.

2. **Pang Chen**, Jiang Li, Li Gang. (2024). "Cannibalization or Enhancement: Effects of Consumer-to-Consumer Resale with Consumers' Utility Dependence", *International Journal of Electronic Commerce, 28*(3), 416-446.

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Chapter 1

Introduction

1.1 Research Background

1.1.1 Impacts of C2C Resale Market on Business Practices

As one of the fastest-growing segments in retail, consumer-to-consumer (C2C) resale markets facilitate individual users to redistribute and purchase used items, evolving into a global phenomenon and becoming a lifestyle choice. As depicted in Figure 1.1, the total volume of China's secondhand e-commerce transactions is expected to reach 548.65 billion yuan in 2023, representing a year-on-year growth of 14.25% (ECRC 2023). Similarly, the U.S. e-commerce resale market also continues its momentum into 2024 (eMarketer 2023), with a growth rate of 8.49%, and its total volume is expected to reach $107.2 billion by 2026, as illustrated in Figure 1.2.

C2C resale platforms (CRPs), as the predominant form of practice in C2C resale markets, are surging to be mainstream online shopping destinations, covering a diverse range of product categories. Table 1.1 summarizes representative CRPs for different product categories. Taking "Xianyu" as an example, it stands as the largest CRP in China, originating in 2014. Not only has xianyu emerged as the favorite CRP among

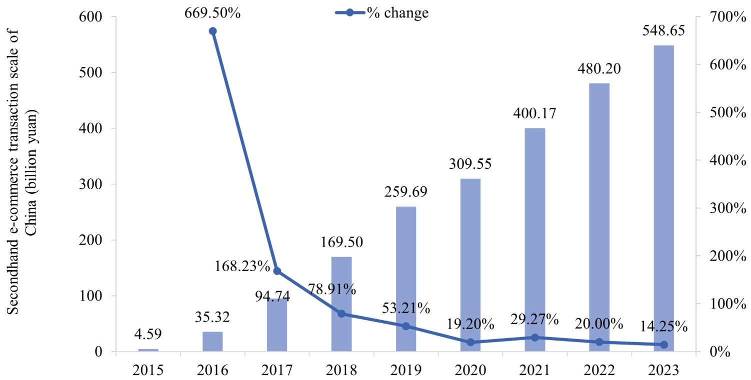


Figure 1.1: Secondhand e-commerce transaction scale and trends of China, 2015-2023

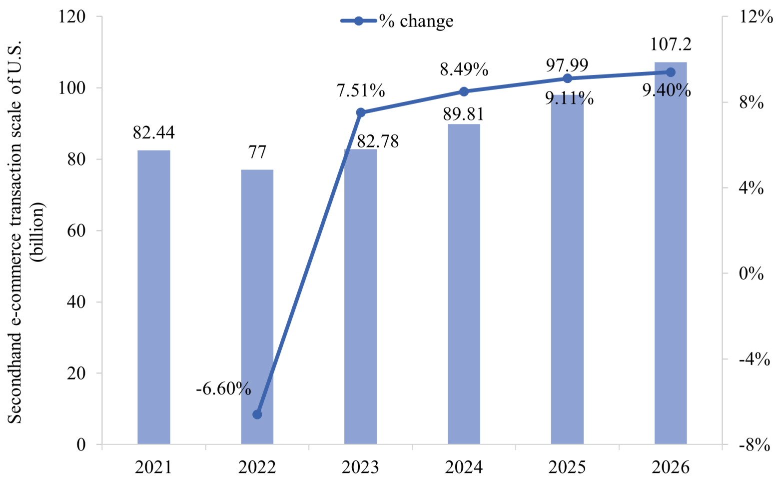


Figure 1.2: Secondhand e-commerce transaction scale and trends of U.S., 2021-2026

young Chinese consumers, but it has also evolved into a vibrant community. The platform possesses over 500 million users, with 65% of its active users belonging to Gen Z (36Kr 2023).

Consumers are embracing the trend of C2C resale markets and shopping more secondhand than ever before. Supported by upgraded technology, C2C resale markets have become increasingly accessible, reliable, and appealing to consumers, particularly the younger generation (eMarketer 2023). ThredUP (2024) indicates that 52% of

Table 1.1: Examples of representative CRPs

Product category	Domestic platforms	Overseas platforms
General category	Xianyu, Zhuanzhuan, Paipai	eBay, Craigslist, Carousell, leboncoin, Mercari, OfferUp
Consumer electronics	Aihuishou, Zhaoliangji, Huishoubao, Paijitang	Swappa, Gazelle
Apparel	Hongbulin, Goshare2	ThredUP, Poshmark, The RealReal, Depop, Etsy
Automotive	Guazi, Renrenche, Youxinpai	Autotrader, Carvana, Bring-A-Trailer
Books	Kungfz, Duozhuayu	BookDeal, BooksRun, AbeBooks
Social media	WeChat	Facebook marketplace
Brand-owned resale	DJI Official Refurbished	COS Resell, IKEA Circular Hub, Ganni Repeat, Levi's Secondhand, Patagonia Worn Wear, SHEIN Exchange

consumers shopped secondhand apparel in 2023, compared to 65% of Gen Z and Millennials. The prevalence of this trend can be attributed to consumers strategically engaging in secondhand shopping, driven by both economic necessity and shifting values (ThredUP 2019). iResearch (2023) reports that the proportion of consumers in China who prioritize purchasing products with better price-performance ratio has reached 84% in 2023. 82% of Gen Z weigh the resale value of an item before purchasing it, and 64% of shoppers shift spending away from purchasing new items to look for used ones (ThredUP 2023b). Figure 1.3 illustrates the user base in China engaged in secondhand e-commerce transactions, which reached 620 million in 2023, reflecting a year-on-year growth of 33.9% (ECRC 2023).

Inspired by these practical observations, we conducted a survey by SoJump and collected 1083 responses to capture consumers' thoughts on secondhand reselling

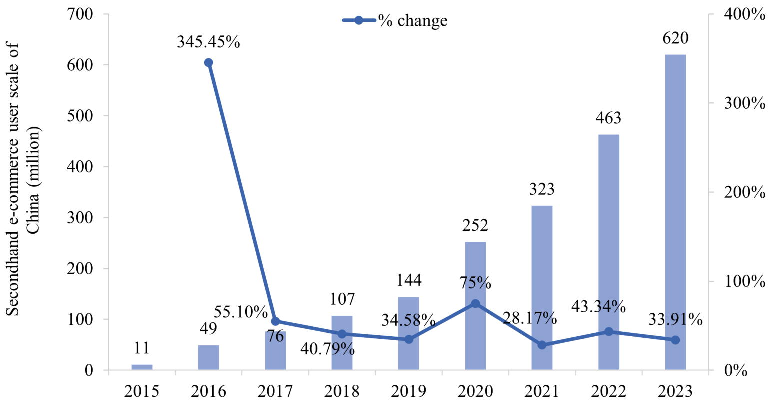


Figure 1.3: Secondhand e-commerce user scale and trends of China, 2015-2023

(see Table 1.2). Appendix D provides details of the survey. The results indicate that 68.3% of the respondents have participated in the transactions of secondhand items, either as suppliers or demanders. Among them, 30.1% of the respondents were involved only through online channels, 28.9% participated in both online and offline transactions, and 9.33% only utilized offline channels for their secondhand transactions. The primary reasons for engaging in secondhand transactions are "*Cheaper price*" (64.59%), "*The quality and usage of the used product meet my requirements*" (31.76%), "*Reap resale revenue*" (28.24%), and "*Convenient resale channel*" (23.11%). Moreover, popluar product categories involved in past secondhand transactions include "*Books*" (48.92%), "*Consumer electronics*" (39.86%), "*Apparel, shoes, and accessories*" (27.16%), "*Furniture and home improvement*" (26.08%), and "*Home appliances*" (25.41%).

Table 1.2: Summary of the survey results on consumers' secondhand transactions

Statement	Percentage of responses that agree
(A) Previously participated in secondhand transactions (including as suppliers and demanders):	
- Only online	30.10%
- Both online and offline	28.90%
- Only offline	9.33%
(B) Previously participated in online secondhand platforms:	
- Xianyu	91.72%
- Zhuanzhuan	11.04%
- Duozhuayu and Kongfz	9.82%
- Aihuishou and Huishoubao	8.90%
(C) Previously participated in offline secondhand platforms:	
- Peer-to-peer exchange	36.63%
- Secondhand marketplace and vintage store	26.73%
- Secondhand bookstore	23.76%
- Offline donation	19.8%
- Secondhand car dealer	12.87%
(D) The reason why participates in secondhand transactions:	
- Cheaper price	64.59%
- The quality and usage of the used product meet my requirements	31.76%
- Reap resale revenue	28.24%
- Convenient resale channel	23.11%
- Pursuit of environmental sustainability	16.49%
(E) Previously transacted secondhand products in the following categories:	
- Books	48.92%

to be continued

Table 1.2 Continued

Statement	Percentage of responses that agree
- Consumer electronics (e.g., digital camera, smart phone, computers, etc.)	39.86%
- Apparel, shoes, and accessories	27.16%
- Furniture and home improvement (e.g., bookshelf, dining sets, bedding, curtains, etc.)	26.08%
- Home appliances (e.g., washer and dryer, refrigerator, etc.)	25.41%
- Sports gears (e.g., tennis racket, football, bikes, etc.)	14.86%
- Beauty and personal care (e.g., makeup, skin care, hair care, etc.)	12.84%
- Automotive	10.54%
- Keepsakes (e.g., blind box, autographs, etc.)	10.54%

Forward-thinking enterprises are adapting to the trend ushered in by the rise of C2C resale markets to attract young and price-conscious shoppers, increase consumer loyalty, and generate profits. Nearly 75% of retail executives say they have or are open to offering a resale program to their consumers, wherein 52% of them believe that resale will be a crucial aspect of their business within five years (ThredUP 2021). As illustrated in Figure 1.4, branded resale programs for apparel experience sustained growth in 2023 with 163 brands establishing their resale outlets, representing a 31% year-over-year increase (ThredUP 2024).

Brands offer resale programs for several reasons: to achieve sustainability objectives (87%), generate revenue (80%), and acquire more consumers (67%). Of these, 67% anticipate that resale programs will yield a significant (¿10% of total) revenue stream for the company within five years (ThredUP 2024). There exists numerous real-life examples of business practices. COS, an apparel retailer affiliated with H&M, has created a C2C resale marketplace called ‘COS Resell’, which enables consumers

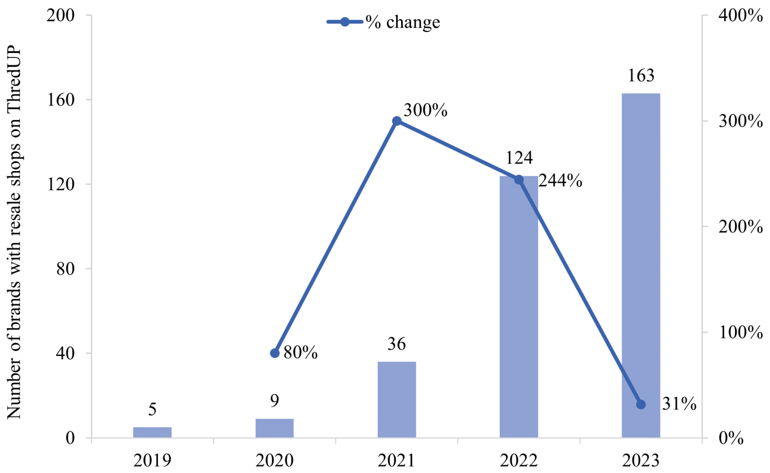


Figure 1.4: ThredUP resale brands volume and trends, 2019-2023

to transact used COS products to prolong product lifespan and open new business opportunities (COS 2023; H&M 2020). IKEA launches programs 'Circular Hub' and 'Re-shop and Re-use' initiative to create spaces in consumers' homes for new IKEA items, inform consumers to extract resale value, and commit to environment sustainability (IKEA 2024a,b; Matzler et al. 2014). Ganni, following the trend that brands are looking to take ownership of the growth in secondhand fashion, launches its resale platform 'Ganni Repeat', which allows consumers to sell and purchase pre-loved pieces in a C2C model (Vogue 2022). Patagonia's 'Worn Wear' allows consumers to resell worn Patagonia clothing in exchange for retail credit up to \$100 (Cortez 2021; Patagonia 2024). Levi's, the world's leading denim maker, offers consumers who resell their products with coupons ranging from \$5 to \$35, thereby extending the lifespan of their denim products and keeping them in circulation (Cortez 2021; Levi's 2024). SHEIN, a rapidly expanding online retailer launches 'SHEIN Exchange', an integrated CRP for buying and selling pre-owned SHEIN products. SHEIN Exchange aims to satisfy community demand by providing a one-stop destination where consumers can actively engage in product circularity (SHEIN 2022).

Inspired by these observations, we conducted five interviews with practitioners in retail industry, to gain an in-depth understanding of resale business, as shown in E.

Our interviewees all commented that the C2C resale market has become widespread in recent years. One notable response is that: "Firms are catering to the trend of consumers' desire for participating in secondhand transactions. By facilitating consumers to resell their used products, we can entice them to repeatedly purchase new products from us. However, the ways whereby firms benefit from C2C resale markets remain unclear." Another response is that: "Firms are balancing the impacts brought about by secondhand channel. On one hand, we are afraid of secondhand channel's cannibalization of new-product demand by competing with the incumbents. On the other hand, we are attracted by the potential opportunity that secondhand channel can expand the market by generating extra values to consumers from reselling." The feedback from the interviews reveals arguable issues about the role of C2C resale markets and indicates that industries still need guidance on how to adapt their operations to the presence of C2C resale markets.

1.1.2 Consumer Behaviors Influence Enterprises' Operational Decisions

The existence of C2C resale markets promotes the reallocation of socialized and decentralized resources by establishing universal connections among individual supply and demand (Belk 2014). Various factors affect consumers' purchasing behavior in C2C resale transactions, including the uncertainty about used-product value, choices on intertemporal purchases, utility dependence due to repeat purchases, and time inconsistency stemming from the misestimation of intertemporal utilities.

In the C2C resale market, used products are supplied by individual consumers without uniform quality regulation. Consequently, consumers face uncertainty about the value of used products on CRPs, leading to their heterogeneous and ex-ante unknown perceived value of secondhand products. Specifically, consumers who resell used products can only observe their exact value after using the product, while those purchasing used products may do so until sellers list the products on CRPs. Our survey findings indicate that 81.4% of the respondents agree that the quality and depreciation level of secondhand products influence their purchasing decisions, whereas 59.2% of the respondents express difficulty in accurately estimating the quality and deprecation level of secondhand products. Besides, 58.9% of the respondents believe the perceived quality level of used products matches its transactions price, while 34.7% are uncertain, and 6.36% think it does not. However, existing literature assumes a homogeneous and ex-ante known perceived value of used products among consumers (Yin et al. 2010; L. Jiang et al. 2017), which does not apply to the practices based on the C2C mode.

The presence of C2C resale markets subtly influences consumers' intertemporal purchase decisions. On one hand, it induces strategic waiting by creating more purchase options for postponed consumers, who can purchase used products instead of new ones or purchase new products at a possibly lower price. For instance, 60% of consumers claim that shopping for secondhand apparel gives them better deals (ThredUP 2024). On the other hand, some consumers opt to purchase new products early and resell them later, forming individual supplies on CRPs, to earn resale revenue (Risberg 2014). For example, in 2023, 69% of consumers who resold apparel did so to generate extra income and 47% of consumers emphasized that resale value is an important consideration when purchasing apparel (ThredUP 2024). As such, we characterize consumers' strategic waiting and individual supply behaviors in our models to investigate their effects on market formation.

After using a firm's product, consumers may find it easier to use other products offered by the same firm. For instance, Apple Inc. maintains consistent iOS interfaces across its product series to facilitate consumer use. A 2019 SellCell survey indicates that 90.5% of iPhone users continue purchasing its models when replacing smartphones (Statista 2019). Similarly, the experience that a consumer gains by driving vehicles can lead to repurchases in the automotive industry (J.D. Power 2020), turning consumers into habitual buyers. A report reveals that 80% of used-car and 76% of new-car owners repeatedly purchase the same car type in their next transaction (AutoTrader 2016). The reason behind this is that repeatedly purchasing products from the same firm enables consumers to save time and effort in familiarizing themselves with the sophisticated functions and possess the gratification from owning new products consecutively. Scholars have defined this behavior as "utility dependence" (Erdem 1996; Moshkin & Shachar 2002). In the existence of C2C resale markets, if utility dependence exists among forward-looking consumers, the option of 'purchasing early - reselling used products and repurchasing new products' becomes more favorable. It significantly affects the supply of secondhand products on CRP and the demand for new products, forcing the enterprise to adapt intertemporal prices to suit the market change thus occurs. Despite prior literature indicates that utility dependence significantly influences consumers' purchasing decisions. However, there is a lack of studies regarding its effects in C2C resale transactions.

Consumers often make quick purchasing decisions of new products, driven by immediate gratification, while later realize that the purchased product has limited usage value or requires effort to fully utilize. This behavior manifests in a temporal distribution of payoffs and payments, where the payments of an action are immediate, but any payoffs are delayed through consumption over time, and it can be explained by the theory of time inconsistency (Meyer et al. 2008; D. V. Thompson et al. 2005; Hoch & Loewenstein 1991). The temporal disparity in payoffs and payments leads to consumers' misestimation of their utilities over time, resulting in inconsistencies in their intertemporal decision-making. With the emergence of C2C resale markets, consumers can align with their time-inconsistent tendencies. On one hand, consumers can spend less by purchasing used products. For instance, 38% of consumers state that they shop secondhand to afford higher-end brands in 2023 (ThredUP 2024). On the other hand, anticipating the availability of CRPs as an outlet for underutilized products, consumers can mitigate the risks associated with impulsive purchasing and product uncertainty. Nevertheless, the existence of time inconsistency discourages potential consumers from purchasing, as they fail to correctly anticipate future behavior. This phenomenon is exacerbated by the presence of CRPs, which poses a threat to the enterprise as they compete for consumers, hence harming the enterprise's profitability. The impact of consumers' time-inconsistent behavior on enterprises' operational decisions in the presence of C2C resale markets is worth investigating.

1.2 Research Questions

The decision for enterprises to embrace C2C resale markets involves weighing trade-offs. The convention suggests that incumbents should deter consumers from purchasing on the CRP (P. Desai et al. 2004; Yin et al. 2010). The reason is that by facilitating transactions of secondhand products among individual consumers, CRPs expose enterprises to direct competition, cannibalizing new-product demand by discouraging consumers purchasing new products (MacKenzie et al. 2013). However, in reality, forward-looking enterprises recognize and support consumers' desire to redistribute used products, and even manage resale markets to follow the trend (Matzler et al. 2014). The rationale lies in the potential opportunities that CRPs offer to enterprises, ushering in new demands (Robertson 2023). On one hand, CRPs can serve as a powerful way to attract new consumers who prioritize environmental sustainability or have budget constraints. On the other hand, CRPs provide existing consumers with a channel to rid of used products so that they can repurchase new products afterwards. Consumers are more willing to spend if they know they can easily resale items later and fetch the resale value (Risberg 2014).

The presence of C2C resale markets expands the purchase options for consumers, granting them the liberty of deciding when to purchase, what to purchase, and where to purchase, forcing enterprises to adjust their selling strategies for new products to suit the market change thus occurs. Consumers strategically act as individual suppliers, postponed demanders, or repeat purchasers. These behaviors interactively influence the demand for both new and used products, thereby affecting the role of CRPs in the marketplace. Moreover, as mentioned in Section 1.1.2, product characteristics and consumers' behavioral factors play a vital role in C2C resale activities. The lack of exploration into the product and consumer characteristics specific to the C2C resale market makes it challenging to provide clear theoretical guidance for business practices. Addressing the gap between theoretical research and practical businesses regarding the prevalence of C2C resale markets is essential. The primary research questions of this thesis are as follows.

First, by considering product characteristics such as depreciation and salvage value in secondhand products, we focus on downstream retailers as the research object to investigate: 1) Given the presence of homogeneous or heterogeneous secondhand products in the C2C resale market, or when secondhand products have a positive disposal value, how should retailers dynamically set intertemporal prices for new products to align with the existence of CRP? 2) Under what conditions can retailers benefit from leveraging strategic consumer behavior in the presence of CRP? 3) What are the implications of C2C resale markets for consumers, society, and environment?

Second, we introduce a new behavioral factor: consumers' utility dependence in C2C secondhand transactions. By incorporating this essential feature, forward-looking consumers can gain both resale value and utility dependence when reselling and repurchasing simultaneously. This dual benefit significantly affects the supply of secondhand products on CRP and the demand for new products, leading to market shifts and forcing retailers to adjust their operational decisions. Based on this, we investigate: 1) How should retailers dynamically manage prices for new products to benefit from the existence of C2C resale markets and consumers' utility dependence? 2) How can consumers and society benefit from CRP as consumers exhibit utility dependence? 3) How should retailers collaborate with CRP if consumers are utility-dependent?

Third, shifting the focus to the upstream manufacturer, we combine the product perspective (product upgrades) with the consumer perspective (time-inconsistent behavior, where discrepancies between payoffs and payments lead to consumers' misestimation of their utilities over time, resulting in inconsistencies in their intertemporal decision-making) to investigate: 1) How does time inconsistency influence market segmentation and manufacturers' dynamic pricing in the presence of CRP? 2) Can manufacturers benefit from the presence of CRP in the context of time inconsistency? 3) What is the manufacturer's optimal release strategy of product upgrade in the existence of CRP?

1.3 Research Significance

1.3.1 Theoretical Significance

The prevalence of the C2C resale market has aroused increasing interest in the academic community. The theoretical significance of the thesis is twofold.

First, our research contributes new insights to the literature on dynamic pricing strategy for new products. Dynamic pricing has been extensively studied in the fields of marketing and operations management. Despite some literature has examined how enterprises should dynamically adapt new product prices over time in response to the presence of secondary markets, there remain arguable issues regarding the characterization of the C2C mode. Specifically, existing literature assumes a homogeneous and ex-ante known perceived value of used products among consumers (Yin et al. 2010; L. Jiang et al. 2017), which does not apply to the practices based on the C2C mode. In the C2C resale market, used products are supplied by individual consumers without uniform quality regulation. Consequently, consumers face uncertainty about the value of used products on CRPs, leading to their heterogeneous and ex-ante unknown perceived value of secondhand products, which is captured in our work. This setting leads us to different findings compared to previous studies by emphasizing the crucial role of consumer heterogeneities.

Second, this study enriches the literature on secondary market by providing a new perspective from the behavioral economics. We integrate several consumer behavioral factors into the research framework alongside C2C resale activities: individual supply, strategic waiting, utility-dependent, and time-inconsistent behaviors. Prior literature indicates that these consumer behaviors significantly influence consumers' purchasing decisions (Su 2007; Moshkin & Shachar 2002; Meyer et al. 2008). However, there is a lack of studies regarding their effects in C2C resale transactions. Existing works have not conclusively provided theoretical support in this regard. This research rigorously examines the effects of consumer behaviors on market segmentation and enterprises' operation performance in the presence of C2C resale markets. Our findings fill the gap in the literature and offer valuable guidance and support for enterprises to navigate their strategic decisions in response to the emergence of CRPs, particularly in consideration of consumer behavioral factors.

1.3.2 Practical Significance

As a new economic entity, C2C resale markets introduces diverse business models and market dynamics. The practical significance of this thesis include the following.

Firstly, this research caters to the growing trend of green consumption habits among consumers in recent years. It also addresses the vital need for practitioners, governments, and the entire society to promote the development of circular economy and collaboration consumption. We systematically investigate the impacts of C2C resale on all market incumbents, including consumers, enterprises, platforms, society, and the environment. Our model settings are applicable to different product categories and industries, such as consumer electronics, furniture and home appliances, branded apparel, and automotive. The results provide a comprehensive understanding for the existence of C2C resale markets as a trading channel for secondhand goods.

Secondly, this study offers operational-level managerial guidance for both upstream and downstream enterprises in the supply chain. This includes dynamic pricing strategies based on product and consumer characteristics, collaboration strategies with CRPs for retailers, and optimal strategy for releasing product upgrades for manufacturers. Specifically, dynamically setting prices is as an efficient marketing tool for enterprises to sell new products and promptly respond to market changes. Simultaneously, in practice, enterprises participating C2C resale markets by collaborating with third-party platforms or self-managing branded resale channels. Some of them offer price subsidies on new products to resellers, while others allow CRPs to choose its optimal commission rate. Besides, firms continuously introduce product upgrades sequentially as part of their innovation agenda to establish market dominance. Our research offers valuable guidance for supply chain members to tackle the operational challenges stemming from C2C resale transactions.

1.4 Research Structure and Content

This thesis undertakes a comprehensive exploration through a series of analytical frameworks to examine enterprises' dynamic pricing strategies for new products in the presence of C2C resale markets, as illustrated in Figure 1.5. The thesis comprises six chapters. The scope of this research ranges from the downstream of the supply chain, as examined in Chapters 3 and 4, to the upstream, considered in Chapter 5, covering from the retailer to the manufacturer. The research first adopts a product-centric perspective in Chapter 3, analyzing the depreciation and salvage value of secondhand products within the C2C resale market. Chapter 4 then shifts to a consumer-centric perspective, exploring consumers' utility dependence in C2C secondhand transactions. Finally, Chapter 5 integrates both the product and consumer perspectives to examine product upgrades and consumers' time-inconsistent behavior in the context of C2C resale markets. A brief summary of each chapter is as follows.

Chapter 1 introduces the research background, research questions, research significance, and structure of the thesis. It also provides an overview of the subsequent chapters.

Chapter 2 reviews the related literature, including the streams of C2C secondary market, consumer behaviors, and dynamic pricing.

Chapter 3 discusses the fundamental role of CRPs and explores its implications on the retailer's optimal dynamic pricing strategy for new products considering secondhand product characteristics.

Chapter 4 extends the framework proposed in Chapter 3 by incorporating a new behavioral factor: utility dependence from consumers' repeat purchases. We delve into the retailer's optimal dynamic pricing strategy for new products and its collaboration strategy with CRPs, taking into account consumers' utility dependence.

Chapter 5 deviates from the assumption of Chapters 3 and 4, which are based on consumers' consistent expectations regarding payment and payoff outcomes. Instead, this chapter investigates the scenario where consumers exhibit time-inconsistent expectations about payments and payoffs. Simultaneously, this chapter introduces product upgrades from the manufacturer's perspective, analyzing the manufacturer's optimal dynamic pricing strategy and the optimal product upgrade release strategy considering consumers' time inconsistency.

Chapter 6 concludes the main findings and contributions of this thesis. It also pinpoints limitations and suggests future research directions.

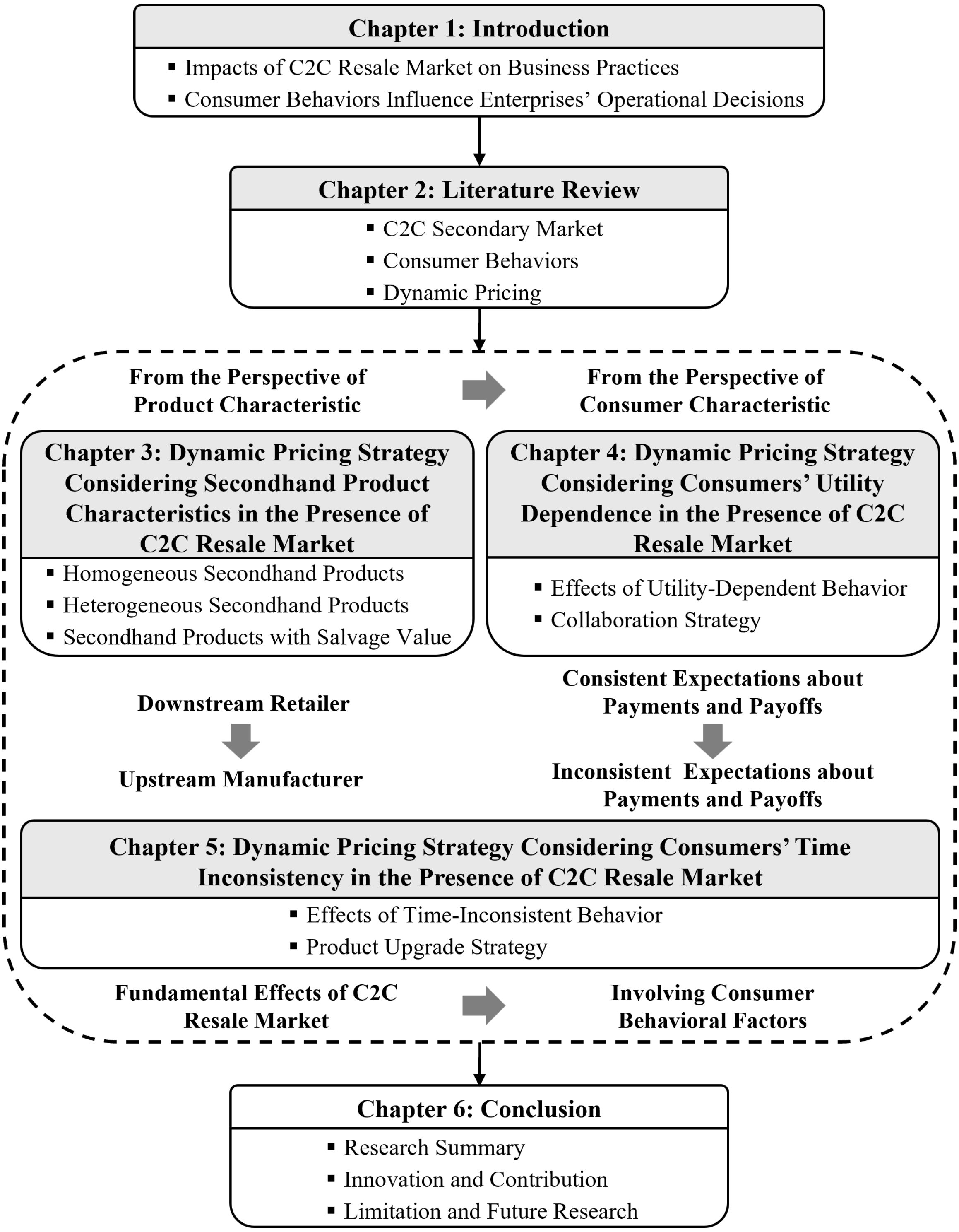


Figure 1.5: Research structure

Chapter 2

Literature Review

This research centers on the dynamics of C2C secondhand market, exploring the shifts in consumer behaviors and operational decisions made by market incumbents. Therefore, we review literature from three streams, including C2C secondary market, consumer behaviors, and dynamic pricing. Each stream draws on a substantial body of literature from economics, operations management, and marketing.

2.1 C2C Secondary Market

The literature on secondary market originates from the studies on business-to-consumer (B2C) interactions. Past works show that B2C secondary markets cannibalize firms' new-product demand (Bulow 1986, 1982; Waldman 1997). However, firms can take advantage of B2C secondary markets to extract more surplus from consumers and improve allocation efficiency by market segmentation (Hendel & Lizzeri 1999; Lee & Whang 2002). Compared to B2C secondary markets, C2C secondary markets enable consumers to interact with each other through reselling and purchasing used products. Table 2.1 offers a concise overview of the highlights in related literature on C2C secondary market.

Table 2.1: A brief review of related literature on C2C secondary market

Research area	References	Focal issue
C2C secondary transactions	MacInnes et al. (2005)	Reputation and dispute
	X. Zhao et al. (2006)	Information asymmetry
	J. Chen et al. (2009)	Members' trust and loyalty
	X. Chen et al. (2017)	Buyers' repurchase intentions
Effects on firm	Anderson & Ginsburgh (1994)	Heterogeneous tastes for new and used goods
	P. Desai et al. (2004); Yin et al. (2010)	Negative impact
	Gümüş et al. (2013)	Return policy
Effects on consumers and society	Abhishek et al. (2021); Fraiberger & Sundararajan (2017); Frenken (2017); B. Jiang & Tian (2018)	C2C rental market with usage transference
	L. Jiang et al. (2017)	C2C secondary market with ownership transference
Effects on environment	Xue et al. (2018)	Firm-enabled C2C secondary platform
	Vedantam et al. (2021)	C2C vs. trade-in
	Niu et al. (2022); L. Wang et al. (2017); F. Zhang & Zhang (2018)	Remanufacturing

Specifically, extant literature has studied reputation and dispute (MacInnes et al. 2005), information asymmetry (X. Zhao et al. 2006), members' trust and loyalty (J. Chen et al. 2009), and buyers' repurchase intentions (X. Chen et al. 2017) in C2C secondary transactions; the effects of C2C secondary platforms on firm (Anderson & Ginsburgh 1994; P. Desai et al. 2004; Yin et al. 2010), consumers and society (L. Jiang et al. 2017), or environment (Xue et al. 2018; Vedantam et al. 2021); and the firm's optimal response to the rise of C2C secondary markets (Gümüş et al. 2013).

2.1.1 Impacts on Firm

Prior literature indicates that C2C secondary platforms are detrimental to firms. For instance, P. Desai et al. (2004) explore the competition between C2C used-product market and new-product market, to show that channel members do not benefit from the addition of a used-product market. Yin et al. (2010) study a supplier introducing product upgrades in the presence of a C2C used-product market, to find that the C2C market harms the manufacturer and the retailer. Different from these studies, we find that this result no longer holds. Chapter 3 demonstrates that the firm can benefit from the CRP through price adaptions in the presence of strategic consumers. Consumers' heterogeneities in valuing new and used products, as captured in our model, play a vital role in market formation. The retailer's price adaptions cause a redistribution of new-product demands over time in parallel to used-product transactions on the CRP, leading to an increase in total new-product demand, termed the demand-expansion effect. From the economic perspective, the monopolist retailer profits from a sustained C2C resale market when consumers perceive certain discrepancies in the values of new and used products.

Other works explore how the firm should respond to the presence of C2C secondhand market. Anderson & Ginsburgh (1994) show that the monopolist can utilize a C2C secondary market to practice second-degree price discrimination and make a higher profit when used products have high quality. This work, along with ours, assumes heterogeneous tastes for new and used goods. In contrast to their findings, we demonstrate that the monopolist benefits from a sustained C2C secondary market if consumers' perceived used-product valuation is low but is harmed otherwise. Gümüş et al. (2013) characterize the optimal return policy by a retailer who competes with a C2C used-product platform. T. Li et al. (2020) examine the effect of a C2C secondhand platform on the retailer's optimal return policy when strategic consumers exhibit uncertainty in their valuations. L. Jiang et al. (2017) state that a profit-maximizing C2C secondary platform mitigates the consumers' product-fit risk by allowing them to trade mismatched products.

Unlike existing works, Chapter 4 introduces two practical features to generate new insights in the presence of C2C secondary market. One is the heterogeneity in consumers' used-product quality levels. Instead, existing works assume a homogeneous discount factor for the value or quality level of used product to consumers, which does not apply to the practices based on the C2C mode. We include an element to capture this heterogeneity, which adjusts the extent of the competition between new and used products. Consistent with practice, we assume that consumers are uncertain about the quality levels of used products until they have used the product or observed the used product on the CRP. The other is the heterogeneity in consumers' utility dependence from repeat purchases. These heterogeneities have substantial influences on the consumers' purchase decisions across periods. It brings us the interesting result that the rise of CRP improves the retailer's revenue in many situations, despite its competition with the retailer for demand by providing used products at a lower price with a comparable quality level.

2.1.2 Impacts on Consumers and Society

Extant literature states that a C2C market has mixed effects on consumer surplus and social welfare (Abhishek et al. 2021; Benjaafar et al. 2019; Fraiberger & Sundararajan 2017; Frenken 2017; B. Jiang & Tian 2018). Fraiberger & Sundararajan (2017) show that, as C2C rental replaces traditional ownership rental, secondary-product price decreases, but consumer surplus increases in certain circumstances. B. Jiang & Tian (2018) investigate product sharing among the consumers to rent out purchased products, to find that participants may achieve a conditional win-win situation. Frenken (2017) shows that sharing platforms allow consumers to enter a positive-sum game to lend or rent out under-utilized products. Abhishek et al. (2021) state that both the manufacturer and the consumers profit from the presence of a C2C rental market if the heterogeneity among consumers in the usage rate of durable goods is moderate. Thus, while introducing a C2C market harms incumbents by incurring channel conflicts, it can mobilize socialized and decentralized resources via universal connections between individual supply and demand to benefit consumers and improve social welfare (Belk 2014).

The studies mentioned above primarily focus on the transfer of product usage within the C2C rental market, whereas a stream of studies emphasizes the transfer of product ownership within the C2C secondary market. L. Jiang et al. (2017) argues that when the unit cost of acquiring one product for the supplier is sufficiently low, a C2C secondhand platform results in negative outcomes for both consumers and society. As a complement to the literature, we demonstrate that the rise of CRP can benefit the consumers and the retailer simultaneously. Coupled with the revenue reaped by the CRP from used-product transactions, a win-win situation emerges for all market participants. Additionally, the rise of CRP is more likely to benefit the society than individual consumers and the retailer.

2.1.3 Impacts on Environment

Our work also contributes to the stream of literature on the environmental performance of business models (Miao et al. 2017; Zhou et al. 2021). Some studies compare traditional selling, leasing, and servitization models. Agrawal et al. (2012) analytically show that leasing is greener than selling for products with low durability and high use-phase environmental impact. Agrawal & Bellos (2017) and Örsdemir et al. (2019) explore the environmental potential of sales and servitization business options, and identify the circumstances where servitization is a more sustainable strategy. Regarding efficient capacity investment and resource allocation, Yang et al. (2023) investigate the interplay between financing and production planning from the environmental perspective. In sharing business, Bellos et al. (2017) demonstrate that car sharing is not always environmentally beneficial. Santos et al. (2023) add one environmental objective to evaluate the environmental impacts of a vehicle routing problem. Other studies extend the discussion on remanufacturing (Niu et al. 2022). L. Wang et al. (2017) show that the key drivers of environmental impact are variable remanufacturing costs and the retailer's power in outsourcing remanufacturing channel. F. Zhang & Zhang (2018) explore the effects of consumer purchasing behavior and remanufacturing efficiency on the economic and environmental values of trade-in remanufacturing. They state that, instead of generating revenue and benefiting the environment, the most significant advantage of trade-in remanufacturing lies in exploiting the forward-looking behavior of strategic consumers.

In the context of C2C secondary markets, Xue et al. (2018) find that whether a firm-enabled C2C secondary platform benefits the environment mainly depends on products' reuse and improvement values, as well as the unit environmental impacts in different phases of product life cycle. Vedantam et al. (2021) compare the impacts of trade-in and C2C secondhand market for the firm's profit and the environment. Chapter 3 differentiates from the above studies by considering a third-party CRP, which interacts with market incumbents in selling to strategic consumers, from both economic and environmental perspectives. We identify a demand-expansion effect that arises from the retailer's price adaptations to exploit strategic consumer behavior. It contributes to the improvement in the retailer's revenue but aggravates the negative environmental impact, which is against the retailer's propaganda for used-product transactions on the CRP as creating an efficient and sustainable mode of consumption to eliminate the negative environmental impact. The rise of CRP can achieve a win-win situation for market incumbents at the expense of a stronger impact on the environment.

2.2 Consumer Behaviors

This research contributes to the literature on consumer behaviors in three streams. Firstly, we delve into the strategic individual supply and strategic waiting behaviors among consumers when engaged in C2C secondhand transactions. Secondly, we examine utility-dependent behavior arising from loyal consumers' repeat purchases. Thirdly, we explore consumers' time-inconsistent behavior. Table 2.2 provides a brief review of the key points in related literature on consumer behaviors.

2.2.1 Strategic Individual Supply and Strategic Waiting Behaviors

Consumers interact directly in C2C secondhand transactions, facilitating strategic individual supply behavior (to be suppliers) and strategic waiting behavior (to be demanders) through the resale and purchase of used products. In previous literature, efforts are devoted to the study of individual strategic suppliers as speculators. These speculators purchase products early on but do not use products themselves; instead, they stock them for resale in later periods. Su (2010) builds a two-period model to study the reselling behavior of speculators, to find that this behavior can increase the expected profit for the firm that competes with a resale market. Lim & Tang (2013) examine a monopolist's pricing policy in advance selling in a market consisting of myopic and forward-looking consumers along with speculators. In our research, speculators no longer exist, but the consumers who purchase new products in the early period can turn into individual suppliers of used products in the later period. Chapter 4 considers two factors motivating consumers to purchase early and become individual suppliers: the state-dependent utility from repeat purchases and the resale income from reselling used products.

Substantial efforts have been devoted to studying consumers' strategic waiting for

Table 2.2: A brief review of related literature on consumer behaviors

Research area	References	Focal issue
Strategic individual supply behavior	Lim & Tang (2013); Su (2010)	Speculator's strategic resale
Strategic waiting behavior	Aviv & Pazgal (2008); Guadagni & Little (1983); Su (2007)	Wait for markdown
Utility-dependent behavior	Guadagni & Little (1983); Gupta (1988); Krishnamurthi & Raj (1988)	State dependence theory
	Erdem (1996); Horsky et al. (2006); Roy et al. (1996); Seetharaman (2004); Moshkin & Shachar (2002); Dubé et al. (2008)	State-dependent utility
Time-inconsistent behavior	Mazur (1987); Laibson (1997); O'Donoghue & Rabin (1999); Ebert & Prelec (2007); Yoon (2020)	Discounting schemes
	S. Jain (2012); Gruber & Köszegi (2001); Kivetz & Simonson (2002); Thaler & Shefrin (1981); Hoch & Loewenstein (1991); Wertenbroch (1998); Haws et al. (2012); Heidhues & Köszegi (2010); S. Zhang et al. (2022)	Self-control problem
	DellaVigna & Malmendier (2004)	Contract design
	Gilpatric (2009)	Rebate program
	Meyer et al. (2008); S. Jain (2019)	Product features
	L. Li & Jiang (2022)	Vertical differentiation
	Kuang & Jiang (2023)	Presales
	Hall & Liu (2023)	Scheduling system
	Nocke & Peitz (2003)	Competitive secondary markets

markdown over periods (Aviv & Pazgal 2008; Guadagni & Little 1983; Su 2007). We elaborate on the impact of consumers' strategic waiting on firm's dynamic pricing in

Section 2.3.2. Nevertheless, little is done to explore consumers' strategic postponing to purchase used products at a possibly lower price, which is a common practice in the existence of C2C secondhand market. Unlike prior studies, we incorporate the interplay of strategic waiting and strategic individual supply behaviors. Importantly, we account for the heterogeneity among consumers in perceiving the value of used products, which affects the extent of competition between new and used products. We follow the practice to assume that this heterogeneity is ex-ante unknown but is realized ex-post product usage for consumers. In practice, consumers who behave strategic individual supply behavior can observe the exact used-product value only after they have used or experienced the product, while consumers who behave strategic waiting behavior can do so until individual suppliers post used products on C2C secondary market. This setup captures the distinctive feature of secondhand products in C2C market and alters market segmentation, thereby influencing the operational decisions of market incumbents.

2.2.2 Utility-Dependent Behavior

Consumers generally exhibit high behavioral loyalty in online purchases (Huang 2011). One manifestation of consumer loyalty is that when the firm offers new products, consumers tend to continue to purchase from the same firm. The act of repeatedly purchasing can be explained by the theory of state dependence. Guadagni & Little (1983) introduce the state dependence measure of brand loyalty based on previous purchase choices. Gupta (1988) and Krishnamurthi & Raj (1988) use a similar measure and provide more empirical support to state dependence in consumers' decisions. Following that, scholars have explored specific forms of state-dependent utility and shown that the utility of a brand is enhanced if it was recently purchased (Erdem 1996; Horsky et al. 2006; Roy et al. 1996; Seetharaman 2004). Specifically, Moshkin & Shachar (2002) build a state-dependent utility model, assuming that purchasing a product in a period increases the utility of purchasing another product from the same firm in the next period. King et al. (2016) propose that an online retailer's website cultivates a particular identity that can cause repeat purchases from committed consumers. Dubé et al. (2008) consider category pricing with state-dependent utility and show the effects of materials on optimal pricing. Dubé et al. (2010) introduce brand inertia whereby the consumers persistently stick to a product they have purchased in the past. They explore economic explanations for state dependence as consumers' preference change due to past purchase or consumption experience.

The focal message of this stream of literature is that current choice behaviorally depends on the previous one, and the previous choice affects the current utility. Chapter 4 follows Moshkin & Shachar (2002) to define a positive parameter to capture the scale of utility dependence on the previous choice and allow it to differ across consumers. Specifically, utility dependence refers to the valuation increment that occurs to the consumers who have consumed or experienced products. The extents of utility dependence are heterogeneous among consumers and depend on their own experiences. This value is crucial to market formation and system performances. Our result indicates that, as a result of enhanced demand management, consumers' utility dependence mitigates the direct competition posed by CRPs to retailers. We contribute to the literature on state dependence by incorporating it into the study of C2C secondary market.

2.2.3 Time-Inconsistent Behavior

In the realm of literature on time inconsistency, we undertake a review of three streams. Firstly, we review the ways scholars characterize time inconsistency via different discounting schemes. Secondly, we list works employing economic models to investigate time inconsistency. Lastly, we illustrate one unique feature within this field: the self-control problem.

Characterization of Time Inconsistency Through Discounting Schemes

The literature commences with classical works that introduce different discounting schemes to illustrate the characteristics of time inconsistency, including the hyperbolic discounting model by Mazur (1987), the quasi-hyperbolic discounting model by Laibson (1997) and O'Donoghue & Rabin (1999), and the constant-sensitivity model by Ebert & Prelec (2007). Yoon (2020) provides a comprehensive overview of these three prominent models of temporal discounting and demonstrates the interaction between impatience and time inconsistency. In this research, we adopt the framework proposed by Laibson (1997) and O'Donoghue & Rabin (1999) to describe the existence of time inconsistency. Specifically, Laibson (1997) states that the weighting of a future outcome at time t follows the function $f(t) = \beta\delta^t$, where δ is the time-consistent discount factor and β is the time-inconsistent parameter. This setting assigns less weight to future income when $t > 0$ but does not discount the immediate outcome at $t = 0$. O'Donoghue & Rabin (1999) presents a (β, δ) present-biased preference model, where for all t, the individual's intertemporal preferences from the perspective of period t are defined as $U^t(u_t, u_{t+1}, \ldots, u_T) = \delta^t u_t + \beta \sum_{t+1}^{T} \delta^{t+1} u_{t+1}$. Here, u_t represents the individual's instantaneous utility in period t. Chapter 5 contributes novel insights to the literature by embedding the quasi-hyperbolic discounting scheme within the context of the secondary market.

Economic Models Exploring Time Inconsistency

One line of literature investigates the impact of time inconsistency on economic or business models. For instance, studies have discussed contract design (DellaVigna & Malmendier 2004), rebate program (Gilpatric 2009), product features (Meyer et al. 2008; S. Jain 2019), vertical differentiation (L. Li & Jiang 2022), scheduling system (Hall & Liu 2023), and presales (Kuang & Jiang 2023). Specifically, Gilpatric (2009) demonstrates that consumers' time-inconsistent purchase behavior can generate slippage, signifying that consumers are incentivized by the rebate to make a purchase but subsequently fail to redeem the rebate. The efficacy of rebate programs in capitalizing on time-inconsistent consumers is constrained in settings where there is substantial variance in the degree of time inconsistency within the population, unless it is highly correlated with their rebate redemption costs. S. Jain (2019) constructs a game-theoretical model in which consumers are required to invest in learning product features. This study reveals that time inconsistency encourages firms to prioritize the ease of learning over investing in additional features. L. Li & Jiang (2022) examine the impact of consumers' time-inconsistent purchasing behavior on the dynamic and static pricing strategies of two vertically differentiated competing firms. The findings suggest that the firms' pricing schemes are jointly influenced by the extent of time inconsistency among consumers and the quality of the products. Hall & Liu (2023) examines the implications of present bias within a simple scheduling system that involves decisions regarding the timing and sequencing of projects. They study devises algorithms capable of optimizing the cost of revenue loss under present bias, catering to both naive and sophisticated decision-makers. Kuang & Jiang (2023) explore a scenario where a firm employs presales with two payments - a preliminary upfront deposit and a deferred arrear - to market a product to time-inconsistent consumers. They discern that presales yield mixed effected on the firm's profit and consumer surplus but consistently leads to an enhancement in social welfare due to the rise in actual sales.

One closely related work is by Nocke & Peitz (2003), which consider both time-consistent (exponential) and time-inconsistent (hyperbolic) discounters facing competitive secondary markets for durable goods. The findings indicate that secondary markets have no impact on the primary market when consumers exhibit time-consistent discounting. However, if consumers display time inconsistency in their discounting behavior, secondary markets lead to a decline in the primary market's price over multiple periods, inducing the primary firm to close down secondary markets. Chapter

5 distinguishes from Nocke & Peitz (2003) by incorporating the strategic purchase behaviors of forward-looking consumers. We demonstrate that the firm can benefit from the effective use of pricing as a strategic tool to regulate demand and capitalize on the presence of time inconsistency.

Self-Control Problem

One unique feature of time inconsistency is the self-control problem. Consumers exert self-control to resist present temptation and achieve a better long-term performance (S. Jain 2012). Abundant literature in the marketing field includes psychological and sociological phenomena to discuss the self-control problems. Gruber & Köszegi (2001) state that time-inconsistent consumers are unable to actualize their desired or predicted future levels of consumption. However, the use of precommitment or self-control devices can handle consumers' impulsive purchase behavior (Kivetz & Simonson 2002; Thaler & Shefrin 1981). For instance, consumers voluntarily and strategically ration their purchase quantities of good (Hoch & Loewenstein 1991; Wertenbroch 1998) or elaborate outcomes to improve self-control (Haws et al. 2012). Self-awareness of one's self-control problems can mitigate the negative impact of hyperbolic discounting (Heidhues & Köszegi 2010). From the operations management perspective, S. Zhang et al. (2022) examine consumers' time-inconsistent preferences and strategic self-control behaviors in digital content consumption. They find that a large segment of price-sensitive consumers is willing to overpay to curb future consumption. Our work explicitly investigates how the existence of a secondary market can give rise to the self-control problem for time-inconsistent consumers, stemming from their misestimation of intertemporal utilities. We indicate three demand effects arising from this self-control problem: demand vanishing, demand migration, and demand expansion. We demonstrate that the firm can leverage the strategic use of pricing as an effective tool to address the self-control problem of time-inconsistent consumers and effectively regulate demand when the degree of self-control problem is low.

2.3 Dynamic Pricing

Abundant literature has investigated how firms should adapt dynamic pricing strategics. Our research contributes to this stream of literature by examining three aspects: new product pricing, intertemporal price discrimination, and product upgrade. Table 2.3 provides a concise review of related literature on dynamic pricing.

Table 2.3: A brief review of related literature on dynamic pricing

Research area	References	Focal issue
New product pricing	Bass & Bultez (1982); Kalish (1983); Kalish & Lilien (1983); G. L. Thompson & Teng (1984); Dockner & Jørgensen (1988); H. Li & Huh (2012); Shen et al. (2014); H. Li (2020)	Analytical model
	D. C. Jain & Rao (1990); Bayus (1992); Bass et al. (1994)	Empirical model
	M. Zhang et al. (2022)	Data-driven model
Intertemproal price discrimination	Besanko & Winston (1990); Coase (1972); Liu & Zhang (2013); Stokey (1979)	Consumers' strategic waiting
	Altug & Aydinliyim (2016); Aviv et al. (2019); Su (2007); Ye & Sun (2016)	Skimming pricing
Product upgrade	Ramachandran & Krishnan (2008); Paulson Gjerde et al. (2002); Gilbert & Jonnalagedda (2011)	Product design
	Kornish (2001); Cui et al. (2018)	Pricing

to be continued

Table 2.3 Continued

Research area	References	Focal issue
	Moorthy & Png (1992); Loch & Kavadias (2002); Morgan et al. (2001)	Release timing
	Moorthy & Png (1992); Liang et al. (2014); Xue et al. (2018)	Single rollover
	Kavadias & Loch (2003); Cui et al. (2018)	Resource allocation
	V. Krishnan & Ramachandran (2011); Ülkü et al. (2012)	Modular upgrades
	Rahmani et al. (2017)	Consumer engagement
	Lobel et al. (2016); Cui et al. (2018)	Optimal launch with strategic consumers
	Levinthal & Purohit (1989); Yin et al. (2010); Xiong et al. (2016); Xue et al. (2018); W. Wang et al. (2023)	Interaction with secondary market

2.3.1 New Product Pricing

Begin with the seminal study by Bass (1969), numerous subsequent works explore new product adoption. The original Bass model posits that sales are temporally influenced by innovators, who make early purchases and experience a product themselves, and imitators, who follow earlier adopters and purchase later on. Variants of the Bass model are employed to demonstrate the influence of competition (T. V. Krishnan et al. 2000; Savin & Terwiesch 2005; Guseo & Mortarino 2014), overlapping generations (Norton & Bass 1987; Bayus 1992), and optimal pricing policies (Robinson & Lakhani 1975; Dolan & Jeuland 1981; Horsky 1990). Following the Bass model, Bass et al. (1994) propose an extension known as the Generalized Bass Model, which discusses the role of price in new product adoption. This extended model has gained widespread acceptance in the marketing literature and has subsequently been applied in industries. T. V. Krishnan et al. (1999) analytically derive the implications of the optimal dynamic pricing of the Generalized Bass Model.

We categorize the extensive literature on new product dynamic pricing based on research methods: analytical, empirical, and data driven modeling. A number of researchers investigate optimal dynamic pricing strategies for new products using analytical models (Bass & Bultez 1982; Kalish 1983; Kalish & Lilien 1983; G. L. Thompson & Teng 1984; Dockner & Jørgensen 1988; H. Li & Huh 2012; Shen et al. 2014; H. Li 2020). Specifically, Kalish & Lilien (1983) investigate the pricing policy of a new product over time for a monopolist aiming to maximize profit, considering the interdependence between dynamic costs of cumulative production and demand of cumulative sales. G. L. Thompson & Teng (1984) and Dockner & Jørgensen (1988) extend this problem to determine the optimal pricing policies for firms operating in oligopolistic markets. Following this line of research, H. Li & Huh (2012) study the optimal pricing decisions for new products experiencing a life-cycle demand pattern resembling a diffusion process. This pattern includes weak demand at the beginning and end of the life cycle, with high demand intensity in between. Shen et al. (2014) examine how a capacity-constrained firm sets prices when introducing new products.

By contrast, a stream of literature utilizes empirical models for new product sales forecasting to estimate the effects of price on new product adoption (D. C. Jain & Rao 1990; Bayus 1992; Bass et al. 1994; Cosguner & Seetharaman 2022). Specifically, D. C. Jain & Rao (1990) enrich the Bass model by incorporating price as a controllable variable. Bayus (1992) construct a model for consumer sales of a new durable product by including replacement behavior between product generations to explain how prices of new products change over time. Cosguner & Seetharaman (2022) propose two versions of a utility-based extension of the Bass diffusion model: the Bass-Gumbel diffusion model and the Bass-Logit diffusion model, to derive the optimal price path for new products.

Additionally, using a data-driven approach, M. Zhang et al. (2022) delve into the interaction between pricing and learning for a monopolist aiming to maximize the expected revenue of a new product over a finite selling horizon. Our study establishes an analytical framework following Bass (1969) to characterize consumers who make purchases of new products at different periods. Different from prior research, we introduce competition from secondhand products to new ones. In our model, consumers have the option to resell their early-purchased products on a resale platform and repurchase new items. By incorporating the effects of C2C resale market, we contribute novel insights to this stream of literature in examining the optimal dynamic pricing strategies for new products.

2.3.2 Intertemporal Price Discrimination

Extensive literature has studied how firms should adapt pricing strategies to consumers' strategic waiting for the markdown of new products (Altug & Aydinliyim 2016; Aviv et al. 2019; Besanko & Winston 1990; Liu & Zhang 2013; Guo et al. 2022; Su 2007; Ye & Sun 2016). Besanko & Winston (1990) state that, in selling to strategic consumers, a monopolistic firm should set a low price prior to the start of the season but commit to a less aggressive markdown afterward. Extending to a duopoly market, Liu & Zhang (2013) explicate the trade-off between the gain of adopting a skimming policy and the loss from strategic waiting. Aviv & Pazgal (2008) find that responsive pricing is detrimental to a monopolistic firm in selling to strategic consumers. Aviv et al. (2019) demonstrate that the benefit of responsive pricing depends crucially on consumer behavior, and such benefit reduces when consumers are all strategic and demand learning is strong. Y. Chen & Yang (2020) suggest that the seller benefits from leveraging the trade-off between consumers' strategic waiting and inventory cost since strategic consumer waiting can be a new source of flexibility.

In this work, we explore how the retailer should set prices dynamically to manage the interactions between strategic consumers, as suppliers (strategic supply) and demanders (strategic waiting) on the CRP, in C2C resale markets. Chapter 3 indicates that, with the rise of CRP, the retailer aggravates intertemporal price discrimination as consumers exhibit heterogeneity in perceiving used-product value in most circumstances, but mitigates it as consumers uniformly perceive a high used-product value. Following that, Chapter 4 presents that in the presence of consumers' utility dependence, the retailer adheres to a skimming policy in setting prices over time but exacerbates intertemporal price discrimination with the rise of CRP. These results contrast with and complement prior works (Besanko & Winston 1990; Coase 1972; Stokey 1979), which state that a monopolist should mitigate intertemporal price discrimination when consumers behave strategically.

2.3.3 Product Upgrade

There exists a substantial literature on optimizing product innovation within firms due to the advancement of technology. For instance, Ofek & Sarvary (2003) examine the dynamic competition in markets where technologically advanced next-generation products are introduced. Kirshner et al. (2017) show a firm's optimal upgrade strategy in the presence of stochastic technology advancements, considering brand commitment and product failure risk. One stream of research that intersects with this study is the sequential versioning of products by monopolist firms. Sequential versioning entails as an ongoing process wherein firms introduce successive versions of the same product over time (Brown & Eisenhardt 1995). Decisions made by firms in managing rapid sequential innovation includes aspects such as product design (Ramachandran & Krishnan 2008; Paulson Gjerde et al. 2002; Gilbert & Jonnalagedda 2011), pricing (Kornish 2001; Cui et al. 2018), release timing (Moorthy & Png 1992; Loch & Kavadias 2002; Morgan et al. 2001), single rollover (Moorthy & Png 1992; Liang et al. 2014; Xue et al. 2018), resource allocation (Kavadias & Loch 2003; Cui et al. 2018), modular upgrades (V. Krishnan & Ramachandran 2011; Ülkü et al. 2012), consumer engagement (Rahmani et al. 2017), and optimal launch with strategic consumers (Lobel et al. 2016; Cui et al. 2018). Specifically, Gilbert & Jonnalagedda (2011) explore the effectiveness of the lock-in strategy where the manufacturer makes their products incompatible with products from other firms. Lobel et al. (2016) examine the optimal launch policy for successive generations of a product in the presence of strategic consumers. Cui et al. (2018) indicate that conditional upgrades enhance the matching between demand and supply. Firms can utilize conditional upgrade strategy to flexibly manage capacity allocations and optimize demand segmentation.

This work also contributes to the literature on the interaction between the secondary market and the introduction of product upgrades (Levinthal & Purohit 1989; H. Zhao & Jagpal 2006; Yin et al. 2010; Xiong et al. 2016; Xue et al. 2018; W. Wang et al. 2023). Specifically, Levinthal & Purohit (1989) explore the optimal strategy of a monopolist regarding whether to continue producing its existing version of the product or to introduce a new one in the presence of a frictionless secondhand market. H. Zhao & Jagpal (2006) investigate the impact of secondary markets for durable goods on a firm's dynamic pricing and new product introduction strategies. The study concludes that the effects of secondary markets on pricing depend on the magnitudes of innovation and the presence of demand externalities. Yin et al. (2010) show how a retailer-owned C2C secondhand market shapes the upstream manufacturer's product upgrade strategy and the downstream retailer's pricing strategy. Following that, Xiong et al. (2016) examine the impact of a third-party secondary market on manufacturers' upgrading strategies for durable products. W. Wang et al. (2023) delve into the optimal pricing decisions of a monopolist firm that sells new products with quality improvement and/or trade-in program.

What sets our study apart from the extant literature is the involvement of consumers' time-inconsistent behavior. Chapter 5 demonstrates how time inconsistency affects the firm's control over product upgrade and summarize two key effects - the assistant effect and the deterrent effect - to explain whether the firm should release the upgraded version. This finding is in contrast to Yin et al. (2010), which indicates that the C2C resale market always deters the release of the upgraded version.

2.4 Research Comments

To highlight the positioning of this research in the literature and identify the gaps it addresses, we summarize the theoretical contributions of this thesis in Table 2.4.

Table 2.4: A brief review of theoretical contributions

Research area	Previous literature	Our research
C2C secondary market	• C2C secondary market cannibalizes new-product demand	• C2C secondary market can lead to an increase in total new-product demand
	• CRP is detrimental to enterprises	• Enterprises can profit from CRP through price adaptions
	• Homogeneous discount factor for the value of secondhand products	• Heterogeneous discount factor for the value of secondhand products
	• Consumers are ex-ante known about the value of secondhand products	• Consumers are ex-ante unknown about the value of secondhand products until they have used the product or observed the product on the CRP
	• C2C secondary market harms the firm but benefits consumers and improves social welfare	• C2C secondary market can achieve a win-win situation for the firm, consumers, and the society

to be continued

Table 2.4 Continued

Research area	Previous literature	Our research
	• C2C secondary market benefits the environment	• C2C secondary market aggravates the negative environmental impact
Consumer behavior	• Little is done to explore strategic individual supply and strategic waiting behaviors in the context of C2C secondary market	• The interplay of these two behaviors captures the distinctive feature of C2C secondhand transactions
	• Little is done to explore the utility-dependent behavior in the context of C2C secondary market	• Consumers' utility-dependent behavior can mitigate the direct competition posed by CRP to firms.
	• Little is done to explore the time-inconsistent behavior in the context of C2C secondary market	• Despite consumers' time-inconsistent behavior may intensify the competition brought by CRP, firms can still profit by leveraging C2C resale markets to alleviate the negative impact of consumers' misestimation of intertemporal utilities
Dynamic pricing	• Intertemporal price discrimination is suboptimal when selling to strategic consumers	• Enterprises can benefit from aggravating intertemporal price discrimination to encourage consumers' strategic waiting
	• C2C secondary market always deters the release of the upgraded version	• C2C secondary market can either assist or deter the release of the upgraded version

Chapter 3

Dynamic Pricing Strategy for New Products Considering Secondhand Product Characteristics in the Presence of C2C Resale Market

3.1 Research Motivation

C2C resale markets have emerged as mainstream online shopping experiences. It enables users to redistribute used goods individually, arising from the intersection of peer-to-peer exchange and circular economy trends (Frenken 2017). As used products are supplied by individual consumers, their perceived value by consumers is heterogeneous and ex-ante unknown. More precisely, consumers who resell used products can only observe their exact value after using the product, while consumers who purchase used products may do so until sellers post used products on the CRP. Our survey reveals that 81.4% of the respondents agree that the quality and depreciation level of secondhand products influence their purchasing decisions, whereas 59.2% of the respondents indicate that they can not accurately estimate the quality and depreciation level of secondhand products (See Appendix D). Nevertheless, the literature is sparse in the exploration of how retailers should adapt prices to leverage secondhand product characteristics, which is one focus of this chapter.

Consumers envision the C2C resale market as a way to seek value options in terms of both price and sustainability. 47% of Gen Z refuse to buy from non-sustainable apparel brands and retailers (ThredUP 2023b). Almost 66.7% of consumers believe that their individual consumption habits can produce a significant impact on the planet (ThredUP 2022). Incumbents use resale models to acquire younger and price-conscious shoppers, increase customer loyalty, and drive revenue - all while doing good for the environment (ThredUP 2022). 62% of retail executives say their customers care about their brand being sustainable. 87% of brands that offer resale programs promote their advanced sustainability goals (ThredUP 2024). For example, IKEA declares that more than 60% of its products are made from renewable materials, with over 10% containing recycled materials. They claim to have given more than 42.6 million products a second life in the fiscal year of 2022 (IKEA 2024b). Levi's states that they design clothes with the entire product lifecycle in mind, with 69% of their products made using waterless processes (Levi's 2024). These observations manifest that the retailer and consumers collectively embrace a more sustainable mindset, and they believe that the presence of CRP has a significant positive impact on the environment. Whether CRP supports firms' and consumers' environmental-friendly ethos and recycling of existing products is the other focus of this chapter.

The remainder of this chapter is organized as follows. Section 3.2 puts forward the research questions. Section 3.3 introduces the model settings and presents equilibrium outcomes in the absence and presence of CRP. Section 3.4 delves into the retailer's optimal dynamic pricing strategy for new products and presents the implications of CRP on different stakeholders, including the retailer, consumers, society, and the environment, in the scenario where homogeneous secondhand products dominate the market. Section 3.5 discusses the retailer's optimal dynamic pricing strategy when heterogeneous secondhand products coexist in the market. Section 3.6 investigates the retailer's optimal dynamic pricing strategy for new products when disposed used products have a positive salvage value. Section 3.7 explores extended models to bridge theoretical findings with practical applications and to uncover additional insights. Section 3.8 proposes theoretical contributions and managerial implications and Section 3.9 concludes the chapter. The proofs for the main results are presented in Appendix A.

3.2 Research Questions

Motivated by the gap between academic literature and industry practice on the role of CRPs in influencing market formation and system performance with both economic and environmental implications, we conduct a systematic investigation into the following questions. Given the presence of homogeneous or heterogeneous secondhand products in the C2C resale market, or when secondhand products have a positive disposal value:

1. How should retailers dynamically set intertemporal prices for new products to fit with the existence of CRP?
2. Can retailers benefit from leveraging strategic consumer behavior in the presence of CRP, and, if so, under what circumstances?
3. What are the implications of CRP for consumers, society, and environment?

To answer these questions, we consider a monopolistic retailer, who dynamically sets prices to sell new products in two periods. In period one, consumers can either purchase new products or postpone purchase until period two; we call the former pre-owned consumers and the latter waited consumers. In period two, pre-owned consumers can keep using products, or resell used products on the CRP followed by repurchasing new products from the retailer or leaving, while waited consumers can purchase new products from the retailer or used products on the CRP, or leave without a purchase. The CRP retains a fraction, termed commission rate, of the revenue for each transaction finalized on its platform. We note that the CRP competes with the retailer for demand from waited consumers because the used product sold on the CRP and the new product sold by the retailer are vertical substitutes. Consumers are heterogeneous in valuing new products, and, moreover, they are heterogeneous in perceiving the value of used products. Detailed answers to these questions can provide theoretical support to empirical findings and generate novel managerial insights into the retailing practice.

3.3 Model Framework

3.3.1 Model Description

Market. Figure 3.1 illustrates the market structure. We follow Besanko & Winston (1990) to develop a two-period model. A monopolist retailer sells new products to a fixed population of strategic consumers over two periods. The responsive pricing strategy is employed, whereby the retailer first announces period-one price p_1 and delays the period-two announcement p_2 until the beginning of period two. The number of consumers is normalized to one. Each consumer holds at most one unit of product. A new product sold in period one winds up as a used one in period two. A CRP is present in period two to sustain transactions of used products among consumers. Consumers are aware of the selling of new products by the retailer in the two periods and the existence of CRP to transact used products in period two. Consumers are forward-looking and can accurately predict the new-product prices set by the retailer and the transaction price on the CRP. The model setup is applicable to the industries like consumer electronics, furniture, branded apparel, appliances, and automotive.

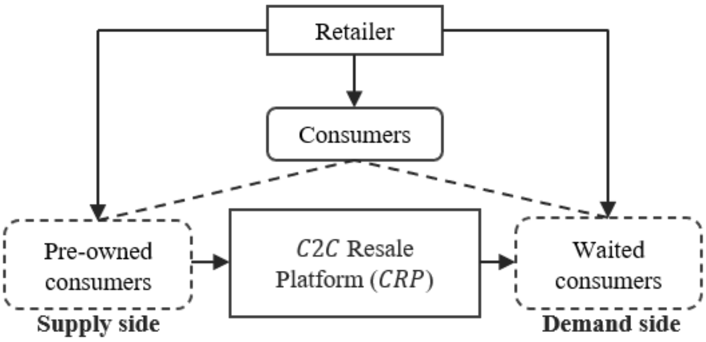


Figure 3.1: Market structure

Timeline. In period one, the retailer sets the new-product price p_1. A consumer can either purchase a new product from the retailer or postpone the purchase; we refer to a consumer who purchases a new product in period one (postpones purchase) as a pre-owned (waited) consumer. All consumers remain in the market. In period two, the retailer sets the new-product price p_2. Pre-owned consumers can keep used products (termed 'keep' option), sell used products through the CRP and repurchase new products from the retailer (termed 'resell and repurchase' option), or leave after reselling (termed 'resell and leave' option). Waited consumers have three options: one is to purchase new products from the retailer (termed 'buy new' option), another is to purchase used products on the CRP (termed 'buy used' option), and the third is to leave without purchasing (termed 'leave' option). The entire season of selling and transaction terminates at the end of period two. Given our assumption that the products of interest (e.g., consumer electronics, furniture, branded apparel, appliances, and automobiles) have a finite, two-period useful life, a multi-period setting would essentially involve repeating the dynamics of the second period. Specifically, in each additional period: (1) new and used products coexist; (2) products sold in the preceding period transition into used products; and (3) a CRP facilitates transactions of these used products among individual consumers. Figure 3.2 depicts the decision framework.

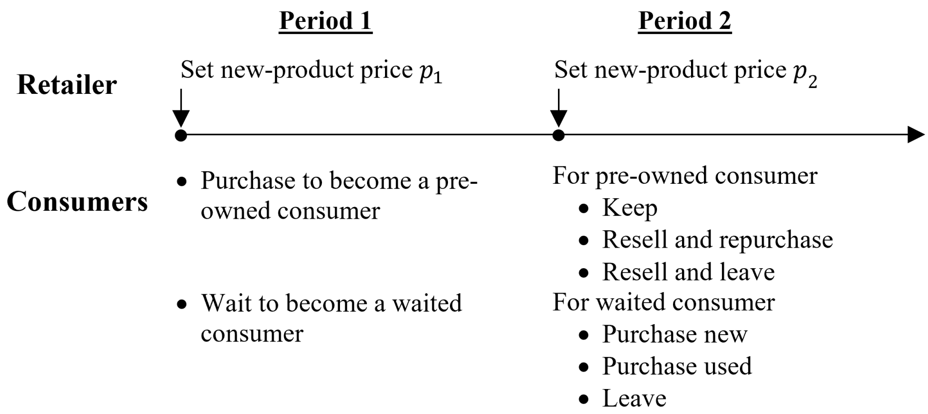


Figure 3.2: Model dynamics

Our main model does not consider a new cohort of consumers entering the market in period two. The 'repurchase' option granted to pre-owned consumers leads to a stream of period-two new-product demand. It enables us to focus on the impact of CRP on redistributing and alternating the ownership of products in the hands of existing consumers. In Section 3.7.1, we analyze the scenario wherein new consumers arrive in period two, to generate additional results and insights.

Retailer. The retailer maximizes total revenue by setting new-product prices over periods to manage consumers' purchase behavior on when (period one vs. two) and what (used vs. new product) to purchase, alongside the competition with the CRP for demands.

CRP. The CRP provides a transaction venue for used products and retains a proportion $\tau \in [0, 1]$ of the revenue for each transaction; we call τ the commission rate. At a transaction price p_s, at which supply (from pre-owned consumers) is matched with demand (from waited consumers) on the CRP, each transaction ushers in $(1 - \tau)\, p_s$ to the pre-owned consumer and τp_s to the CRP. In the spirit of Shugan (2002) that a monopolistic setting allows models to focus on their research objectives, we assume that there is a monopolist CRP. It allows us to isolate the effects of CRP on market participants and increase analytical tractability. Monopoly models have been widely adopted in the literature on platform economy (B. Jiang & Tian 2018;

L. Jiang et al. 2017; Tian & Jiang 2018). Specifically, B. Jiang & Tian (2018) and Tian & Jiang (2018) assume a single platform to facilitate consumers' product sharing and examine the strategic and economic impact of product sharing among consumers on market incumbents. L. Jiang et al. (2017) consider a single profit-maximizing C2C platform to highlight its effects on supply chain members. Additionally, we explore the competition of multiple CRPs and find that it does not fundamentally alter the qualitative nature of the results, as described in Section 3.7.3.

Consumers. A consumer values the usage of a new product in a period at v, which is time-invariant but is heterogeneous among consumers. We assume that v is uniformly distributed on $[0, 1]$, i.e., $v \sim U[0, 1]$. By assuming v to be time-invariant, we approximate the situation where no fundamental difference exists between the new products sold in the two periods. This assumption helps to isolate the effects of the heterogeneities in consumers' valuations and enhances analytical tractability. If consumers' valuation increases over time, the segmentation of pre-owned and waited consumers may shift, leading to changes in transaction volumes on the CRP and in the demand for new products. These shifts would, in turn, influence the retailer's dynamic pricing strategy for new products. This suggests a promising direction for future research. Consumers are heterogeneous in perceiving used-product value θv, where θ is the discounting factor with respect to the new-product value. A proportion η of consumers perceive a high value of used products with factor θ_H (i.e., these consumers perceive a peach), and a proportion $1 - \eta$ of consumers perceive a low value of used products with factor θ_L (i.e., these consumers perceive a lemon), i.e., $\theta = \theta_H$ with probability η and $\theta = \theta_L$ with probability $1 - \eta$, where $1 \geq \theta_H > \theta_L \geq 0$ and $\eta \in [0, 1]$ (Rao et al. 2009). We assume $\theta_L = 0$ so that consumers who perceive a lemon never purchase used products on the CRP. With a slight abuse of notations, we let $\theta_H = \theta$. Consumers hold a priori belief about the distribution of θ in period one, with expected value $E(\theta) = \eta\theta_H + (1 - \eta)\,\theta_L = \eta\theta$, while the specific value of θ is realized in period two. Specifically, pre-owned consumers observe the exact used-product value only after using the product, while waited consumers can do so until pre-owned consumers post used products on the CRP. Thus, consumers base on $E(\theta)$ to make period-one decisions. For analytical simplicity, following K. J. Li (2021), we standardize firms' and consumers' discounting factors to one when evaluating intertemporal decisions and utilities.

In the main analysis, we assume that consumers dispose of used products at a negligible salvage value. It reflects the situations for household items like mattresses, where the high disposal cost makes it hard to receive a positive salvage value, or for non-branded apparel, where consumers may donate or throw away worn items. In this case, pre-owned consumers refrain from disposing of used products at the end of period one, i.e., the disposal option is dominated. In addition, the products purchased in either period can be scrapped of freely at the end of period two. In Section 3.6, we include the disposal option with a positive salvage value, to examine the robustness of the main results and generate additional insights.

Environmental effect. Following Agrawal et al. (2012), the total environmental impact is the sum of the impacts in three lifecycle phases: production, use, and disposal. The environmental impact in a phase is equal to the product volume multiplied by per-unit impact. The per-unit impact in the production phase is e_p, the per-unit impacts of a new and a used product in the use phase are e_{un} and e_{us}, respectively, and the per-unit impact in the disposal phase is e_d.

For convenience, Table 3.1 summarizes the notations used in this chapter.

3.3.2 Benchmark: In the Absence of CRP

First, we study a benchmark setting where the CRP is absent, and use superscript B on the quantities of interest. The results are useful for evaluating the effects of CRP. Figure 3.3 illustrates consumers' decision sequence.

Table 3.1: List of notations

Notation	Definition
v	Consumers' valuation of new product in a period
θ_H, θ_L	High and low used-product discounting factors, respectively
η	The proportion of consumers who perceive a peach
τ	CRP's commission rate
$i \in \{1, 2\}$	Subscript indicating time period
$j \in \{B, D, A\}$	Superscript indicating the benchmark scenario, the scenario with the disposal option at a positive salvage value, the scenario with new entrants in period two, respectively
p, w	Subscript indicating pre-owned or waited consumers, respectively
k, sn, sl	Subscript indicating 'keep', 'resell and repurchase', 'resell and leave' options, respectively for pre-owned consumers
n, s, l	Subscript indicating 'buy new', 'buy used' or 'leave' options, respectively, for waited consumers
p_i	New-product retail price in period i
d_i	New-product demand in period i
d_s	Used-product demand
p_s	Used-product market-clearing price
r	Retailer's revenue
cs	Consumer surplus
sw	Social welfare
e_p	Per-unit impact in the production phase
e_{un}, e_{us}	Per-unit impact of a new and a used product, respectively, in the use phase
e_d	Per-unit impact in the disposal phase
E	Total environmental impact
s_i	Net salvage value in period i

A pre-owned consumer, who purchases a new product in period one, keeps it in period two, while a waited consumer, who forgoes purchase in period one, purchases a new product or leaves in period two. In period one, the marginal consumer receives

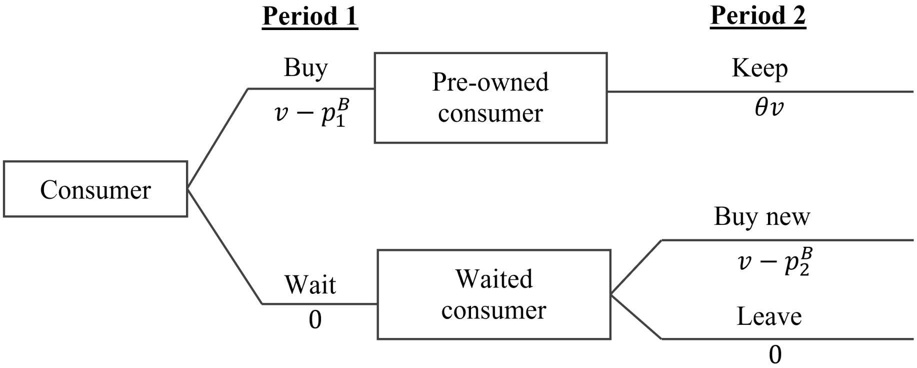


Figure 3.3: Decision sequence in the absence of CRP

the same expected utility by becoming a pre-owned and a waited consumer:

$$\underbrace{v - p_1^B + E(\theta)v}_{to\ be\ a\ pre-owned\ consumer} = \underbrace{\max\left\{v - p_2^B, 0\right\}}_{to\ be\ a\ waited\ consumer} \tag{3.1}$$

where a consumer purchasing a new product in period one receives an expected utility of $E(\theta)v$ by keeping the used product in period two, while a consumer who postpones purchase expects to receive utility $v - p_2^B$ by purchasing a new product in period two.

The retailer maximizes total revenue $r^B = p_1^B d_1^B + p_2^B d_2^B$, where (p_1^B, p_2^B) are the prices and (d_1^B, d_2^B) are the demands for new products in the two periods. Using backward induction, we first analyze the retailer's period-two optimal price as a function of the period-one price and then characterize the optimal period-one price. All the derivations are provided in Appendix A.2.1.

Homogeneous Secondhand Products

When all consumers perceive a lemon ($\eta = 0$), the market segmentation is depicted in Figure 3.4. The retailer sets new-product price $p_1^{B*} = p_2^{B*} = \frac{1}{2}$, inducing all the consumers to postpone the purchase to period two, and it serves half of the market ($d_2^{B*} = \frac{1}{2}$) to receive revenue $r^{B*} = \frac{1}{4}$.

When all consumers perceive a peach ($\eta = 1$), the market segmentation is illustrated in Figure 3.5. A threshold $\frac{1+2\theta}{1+4\theta}$ exists for new-product valuation v, above

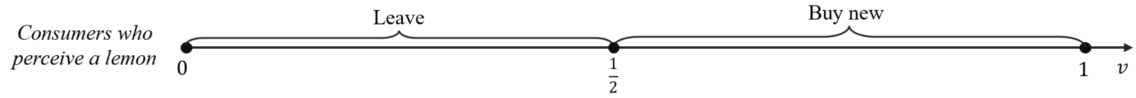


Figure 3.4: Market segmentation in the absence of CRP, with $\eta = 0$

which a consumer purchases a new product in period one (to be a pre-owned consumer) and below which a consumer postpones purchase to period two (to be a waited consumer). In period two, a pre-owned consumer always keeps used products, while a waited consumer purchases a new product from the retailer when the new-product value is medium, i.e., $v \in \left[\frac{1+2\theta}{2(1+4\theta)}, \frac{1+2\theta}{1+4\theta}\right)$, but leaves the market when the new-product value is low, i.e., $v \in \left[0, \frac{1+2\theta}{2(1+4\theta)}\right)$. The equilibrium outcomes are presented in Table 3.2. A lowered used-product value (value of θ decreases) makes them less likely to purchase new products in period one, and once they wait, more likely to leave without purchasing in period two, causing a reduction in total demand to worsen the retailer's revenue.

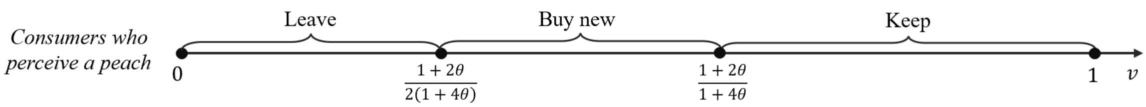


Figure 3.5: Market segmentation in the absence of CRP, with $\eta = 1$

Table 3.2: Performance outcomes in the absence of CRP, with $\eta = 1$

	Period one	Period two	Total
New-product price	$p_1^{B*} = \frac{(1+2\theta)^2}{2(1+4\theta)}$	$p_2^{B*} = \frac{1+2\theta}{2(1+4\theta)}$	-
New-product demand	$d_1^{B*} = \frac{2\theta}{1+4\theta}$	$d_2^{B*} = \frac{1+2\theta}{2(1+4\theta)}$	$d^{B*} = \frac{1+6\theta}{2(1+4\theta)}$
Revenue	$r_1^{B*} = \frac{\theta(1+2\theta)^2}{(1+4\theta)^2}$	$r_2^{B*} = \frac{(1+2\theta)^2}{4(1+4\theta)^2}$	$r^{B*} = \frac{(1+2\theta)^2}{4(1+4\theta)}$

Heterogeneous Secondhand Products

When consumers perceive either a peach or a lemon, Figure 3.6 illustrates the pattern for market segmentation. A threshold $\frac{1+2\theta\eta^2}{1+4\theta\eta^2}$ exists for new-product valuation v, above which a consumer purchases a new product in period one (to be a pre-owned consumer) and below which a consumer postpones purchase to period two (to be a waited consumer). In period two, a pre-owned consumer always keeps used products, while a waited consumer purchases a new product from the retailer when the new-product value is medium, i.e., $v \in \left[\frac{1+2\theta\eta^2}{2(1+4\theta\eta^2)}, \frac{1+2\theta\eta^2}{1+4\theta\eta^2}\right)$, but leaves the market when the new-product value is low, i.e., $v \in \left[0, \frac{1+2\theta\eta^2}{2(1+4\theta\eta^2)}\right)$. The performance outcomes are presented in Table 3.3.

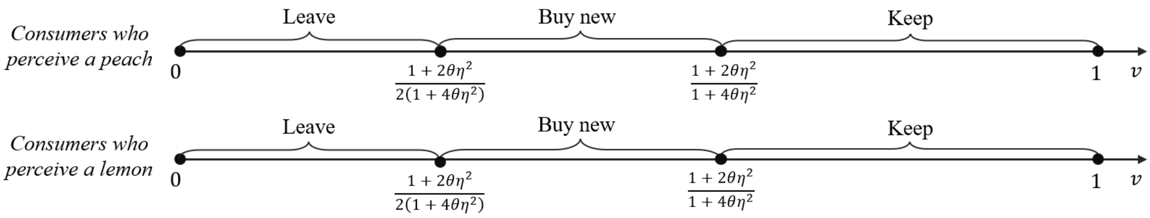


Figure 3.6: Market segmentation in the absence of CRP

Table 3.3: Performance outcomes in the absence of CRP

	Period one	Period two	Total
New-product price	$p_1^{B*} = \frac{\left(1+2\theta\eta^2\right)^2}{2(1+4\theta\eta^2)}$	$p_2^{B*} = \frac{1+2\theta\eta^2}{2(1+4\theta\eta^2)}$	-
New-product demand	$d_1^{B*} = \frac{2\theta\eta^2}{1+4\theta\eta^2}$	$d_2^{B*} = \frac{1+2\theta\eta^2}{2(1+4\theta\eta^2)}$	$d^{B*} = \frac{1+6\theta\eta^2}{2(1+4\theta\eta^2)}$
Revenue	$r_1^{B*} = \frac{\theta\eta^2\left(1+2\theta\eta^2\right)^2}{(1+4\theta\eta^2)^2}$	$r_2^{B*} = \frac{\left(1+2\theta\eta^2\right)^2}{4(1+4\theta\eta^2)^2}$	$r^{B*} = \frac{\left(1+2\theta\eta^2\right)^2}{4(1+4\theta\eta^2)}$

The retailer sets a higher price in period one than in period two, i.e., $p_1^{B*} > p_2^{B*}$, which echoes the well-known skimming policy. The new-product demand in period one (two, resp) comes from pre-owned (waited, resp) consumers, while a proportion of consumers refrain from purchasing and their demand is lost to the retailer. As consumers perceive a higher used-product value (value of θ increases), they have a stronger incentive to purchase early in the absence of CRP. It leads to an increase in new-product demand in period one but a decrease in new-product demand in period two (d_1^{B*} increases but d_2^{B*} decreases). The total demand $d_1^{B*} + d_2^{B*}$ increases. The retailer aggravates the intertemporal price difference ($p_1^{B*} - p_2^{B*}$ increases) and reaps a higher revenue. Moreover, as more consumers perceiving a peach are in the market (value of η increases), the expected utility of keeping used products ($E(\theta)v = \eta\theta v$) increases. It causes the new-product demand and price in period one (two, resp) to increase (decrease, resp), i.e., d_1^{B*} and p_1^{B*} increase, while d_2^{B*} and p_2^{B*} decrease. The retailer serves more consumers, with fewer consumers leaving without a purchase, to make a higher revenue.

3.3.3 Main model: In the Presence of CRP

With the rise of CRP, pre-owned consumers can resell and waited consumers can purchase used products on the platform in period two, i.e., pre-owned (waited, resp) consumers form supply (demand, resp) on the CRP. The introduction of this platform provides consumers with more options for what and when to purchase. Specifically, a consumer can purchase a new product from the retailer in period one and resell it on the CRP to repurchase a new product from the retailer in period two, while waited consumers may purchase used products on the CRP in period two. Thus, the quantity and the composition of consumers who purchase new products in the two periods alter, forcing the retailer to adjust prices to cater to the presence of CRP.

Figure 3.7 enumerates all the purchase options alongside the incurred utilities. The retailer sets prices (p_1, p_2) to sell new products in the two periods. On the CRP, a general-equilibrium price p_s^* is reached to match the supply (from pre-owned consumers) with the demand (from waited consumers) for used products (Anderson & Ginsburgh 1994; B. Jiang & Tian 2018; Tian & Jiang 2018; Yin et al. 2010). In period one, the marginal consumer receives an expected utility as indicated below:

$$\underbrace{v - p_1 + \max\{E(\theta)v, (1-\tau)\,p_s + v - p_2, (1-\tau)\,p_s\}}_{to\ be\ a\ pre-owned\ consumer} = \underbrace{\max\{v - p_2, E(\theta)v - p_s, 0\}}_{to\ be\ a\ waited\ consumer} \tag{3.2}$$

where a consumer purchasing a new product in period one expects to receive utility $E(\theta)v$, $(1-\tau)\,p_s + v - p_2$, and $(1-\tau)\,p_s$ by keeping the used product, reselling the used product and repurchasing a new one, and reselling the used product and leaving in period two, respectively. A consumer who postpones purchase in period one expects to receive utility $v - p_2$ by purchasing a new product, and $E(\theta)v - p_s$ by purchasing a used product in period two.

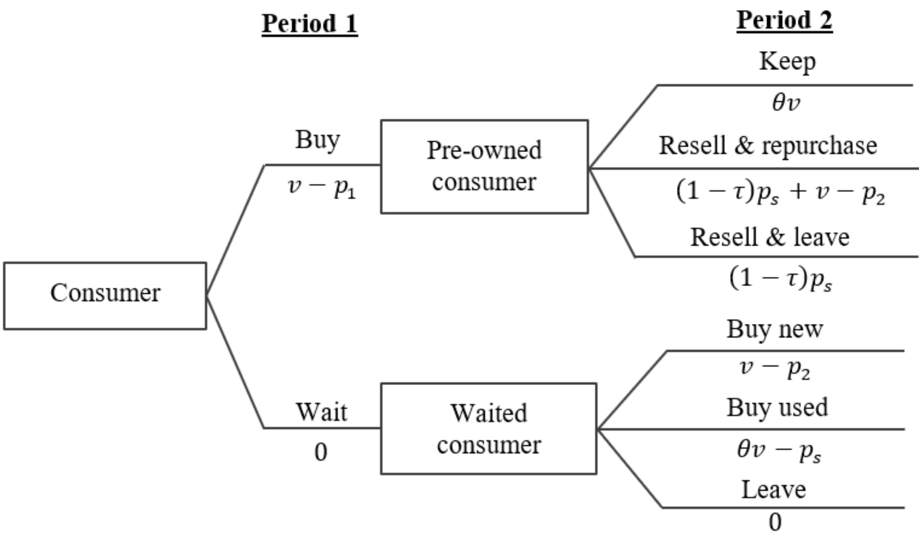


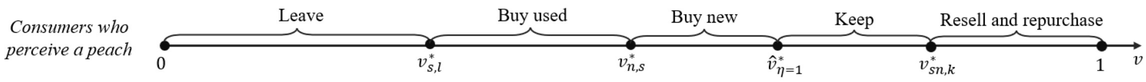
Figure 3.7: Decision sequence in the presence of CRP

The retailer maximizes total revenue $r = p_1 d_1 + p_2^B d_2$, where (p_1, p_2) are the prices and (d_1, d_2) are the demands for new products in the two periods. Using backward induction, we first analyze the retailer's period-two optimal price as a function of the period-one price and then characterize the optimal period-one price. We apply the notion of Rational Equilibrium (RE) by Muth (1961): consumers' expectations about the prices for new and used products are consistent with those realized in the equilibrium; the CRP's expectation about the matchup of supply and demand for used products along with the market-clearing price for used products is consistent with that realized in the equilibrium; and the expectations constitute a consistent system. All the derivations are provided in Appendix A.2.2.

Homogeneous Secondhand Products

When all consumers perceive a lemon ($\eta = 0$), the CRP breaks down as no waited consumers would have the incentive to purchase used products. The market degenerates to the one without CRP as shown in Section 3.3.2.

When all consumers perceive a peach ($\eta = 1$), Figure 3.8 details the market segmentation. $\hat{v}^*_{\eta=1}$ is the threshold new-product valuation to partition consumers into pre-owned and waited segments. In period two, the supply and the demand for used products on CRP are $d^*_{p,sn} = 1 - v^*_{sn,k}$ and $d^*_{w,s} = v^*_{n,s} - v^*_{s,l}$. The number of pre-owned consumers who keep used products is $d^*_{p,k} = v^*_{sn,k} - \hat{v}^*_{\eta=1}$, while the number of waited consumers who purchase new products and leave without purchasing are, respectively, $d^*_{w,n} = \hat{v}^*_{\eta=1} - v^*_{n,s}$ and $d^*_{w,l} = v^*_{s,l}$. The results are grouped in Table 3.4.



Note. $\Lambda_1 = 1 + \theta\,(9 - \tau)$, $\Lambda_2 = 1 + \theta\,(1 - \tau)$, $\hat{v}^*_{\eta=1} = \frac{1+\theta(5-\tau)}{\Lambda_1}$,

$v^*_{sn,k} = \frac{\theta^3\left(\tau^2(10-\tau)-41\tau+32\right)-2\theta^2\left(\tau^2-12\tau+7\right)+\theta(5\tau-16)-2}{4\Lambda_1\Lambda_2(\theta-1)}$, $v^*_{n,s} = \frac{\theta^3\left(\tau^2(\tau-4)-13\tau+32\right)-2\theta^2\left(2\tau^2-10\tau+7\right)+\theta(5\tau-16)-2}{4\Lambda_1\Lambda_2(\theta-1)}$,

and $v^*_{s,l} = \frac{\theta\left(\theta\left(\tau^2-7\tau+14\right)-\tau-2\right)}{2\Lambda_1\Lambda_2}$.

Figure 3.8: Market segmentation in the presence of CRP, with $\eta = 1$

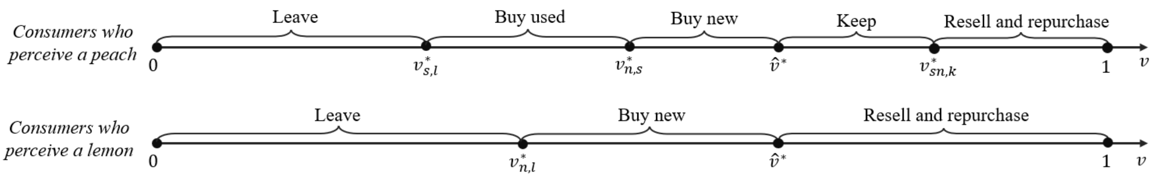
Heterogeneous Secondhand Products

When consumers perceive either a peach or a lemon, Figure 3.9 shows the existence of a threshold new-product valuation $\hat{v}^*$ to regulate consumers' purchase behavior in period one. A consumer with a new-product valuation above $\hat{v}^*$ purchases a new product in period one, while a consumer with a new-product valuation below $\hat{v}^*$ postpones purchase to period two. In period two, among pre-owned consumers, those who perceive a peach adopt the resell-and-repurchase option when their new-product valuations are high ($v^*_{sn,k} \leq v \leq 1$) but adopt the keep option otherwise ($\hat{v}^* \leq$

Table 3.4: Performance outcomes in the presence of CRP, with $\eta = 1$

	Period one	Period two
New-product price	$p_1^* = \frac{\theta^2\left(\tau^2-9\tau+16\right)-3\theta(\tau-6)+2}{4\Lambda_1}$	$p_2^* = \frac{\theta^2\left(\tau^2-5\tau-4\right)-\theta(3\tau-14)+2}{4\Lambda_1}$
New-product demand	$d_1^* = \frac{4\theta}{\Lambda_1}$	$d_2^* = \frac{\theta^2\left(\tau^2-5\tau-4\right)-\theta(3\tau-14)+2}{2\Lambda_1\Lambda_2}$
Total demand	$d^* = \frac{\theta^2\left(\tau^2-5\tau-4\right)-\theta(3\tau-14)+2}{2\Lambda_1\Lambda_2}$	
Used-product price	$p_s^* = \frac{\theta^2\left(\theta\left(\tau^2-7\tau+14\right)-\tau-2\right)}{2\Lambda_1\Lambda_2}$	
Used-product demand	$d_s^* = \frac{\theta^3\left(\tau^3-6\tau^2+\tau+4\right)-2\theta^2\left(\tau^2-4\tau-9\right)+\theta(3\tau-20)-2}{4\Lambda_1\Lambda_2(\theta-1)}$	
Revenue	$r_1^* = \frac{\theta\left(\theta^2\left(\tau^2-9\tau+16\right)-3\theta(\tau-6)+2\right)}{\Lambda_1{}^2}$	$r_2^* = \frac{\left(\theta^2\left(\tau^2-5\tau-4\right)-\theta(3\tau-14)+2\right)^2}{8\Lambda_1{}^2\Lambda_2}$
Total revenue	$r^* = \frac{\theta^3\left(\tau^2(9-\tau)+16(1-\tau)\right)+\theta^2\left(5\tau^2-36\tau+16\right)-4\theta(2\tau-9)+4}{8\Lambda_1\Lambda_2}$	

$v < v_{sn,k}^*$), while those who perceive a lemon adopt the resell-and-repurchase option ($\hat{v}^* \leq v \leq 1$). Among waited consumers, those who perceive a peach purchase new products from the retailer, purchase used products on the CRP and leave when their new-product valuations are high ($v_{n,s}^* \leq v < \hat{v}^*$), intermediate ($v_{s,l}^* \leq v < v_{n,s}^*$), and low ($0 \leq v < v_{s,l}^*$), respectively, while those who perceive a lemon purchase new products when their new-product valuations are high ($v_{n,l}^* \leq v < \hat{v}^*$), but leave otherwise ($0 \leq v < v_{n,l}^*$).



Notes. $v_{sn,k}^* = \frac{p_2^*-(1-\tau)p_s^*}{1-\theta}$, $v_{n,s}^* = \frac{p_2^*-p_s^*}{1-\theta}$, $v_{n,l}^* = p_2^*$, $v_{s,l}^* = \frac{p_s^*}{\theta}$.

Figure 3.9: Market segmentation in the presence of CRP

Table 3.5 presents performance outcomes. The new-product demand in period one comes from pre-owned consumers, i.e., $d_1 = 1-\hat{v}^*$, while that in period two comes from the pre-owned consumers who resell and repurchase (which equals in quantity to that of the waited consumers who purchase used products on the CRP) and the waited consumers who purchase new products, i.e.,

$$d_2 = \underbrace{\underbrace{\eta\left(1 - v^*_{sn,k}\right)}_{perceive\ a\ peach} + \underbrace{(1-\eta)\left(1 - \hat{v}^*\right)}_{perceive\ a\ lemon}}_{pre-owned\ consumers} + \underbrace{\underbrace{\eta\left(\hat{v}^* - v^*_{n,s}\right)}_{perceive\ a\ peach} + \underbrace{(1-\eta)\left(\hat{v}^* - v^*_{n,l}\right)}_{perceive\ a\ lemon}}_{waited\ consumers}. \tag{3.3}$$

On the CRP, the used-product supply comes from the pre-owned consumers who resell, in a number of $\underbrace{\eta\left(1 - v^*_{sn,k}\right)}_{perceive\ a\ peach} + \underbrace{(1-\eta)\left(1 - \hat{v}^*\right)}_{perceive\ a\ lemon}$, while the used-product demand comes from the waited consumers, in a number of $\eta\left(v^*_{n,s} - v^*_{s,l}\right)$. The number of waited consumers who leave without purchasing is $d^*_{w,l} = \underbrace{\eta v^*_{s,l}}_{perceive\ a\ peach} + \underbrace{(1-\eta)\, v^*_{n,l}}_{perceive\ a\ lemon}$.

Table 3.5: Performance outcomes in the presence of CRP

	Period one	Period two
New-product price	$p_1^* = \frac{\Lambda_{p_1^*}}{\eta\Lambda_2(\theta(1-\eta)(\tau-1)-\eta-1)}$	$p_2^* = \frac{\theta(\hat{v}^*(2-\tau)-\hat{v}^*\eta-1)+\hat{v}^*\eta+1}{2\theta(\eta-1)+2(\eta+1)(\tau-1)}$
New-product demand	$d_1^* = 1-\hat{v}^*$	$d_2^* = \frac{\theta(\hat{v}^*(2-\tau-\eta)-1)+\hat{v}^*\eta+1}{2\Lambda_2}$
Total demand	$d^* = \frac{\theta(\hat{v}^*(\tau-\eta)-2\tau+1)-\hat{v}^*(2-\eta)+3}{2\Lambda_2}$	
Used-product price	$p_s^* = \frac{\theta\left(\theta^2(\hat{v}^*(\eta-1)+1)(\eta-1)(\tau-1)+\theta\left(-\hat{v}^*(\tau-1)\eta^2+\eta(1+\tau(\hat{v}^*-1))-\tau(\hat{v}^*-1)\right)+\hat{v}^*-1\right)}{\eta\Lambda_2(\theta(\eta-1)(\tau-1)+\eta+1)}$	
Used-product demand	$d_s^* = \frac{\theta^2(\tau-1)\left(-\hat{v}^*\eta^2+\eta(\hat{v}^*(\tau+2)-1)-2(\hat{v}^*-1)\right)+\theta(\hat{v}^*(\eta-1)+1)(\eta(\tau-2)-2\tau)+\eta-2(\hat{v}^*-1)}{(1-\eta)\Lambda_2(\eta-\Lambda_2)(\theta-1)}$	
Revenue	$r_1^* = \frac{(1-\hat{v}^*)\Lambda_{p_1^*}}{\eta\Lambda_2(\theta(1-\eta)(\tau-1)-\eta-1)}$	$r_2^* = \frac{(\theta(\hat{v}^*\eta+1-\hat{v}^*(\tau-2))-\hat{v}^*\eta-1)^2}{4\Lambda_2(\theta(\eta-1)(\tau-1)+\eta+1)}$
Total revenue	$r^* = \frac{(1-\hat{v}^*)\Lambda_{p_1^*}}{\eta\Lambda_2(\theta(1-\eta)(\tau-1)-\eta-1)} + \frac{(\theta(\hat{v}^*\eta+1-\hat{v}^*(\tau-2))-\hat{v}^*\eta-1)^2}{4\Lambda_2(\theta(\eta-1)(\tau-1)+\eta+1)}$	

Lemma 3.1. *Used-product transactions on the CRP are sustained when consumers perceive a high used-product value, i.e.,* $\theta \geq \underline{\theta}(\tau,\eta)$*, where* $\underline{\theta}(\tau,\eta)$ *is defined in Appendix A.1, and it increases with* τ *but decreases with* η*.*

A notable issue pertains to the sustainability of transactions on the CRP so that the used-product market can be maintained in parallel to the new-product market managed by the retailer. Lemma 3.1 states that the CRP is functional when consumers perceive a high value from used-product consumption. The option of reselling used products for a resale revenue and repurchasing new products at a possibly lower price in period two incentivizes consumers to purchase new products in period one, forming the supply of used products on the CRP. Recall that the waited consumers purchase used products on the CRP only when they perceive a peach. Their incentive to purchase is weak when they perceive a low value of used-product consumption. A high supply relative to a low demand breaks down the used-product market, which regains balance only when consumers perceive a high value of used products. Intuitively, the CRP is less likely to function (threshold $\underline{\theta}(\tau, \eta)$ increases) when it sets a higher commission rate (value of τ increases), which curbs supply, but it is more likely to function (threshold $\underline{\theta}(\tau, \eta)$ decreases) as a higher proportion of consumers perceive a peach (value of η increases), which drives in more demand.

In the following analysis, we assume $\theta \geq \underline{\theta}(\tau, \eta)$ to ensure the validity of transactions on the CRP. The CRP competes with the retailer for demand, the intensity of which strengthens as consumers perceive a higher value of used products so that used and new products are more substitutable in selling to waited consumers, i.e., vertical differentiation between used and new products weakens. Specifically, we can show that as θ increases, the transaction price p_s^* for used products increases while new-product price in period two p_2^* decreases. It results in a reduction in $p_2^* - p_s^*$, indicating intensified competition between used and new products for waited consumers.

Premised on the performance outcomes with and without CRP, we examine the impact of CRP on the retailer, consumers, social welfare, and environment through a comparative investigation. We first consider the situation where all consumers perceive a peach or a lemon in Section 3.4, to isolate the key effects of CRP. Then, we explore the general situation where consumers perceive either a peach or a lemon to produce more insights into the role of CRP in influencing the retailer's pricing adaptations in Section 3.5.

3.4 Dynamic Pricing Strategy for New Products Considering Homogeneous Secondhand Products

Note that when all consumers perceive a lemon ($\eta = 0$), the CRP ceases to sustain secondhand transactions. It is the case for products such as daily necessities and perishable foods. This section focuses on the case where all consumers perceive a peach ($\eta = 1$). The condition for the CRP to function in the peach-dominating market is $\theta \geq \underline{\theta}_{\eta=1}(\tau) = \frac{\tau+2}{\tau^2-7\tau+14}$.

Prior literature states that the presence of C2C used-product platform is detrimental to the retailer's revenue (Yin et al. 2010; P. Desai et al. 2004). As to be demonstrated, this result no longer holds in our setting, attributed to the effects of CRP on the retailer's prices and demand. Lemma 3.2 states the effects of the used-product value perceived by consumers on the new-product prices set by the retailer and the transaction price for used products on the CRP, along with the number of pre-owned and waited segments.

Lemma 3.2. *In the presence of CRP, the retailer adopts a skimming policy to set new-product prices over periods. As consumers' perceived used-product value increases (value of θ increases),*

1. *the number of pre-owned (waited) consumers increases (decreases);*
2. *the new-product price in period one (period two) increases (decreases), thus increasing intertemporal price discrimination;*
3. *on the CRP, the transaction price increases, while the transaction volume decreases;*
4. *more consumers leave without purchasing.*

The presence of CRP incubates the competition between used and new products in period two. The retailer sets a lower new-product price in period two relative to that in period one ($p_1^* > p_2^*$); otherwise, consumers would have no incentive to postpone purchasing new products to period two. At an increased value of used-product consumption, waited consumers are willing to pay a higher price for used products, boosting the transaction price, and pre-owned consumers receive a higher value by keeping used products. As such, owning products enables consumers to extract more surplus from used-product deployment and consumption, incentivizing them to purchase new products in period one instead of postponing purchase to period two. The demand increase drives the retailer to raise the new-product price in period one. Nevertheless, an increased used-product value implies stronger substitutability of used and new products, clamping down on the retailer's new-product price in period two to compete with CRP for demand. Consequently, intertemporal price difference aggravates.

An increase in the value perceived by consumers of used-product consumption weighs on their purchase incentives. On the one hand, the number of consumers who purchase new products in period one increases, while more pre-owned consumers keep used products, reducing the supply to the CRP. On the other hand, the substitutability of used to new products strengthens, inducing more waited consumers to purchase used products rather than new products, against a reduced number of waited consumers. A higher demand relative to a lower supply boosts the transaction price, decreasing the transaction volume and resulting in more consumers leaving the market without a purchase. As such, the retailer has the liberty of managing new-product prices to balance new-product demands over periods, by deterring strategic consumer waiting to shift demand to period one and sustain used-product transactions on the CRP in the meanwhile.

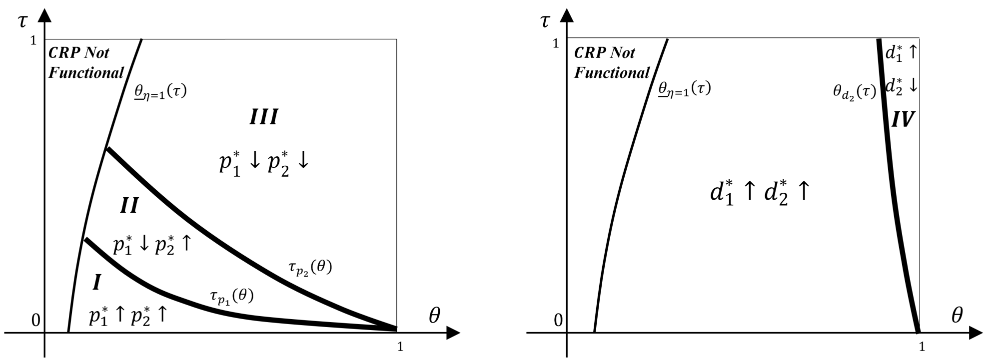
Proposition 3.1. *When all consumers perceive a peach ($\eta = 1$), compared to the situation without CRP, referring to Figure 3.10, in the presence of CRP:*

1. *period-one new-product price increases if the CRP's commission rate is low, i.e.,* $\tau < \tau_{p_1}(\theta)$*, but decreases otherwise; period-two new-product price increases if the CRP's commission rate is low to medium, i.e.,* $\tau < \tau_{p_2}(\theta)$*, but decreases otherwise;*

2. *period-one new-product demand increases; period-two new-product demand increases except when consumers' perceived used-product value is extremely high, i.e.,* $\theta \geq \theta_{d_2}(\tau)$*; total new-product demand increases;*

3. *mitigates intertemporal price discrimination adopted by the retailer, i.e.,* $p_1^* - p_2^* < p_1^{B*} - p_2^{B*}$.

Proposition 3.1 states the effects of CRP on the retailer's operations performances. The rise of CRP causes the new-product price in period one to increase when the commission rate is low (i.e., $\tau < \tau_{p_1}(\theta)$, area *I* in Figure 3.10) but decrease otherwise. The new-product demand increases relative to that in the absence of CRP because the CRP provides a venue for used-product transactions, enticing consumers to purchase early and sell later to receive a reselling revenue. It becomes more prominent as the CRP's commission rate decreases.



Note. $\downarrow$ *indicates "worsens" and* $\uparrow$ *indicates "improves";* $\tau_{p_1}(\theta)$, $\tau_{p_2}(\theta)$*, and* $\theta_{d_2}(\tau)$ *are defined in Appendix A.1.*

Figure 3.10: Effects of CRP on price and demand, with $\eta = 1$

In period two, vertical-differentiation-triggered competition arises between used products sold on the CRP and new products sold by the retailer. At a low-to-medium commission rate (i.e., $\tau < \tau_{p_2}(\theta)$, areas I and II in Figure 3.10(a)), pre-owned consumers have a strong incentive to resell used products. As the pre-owned consumers who resell on the CRP repurchase new products from the retailer, the competition pressure that the CRP imposes on the retailer is weak, inducing it to raise new-product price in period two without worrying too much about demand. Otherwise, at a high commission rate (i.e., $\tau \geq \tau_{p_2}(\theta)$, area III in Figure 3.10(a)), the reselling option no longer appeals to pre-owned consumers. The retailer lowers new-product price to mainly attract demands from waited consumers. The new-product demand in period two increases relative to that without CRP except when consumers perceive a sufficiently high used-product value (i.e., $\theta \geq \theta_{d_2}(\tau)$, area IV in Figure 3.10(b)). In this case, despite the large number of pre-owned consumers, few of them are inclined to resell, causing the transaction volume on the CRP to drop and thus lowering the repurchase volume. The demand for new products from waited consumers reduces as well. Consequently, the new-product demand in period two reduces relative to when the CRP is absent.

As all consumers perceive a peach, the retailer shrinks the price gap across periods relative to that in the absence of CRP. This finding is consistent with previous studies. For instance, the seminal work of Coase (1972) indicates that a monopolist can deter consumers' strategic waiting by maintaining a stable price. Stokey (1979) and Besanko & Winston (1990) reveal the negative impact of strategic consumers on the firm's intertemporal price discrimination. Liu & Zhang (2013) find that price skimming can harm firms in a duopoly market with strategic consumers. Our result unveils a concrete situation in the presence of CRP, where the firm manages intertemporal price discrimination to deter strategic waiting.

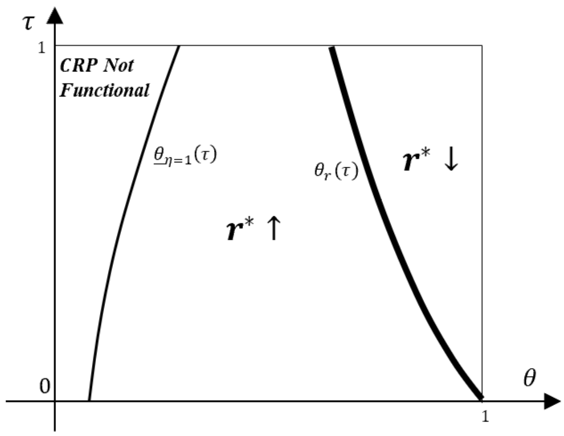
Compared to that in the absence of CRP, the rise of CRP causes the new-product demand in period one to increase, and it causes the new-product demand in period two to increase in most situations, contributing to a revenue gain in each period;

we term it the *demand-expansion effect*. The platform's commission rate and the used-product value perceived by the consumers interplay to weigh on the prices over periods. The new-product price in a period increases when the commission rate is low, while the price increase is more prominent in the later period than in the early period. Against the demand-expansion effect, the price adaptation has mixed effects on the revenue.

3.4.1 Impacts on Retailer's Revenue

Proposition 3.2 states the aggregate effect on the revenue.

Proposition 3.2. *Compared to the situation without CRP, in the presence of CRP, referring to Figure 3.11, the retailer's revenue improves when consumers' perceived used-product value is medium, i.e.,* $\underline{\theta}_{\eta=1}(\tau) \leq \theta < \theta_r(\tau)$*, where* $\theta_r(\tau)$ *is defined in Appendix A.1, but it decreases otherwise.*



Note. ↓ *indicates "worsens" and* ↑ *indicates "improves".*

Figure 3.11: Effects of CRP on the retailer's revenue, with $\eta = 1$

The demand-expansion effect arising from the rise of CRP improves the revenue for the retailer in each period. As consumers perceive a low value of used products, the retailer manages a small intertemporal price difference to deter strategic waiting. Compared to when the CRP is absent, in the presence of CRP, more consumers purchase new products in period one, and they are more likely to resell and repurchase than to keep using the products in period two. In the meanwhile, waited consumers are more likely to purchase used products than leaving because of the low used-product transaction price. Consequently, the transaction volume on the CRP increases and fewer consumers leave without purchasing. While a low (high) commission rate entices the retailer to increase (decrease) prices, the demand-expansion effect is dominant in improving the retailer's total revenue.

As consumers perceive a high value of used products, the retailer manages a large intertemporal price difference to induce consumers to postpone purchases. It is to curb the number of pre-owned consumers, who are more likely to keep used products than to resell and repurchase in period two. The supply to the CRP is low, lowering the transaction volume and resulting in more waited consumers leaving without a purchase. Thus, the demand-expansion effect of the CRP is weak in each period. The low new-product demand in period one clamps down on the price, forcing the retailer to lower the new-product price in period two. The lowered price attracts pre-owned consumers to turn into used-product suppliers and new-product repeat purchasers, allowing the retailer to compete with the CRP for waited consumers. The effect of price reductions in the two periods outweighs the demand-expansion effect to worsen the retailer's total revenue.

Notably, although the presence of CRP exposes the retailer to competition as consumers can purchase used products at a lowered price, it does not necessarily cause the retailer's revenue to drop. Instead, the retailer's revenue can increase. It contrasts with the existing literature, which states that the prevalence of a C2C platform harms the retailer (P. Desai et al. 2004; Yin et al. 2010). The rationale is as follows. In our model, consumers can repurchase new products from the retailer after selling used ones on the CRP, and the retailer can manage new-product demands by adapting prices over periods to leverage consumers' strategic waiting and reselling behaviors. Our results unveil a decreasing trajectory for new-product prices ($p_1^* > p_2^*$) and a higher total new-product demand ($d^* > d^{B*}$), with a proportion of new-product demand in period one converted to used-product transactions on CRP in period two. Dynamically setting new-product prices over periods enables the retailer to manage new-product sales in parallel to aligning the matchup of supply and demand of used products on the CRP, leading to a more efficient distribution of demand. This echoes retailers' strategic choice to enter resale: 88% of retail executives who currently offer resale say it helps drive revenue (ThredUP 2022).

3.4.2 Impacts on Consumer Surplus and Social Welfare

Based on the performance outcomes in the absence and presence of CRP, we explore the effects of CRP on consumer surplus and social welfare. Consumer surplus aggregates consumers' total net utilities in the consumption of new and used products in the two periods. As all the consumers perceive a peach, in the absence of CRP, consumer surplus is:

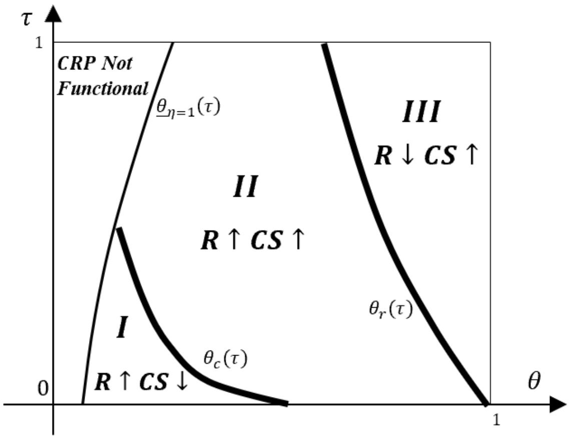
$$cs^B = \underbrace{\int_{\frac{1+2\theta}{1+4\theta}}^{1} \left(v - p_1^{B*} + \theta v\right) dv}_{pre-owned\ consumers} + \underbrace{\int_{0}^{\frac{1+2\theta}{1+4\theta}} \left(v - p_2^{B*}\right) dv}_{waited\ consumers} = \frac{\theta\left(2\theta^2 + 4\theta + 1\right)}{(1+4\theta)^2} \tag{3.4}$$

while in the presence of CRP, it is:

$$\begin{aligned} cs = & \underbrace{\int_{v^*_{sn,k}}^{1} \left(v - p_1^* + (1-\tau)\, p_s^* + v - p_2^*\right) dv}_{pre-owned\ consumers\ who\ resell\ and\ repurchase} + \underbrace{\int_{\hat{v}^*_{\eta=1}}^{v^*_{sn,k}} \left(v - p_1^* + \theta v\right) dv}_{pre-owned\ consumers\ who\ keep} \\ & + \underbrace{\int_{v^*_{n,s}}^{\hat{v}^*_{\eta=1}} \left(v - p_2^*\right) d\theta}_{waited\ consumers\ who\ buy\ new} + \underbrace{\int_{v^*_{s,l}}^{v^*_{n,s}} \left(\theta v - p_s^*\right) d\theta}_{waited\ consumers\ who\ buy\ used} = \frac{\Lambda_c}{16{\Lambda_1}^2{\Lambda_2}^2\left(\theta - 1\right)}. \end{aligned} \tag{3.5}$$

Proposition 3.3 states the impact of the CRP on consumer surplus.

Proposition 3.3. *Referring to Figure 3.12, the presence of CRP makes the consumers better off when consumers perceive a high used-product value, i.e., $\theta \geq \theta_c(\tau)$,* *where $\theta_c(\tau)$ is the threshold and is defined in Appendix A.1, but makes the consumers worse off otherwise, i.e., $\underline{\theta}_{\eta=1}(\tau) \leq \theta < \theta_c(\tau)$.*



Notes. "R" stands for retailer and "CS" stands for consumer surplus; ↓ indicates "worsens" and ↑ indicates "improves".

Figure 3.12: Effects of CRP on consumer surplus, with $\eta = 1$

Intuitively, consumers should be the main beneficiaries of CRP, which grants them more purchase choices. Recall that, in the absence of CRP, consumers only purchase new products, with pre-owned consumers purchasing in period one and waited consumers purchasing in period two. In the presence of CRP, pre-owned consumers can resell used products and repurchase new ones, while waited consumers can choose between used and new products. Our result indicates that consumer surplus improves when consumers perceive a high used-product value. In this case, the high transaction price on the CRP benefits the pre-owned consumers who resell, the high value of used products benefits the pre-owned consumers who keep using products, the low used-product price caused by the vertical substitutability of used and new products benefits the waited consumers who purchase used products, i.e., $\frac{\partial(p_2^*-p_s^*)}{\partial\theta} < 0$, and the low new-product price benefits the waited consumers who directly purchase new products from the retailer in period two.

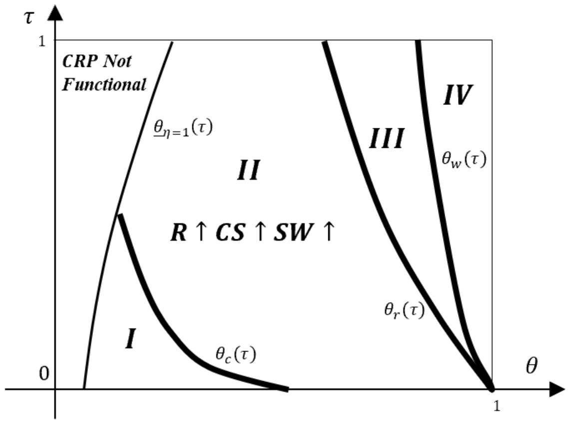
As consumers perceive a higher value of used products, the retailer lowers the new-product price in period one to deter strategic waiting, and lowers the new-product price in period two to compete with CRP. All these results in an improved consumer surplus when $\theta \geq \theta_c(\tau)$, even when the CRP retains all the transaction revenue at a commission rate of $\tau = 1$ (areas II and III in Figure 3.12). Nevertheless, consumer surplus decreases when the commission rate is low and consumers perceive a low value of used products, i.e., $\underline{\theta}_{\eta=1}(\tau) \leq \theta < \theta_c(\tau)$, in which case, the retailer raises prices in both periods relative to those in the absence of CRP. While the decreased transaction price of used products benefits the waited consumers who purchase from the CRP, the increased new-product prices harm the consumers who purchase from the retailer, leading to a reduction in consumer surplus.

The retailer takes advantage of the increased purchase options made possible by the rise of CRP in selling to consumers. It is noteworthy that the existence of CRP can benefit the retailer and the consumers simultaneously. One exception is that when the used-product value perceived by the consumers is low (high) and the commission rate set by the retailer is high (low), i.e., areas I and III in Figure 3.12, in which case, the CRP exerts opposite effects on the retailer and the consumers. Thus, the retailer and consumers are likely to converge in their preferences over the establishment of CRP (area II in Figure 3.12), which competes with the retailer for demand but offers the consumers more opportunities to purchase or resell.

In the absence of CRP, social welfare aggregates retailer's revenue and consumer surplus, i.e., $sw^B = r^{B*} + cs^B = \frac{12\theta\left(2\theta^2+3\theta+1\right)+1}{4(1+4\theta)^2}$. In the presence of CRP, the transaction revenue received by the CRP is counted as well, with $sw = r^* + \tau p_s^* d_s^* + cs = \frac{\Lambda_w}{16{\Lambda_1}^2{\Lambda_2}^2(\theta-1)}$. Proposition 3.4 demonstrates the impact of the CRP on social welfare.

Proposition 3.4. *Referring to Figure 3.13, compared to the situation when CRP is absent, the presence of CRP improves social welfare except when consumers perceive a high value of used products, i.e.,* $\theta \geq \theta_w(\tau)$, *where* $\theta_w(\tau)$ *is defined in Appendix A.1.*

Wherever both the retailer and the consumers are better off, i.e., $\theta_c(\tau) \leq \theta <$



Notes. *"R" stands for retailer, "CS" stands for consumer surplus, and "SW" stands for social welfare;* $r^* \uparrow cs \downarrow sw \uparrow$ *in area I;* $r^* \downarrow cs \uparrow sw \uparrow$ *in area III; and* $r^* \downarrow cs \uparrow sw \downarrow$ *in area IV;* $\downarrow$ *indicates "worsens" and* $\uparrow$ *indicates "improves".*

Figure 3.13: Effects of CRP on social welfare, with $\eta = 1$

$\theta_r(\tau)$, the commission revenue received by the CRP strengthens the gain in social welfare, leading to a win-win situation for all market participants (area II in Figure 3.13). In other situations, either the consumers or the retailer is worse off with the rise of CRP, while the CRP's revenue exerts a moderating effect on social welfare. Specifically, as consumers perceive a low value of used-product consumption (area I in Figure 3.13), the revenue gain to the retailer, which is attributed to the increases in new-product prices and demands, and the CRP's revenue outweigh the reduced consumer surplus to improve social welfare. As consumers perceive a medium-high value of used products (area III in Figure 3.13), the high revenue reaped by the CRP, which is attributed to the high transaction price, and the gain in consumer surplus outweigh the revenue loss to the retailer to improve social welfare. In contrast, as consumers perceive a sufficiently high used-product value (area IV in Figure 3.13), the revenue loss to the retailer can outweigh the gain in consumer surplus and the CRP's revenue, which suffers a low transaction volume despite a high transaction price, to worsen social welfare. Thus, the rise of CRP is more likely to benefit the society than individual consumers and the retailer.

3.4.3 Impacts on Environment

Next, we explore from the environment's perspective. The extant literature (Agrawal et al. 2012; Xue et al. 2018) quantify the environmental impact over three lifecycle phases: production, use, and disposal. Table 3.6 presents the impacts in the three phases in the absence and presence of CRP. Proposition 3.5 states the environmental impact of the CRP.

Table 3.6: Environmental impacts without and with CRP

	Production	Use	Disposal	Total
Without CRP	$e_p(d_1^{B*} + d_2^{B*})$	$e_{un}(d_1^{B*} + d_2^{B*}) + e_{us}d_{p,k}^{B*}$	$e_d(d_1^{B*} + d_2^{B*})$	E^B
With CRP	$e_p(d_1^* + d_2^*)$	$e_{un}(d_1^* + d_2^*) + e_{us}(d_{p,k}^* + d_{w,s}^*)$	$e_d(d_1^* + d_2^*)$	E

Proposition 3.5. *The demand-expansion effect arising from the presence of CRP aggravates the negative impact on the environment.*

The rise of CRP weakens intertemporal price discrimination to increase the new-product demand. The retailer's revenue largely improves as Proposition 3.2 states. It echoes a survey finding that nearly 66.7% of retail executives say that resale is having a positive impact on retail (ThredUP 2022). However, it sparks an inquiry into whether the CRP upholds the ethos of environmental friendliness held by the firms and consumers, and recycling of existing products. Despite its role in promoting C2C transactions to prolong the lifetime of existing products, the CRP results in a increase in the product quantity by influencing the alternation and usage between used and new products. Note that the rise of CRP not only ushers in a redistribution of demands for new products across periods but induces repeat purchases to increase consumption. Consumers, able to resell used products for monetary rewards, have the liquidity and space to repeatedly purchase new items (Matzler et al. 2014). The retailer adapts prices to fit the change in the consumers' purchase pattern.

We find that $E \geq E^B$ since $d \geq d^B$. It is against retailers' propaganda and consumers' motive for used-product transactions on CRP as creating an efficient and sustainable mode of consumption to eliminate the negative impact on the environment. This finding contrasts with Xue et al. (2018), who demonstrate that CRP can benefit the environment in certain conditions. The difference can be attributed to that Xue et al. (2018) assume consumers are myopic and ignore forward-looking consumers' strategic behavior. We identify a demand-expansion effect that arises from the retailer's price adaptations to exploit strategic consumer behavior. Overall, the rise of CRP can create a win-win situation to benefit all market participants, but at the expense of aggravated environmental impact.

Furthermore, practitioners can exert positive impact on the environment and cultivate a green image. They can include 'minimizing environmental impact' into their objectives, instead of focusing only on maximizing revenue. Recall that the rise of CRP ushers in a redistribution of demands for new products across periods and induces repeat purchases to increase consumption of products. When solely maximizing revenue, the retailer adapts prices to exploit strategic consumer behavior, which results in a demand-expansion effect to benefit the retailer but aggravate the environmental impact. Intending to mitigate the environmental impact, retailers may shift attention away from leveraging strategic consumer behavior to expand demand through intertemporal price discrimination. For instance, they can facilitate used product circulation by adopting measures to enhance consumers' perceived value of used products. One such means is to align with CRP to provide certified used-product credentials. As stated in Proposition 3.2, as consumers perceive a high value of used products, the retailer is inclined to enlarge intertemporal price difference to induce consumers to postpone purchases. It curbs the number of pre-owned consumers, reducing the segment of consumers who repurchase and resulting in more waited consumers leaving without a purchase. Consequently, the demand-expansion effect of the CRP is weakened in each period, which is to the benefit of the environment.

3.5 Dynamic Pricing Strategy for New Products Considering Heterogeneous Secondhand Products

In this section, we explore the general situation where consumers are segmented according to their perceptions of used-product values, that is, lemon and peach coexisting in the market. Compared to the situation where all the consumers perceive a peach ($\eta = 1$), as consumers perceiving a lemon participate in the market ($0 < \eta < 1$), the effects arising from CRP discussed in Section 3.4 largely remain valid except for a key difference in the retailer's price adaptations. Referring to Figure 3.9 and Figure 3.8, the used-product demand on the CRP still only comes from the consumers who perceive a peach, while the supply comes from the consumers who perceive either a peach or a lemon. Pre-owned consumers who perceive a lemon always resell and repurchase, implying that mixing consumers who perceive a lemon into the consumers who perceive a peach increases the supply to the CRP. The consumers who perceive a lemon are new-product chasers, leaving the retailer more room to adapt prices. All this incentivizes the retailer to intensify intertemporal price discrimination.

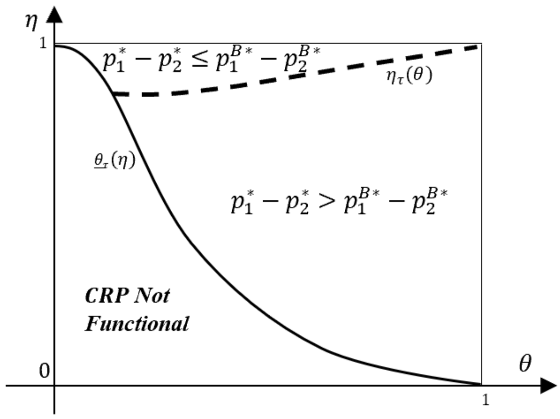


Figure 3.14: Effects of CRP on intertemporal pricing when commission rate τ is low

Proposition 3.6. *The presence of CRP exacerbates intertemporal price discrimination committed by the retailer, i.e.,* $p_1^* - p_2^* > p_1^{B*} - p_2^{B*}$*, if the proportion of consumers who perceive a peach is low, i.e.,* $\eta < \eta(\theta, \tau)$*, where* $\eta(\theta, \tau)$ *is defined in Appendix A.1, but mitigates intertemporal price discrimination otherwise, i.e.,* $\eta \geq \eta(\theta, \tau)$*.*

Recall that when the market is dominated by the consumers perceiving the used product to be a peach ($\eta = 1$), the retailer mitigates intertemporal price discrimination to deter consumers' strategic waiting. With heterogeneity among consumers in perceiving used-product valuations, the presence of CRP entices the retailer to exacerbate intertemporal price discrimination in most cases. Based on numerical simulations, L. Jiang et al. (2017) observe that the retailer encourages strategic waiting by managing intertemporal segmentation when the platform poses a limited competitive threat to the retailer. We unveil a similar finding, despite the significant difference between our model setting and that in L. Jiang et al. (2017). L. Jiang et al. (2017) assume the arrival of a new cohort of consumers in period two, thereby constituting the demand during this period. In our model, those pre-owned consumers who resell used products on the CRP repurchase new products from the retailer, forming part of its demand in addition to the demand from waited consumers. Moreover, L. Jiang et al. (2017) assume that the retailer adopts price commitment, and the consumers know how period-two price compares to period-one price, albeit without knowing their specific values. In contrast, we assume that the retailer engages in dynamic pricing and that consumers can rationally predict the price path. Regardless, our results specify the concrete situations wherein the retailer encourages strategic waiting in the presence of heterogeneity among the consumers in perceiving used-product values.

Lemma 3.3 details the effect of market composition in terms of the proportions of consumers who perceive a lemon and a peach on performance outcomes.

Lemma 3.3. *As the proportion of consumers who perceive a lemon increases, in most circumstances,*

1. *the number of pre-owned (waited) consumers decreases (increases);*

2. *the new-product demand in period two increases;*

3. *the transaction volume on the CRP increases;*

4. *more consumers leave without purchasing.*

As more consumers who perceive a lemon participate in the market, the expected utility that consumers receive by purchasing a new product in period one decreases, causing fewer consumers to purchase in period one but more consumers to postpone purchases to period two. Pre-owned consumers who perceive a peach either keep used products or resell them to repurchase new ones, while waited consumers who perceive a peach may purchase new or used products or even leave without a purchase. In contrast, the pre-owned consumers who perceive a lemon always resell used products to repurchase new ones and waited consumers who perceive a lemon never purchase used products. Recall that the CRP matches the supply by the pre-owned consumers who perceive either a peach or a lemon with the demand by the waited consumers who perceive a peach. The presence of the consumers who perceive a lemon brings in more new-product demand to the retailer in period two, by generating more supply from pre-owned consumers to the CRP that later converts into new-product demand and increasing the demand for new products from waited consumers. Despite the shrunken number of consumers who perceive a peach, once they postpone purchase, more of them purchase used products on the CRP. Nevertheless, more waited consumers who perceive a lemon leave without purchasing, causing a higher overall demand loss.

3.6 Dynamic Pricing Strategy for New Products Considering Secondhand Products with Salvage Value

Our analysis thus far assumes the disposal option offers a negligible salvage value of used products. In reality, however, consumers can dispose of used items to receive a positive salvage value, which is particularly the case in the automotive industry. We consider this option and study its impact on the value of CRP. Suppose that consumers can dispose of used products at an exogenous salvage value s_i at the end of period i with $s_1 \geq s_2$. The disposal option with a positive salvage value only affects the purchase decisions of pre-owned consumers, by granting them the additional options of disposing of used products.

Figure 3.15 depicts consumers' decision sequence in the absence of CRP with disposal. In this case, the marginal consumer receives the same expected utility to be a pre-owned or a waited consumer:

$$\underbrace{v - p_1^{B,D} + \max\left\{E(\theta)v + s_2, s_1 + v - p_2^{B,D} + s_2, s_1\right\}}_{to\ be\ a\ pre-owned\ consumer} = \underbrace{\max\left\{v - p_2^{B,D} + s_2, 0\right\}}_{to\ be\ a\ waited\ consumer} \tag{3.6}$$

where a consumer purchasing a new product in period one expects to receive utility $E(\theta)v + s_2$ under the keep option, $s_1 + v - p_2^{B,D} + s_2$ under the dispose-and-repurchase option, and s_1 under the dispose-and-leave option in period two. A consumer postponing purchase in period one expects to receive utility $v - p_2^{B,D} + s_2$ under the buy-new option in period two.

Following the same logic as that in the main analysis, we derive the optimal new-product prices set by the retailer in the two periods using backward induction. Please refer to Appendix A.4. To facilitate expressions, we assume $s_1 = s$ and $s_2 = 0$. Table 3.7 presents the performance outcomes. The results indicate that, in the existence

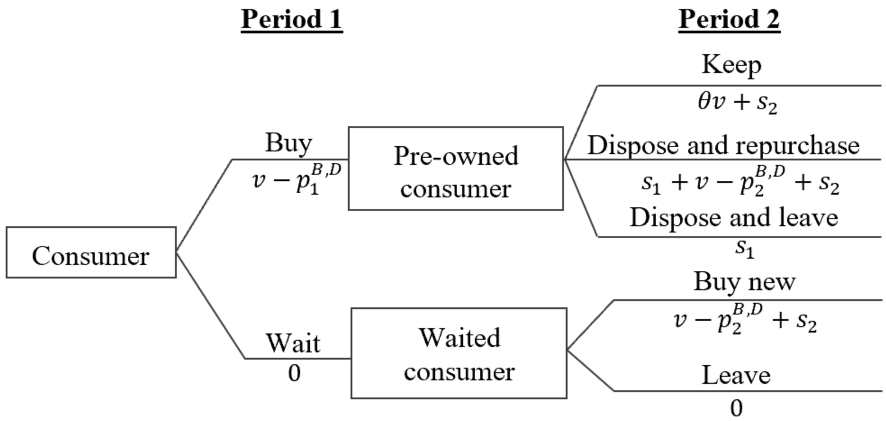


Figure 3.15: Decision sequence in the absence of CRP with disposal

of a disposal option, the retailer adheres to the skimming policy ($p_1^{B,D^*} > p_2^{B,D^*}$) in pricing new products across periods, by tailoring the prices in the two periods to fit with the salvage value. Specifically, the new-product prices increase as the salvage value increases. Figure 3.16 illustrates the pattern for market segmentation. The threshold new-product valuation v^{B,D^*} to segment pre-owned and waited consumers depends on the scale of the salvage value, i.e., $v^{B,D^*} = \frac{1-s}{2}$ when the salvage value is high ($s \geq s^{B,D}$) and $v^{B,D^*} = \frac{\theta\eta^2 - s(1-\eta)+1}{2(\theta\eta^2+1)}$ when the salvage value is low ($s < s^{B,D}$). A higher salvage value lowers the threshold, implying that more consumers are inclined to purchase early, which is intuitive.

Table 3.7: Performance outcomes in the absence of CRP with disposal

When $s < s^{B,D} = \frac{\sqrt{(\theta\eta^2+1)(\theta\eta+1)^2}-1-\theta\eta^2}{2-\eta(1-\theta)}$			
	Period one	Period two	Total
New-product price	$p_1^{B,D^*} = \frac{\theta\eta^2+s(1-\eta)+1}{2}$	$p_2^{B,D^*} = \frac{1-\theta+s\eta}{2(1-\theta(1-\eta))}$	-
New-product demand	$d_1^{B,D^*} = \frac{\theta\eta^2+s(1-\eta)+1}{2(\theta\eta^2+1)}$	$d_2^{B,D^*} = \frac{1-\theta+s\eta}{2(1-\theta)}$	$d^{B,D^*} = 1 + \frac{s\left(1+\theta\left(\eta^3+\eta-1\right)\right)}{2(\theta\eta^2+1)(1-\theta)}$
Revenue	$r_1^{B,D^*} = \frac{(\theta\eta^2+s(1-\eta)+1)^2}{4(\theta\eta^2+1)}$	$r_2^{B,D^*} = \frac{(1-\theta+s\eta)^2}{4(1-\theta)(1-\theta(1-\eta))}$	$r^{B,D^*} = \frac{(\theta\eta^2+s(1-\eta)+1)^2}{4(\theta\eta^2+1)} + \frac{(1-\theta+s\eta)^2}{4(1-\theta)(1-\theta(1-\eta))}$
When $s \geq s^{B,D} = \frac{\sqrt{(\theta\eta^2+1)(\theta\eta+1)^2}-1-\theta\eta^2}{2-\eta(1-\theta)}$			
	Period one	Period two	Total
New-product price	$p_1^{B,D^*} = \frac{1+s}{2}$	$p_2^{B,D^*} = \frac{1-\theta+s\eta}{2(1-\theta(1-\eta))}$	-
New-product demand	$d_1^{B,D^*} = \frac{1+s}{2}$	$d_2^{B,D^*} = \frac{1-\theta+s\eta}{2(1-\theta)}$	$d^{B,D^*} = 1 + \frac{s(1+\eta-\theta)}{2(1-\theta)}$
Revenue	$r_1^{B,D^*} = \frac{(1+s)^2}{4}$	$r_2^{B,D^*} = \frac{(1-\theta+s\eta)^2}{4(1-\theta)(1-\theta(1-\eta))}$	$r^{B,D^*} = \frac{(1+s)^2}{4} + \frac{(1-\theta+s\eta)^2}{4(1-\theta)(1-\theta(1-\eta))}$

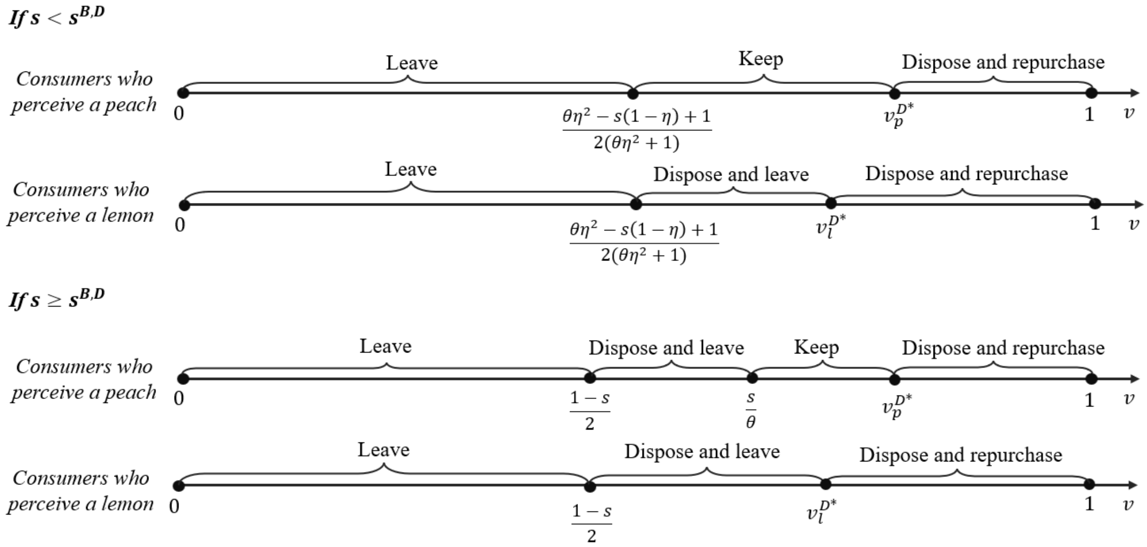


Figure 3.16: Market segmentation in the absence of CRP with disposal

Recall that in the absence of CRP and disposal option, pre-owned consumers always keep used products, while waited consumers may purchase new products or leave without a purchase in period two. Given the disposal option with a positive salvage value, pre-owned consumers may dispose of used products and repurchase new ones in period two, while waited consumers always refrain from purchasing. Thus, the new-product demands in the two periods come only from pre-owned consumers, in the quantities that decrease over time ($d_1^{B,D^*} > d_2^{B,D^*}$). Specifically, the pre-owned consumers with a high new-product valuation ($v \geq v_p^{D*} = \frac{1-\theta(1-2s(1-\eta))-s(2-\eta)}{2(1-\theta)(1-\theta(1-\eta))}$ for consumers who perceive a peach, or $v \geq v_l^{D*} = \frac{1-\theta+s\eta}{2(1-\theta(1-\eta))}$ for consumers who perceive a lemon) repurchase. As salvage value increases, the threshold v_p^{D*} decreases, implying more repurchases by consumers who perceive a peach, but the threshold v_l^{D*} increases, implying fewer repurchases by consumers who perceive a lemon. Other pre-owned consumers dispose of used products and leave except for consumers who perceive a peach, who keep used products when new-product valuation is moderate, i.e., $v \in \left[\frac{\theta\eta^2-s(1-\eta)+1}{2(\theta\eta^2+1)}, v_p^{D*}\right)$ for $s \geq s^{B,D}$ and $v \in \left[\frac{s}{\theta}, v_p^{D*}\right)$ for $s < s^{B,D}$.

Absent CRP, in the presence of the disposal option with a positive salvage value, the environmental impact is $e_p(d_1^{B,D^*} + d_2^{B,D^*})$ in the production phase, $e_{un}(d_1^{B,D^*} +$

$d_2^{B,D^*}) + e_{us}d_{p,k}^{B,D^*}$ in the use phase, where $d_{p,k}^{B,D^*}$ is the number of pre-owned consumers who keep used product, and $e_d(d_1^{B,D^*} + d_2^{B,D^*})$ in the disposal phase. Total environmental impact is as follows:

$$E^{B,D^*} = \underbrace{e_p\left(d_1^{B,D^*} + d_2^{B,D^*}\right)}_{production} + \underbrace{e_{un}\left(d_1^{B,D^*} + d_2^{B,D^*}\right) + e_{us}d_{p,k}^{B,D^*}}_{use} + \underbrace{e_d\left(d_1^{B,D^*} + d_2^{B,D^*}\right)}_{disposal}. \tag{3.7}$$

Proposition 3.7 states the effects of the presence of disposal option on the retailer's revenue and the environment in the absence of CRP.

Proposition 3.7. *In the absence of CRP, compared to the situation with a negligible salvage value, the presence of the disposal with a positive salvage value improves the revenue to the retailer but aggravates the negative impact on the environment.*

Compared to the situation that the disposal option bringing negligible salvage value, the presence of the disposal with a positive salvage value causes the retailer to raise prices across periods when the salvage value is sufficiently high. In particular, when $s \geq \max\left\{\frac{4\theta^2\eta^4}{4\theta\eta^2+1}, s^{B,D}\right\}$ in period one and when $s \geq \max\left\{\frac{2\theta^2\eta^2-2\theta\eta(1-\theta)+\theta}{4\theta\eta^2+1}, s^{B,D}\right\}$ in period two. At a low salvage value, the retailer raises period-one price ($p_1^{B,D^*} > p_1^{B*}$) but lowers period-two price ($p_2^{B,D^*} < p_2^{B*}$). Despite the mixed pattern for price adaptations over time, a positive salvage value attracts more consumers to purchase new products in period one ($d_1^{B,D^*} > d_1^{B*}$) and generates a higher total demand, increasing the revenue for the retailer. Nevertheless, a higher total demand gives rise to a heavier environmental impact, i.e., $E^{B,D} > E^B$. As such, the disposal option with a positive salvage value influences the alternation and usage between used and new products, resulting in a larger product quantity to aggravate the negative environmental impact.

Figure 3.17 illustrates consumers' decision sequence in the presence of CRP with disposal. The marginal consumer receives an expected utility as follows:

$$\underbrace{v - p_1^D + \max\left\{E(\theta)v + s_2, s_1 + v - p_2^D + s_2, s_1, (1-\tau)\, p_s^D + v - p_2^D + s_2, (1-\tau)\, p_s^D\right\}}_{to\ be\ a\ pre-owned\ consumer}$$
$$= \underbrace{\max\left\{v - p_2^D + s_2, E(\theta)v - p_s^D + s_2, 0\right\}}_{to\ be\ a\ waited\ consumer} \tag{3.8}$$

where a consumer purchasing a new product in period one expects to receive utilities from keeping, disposing, and reselling the used product in period two; while a consumer who postpones purchase expects to receive utilities from buying a new and a used product in period two.

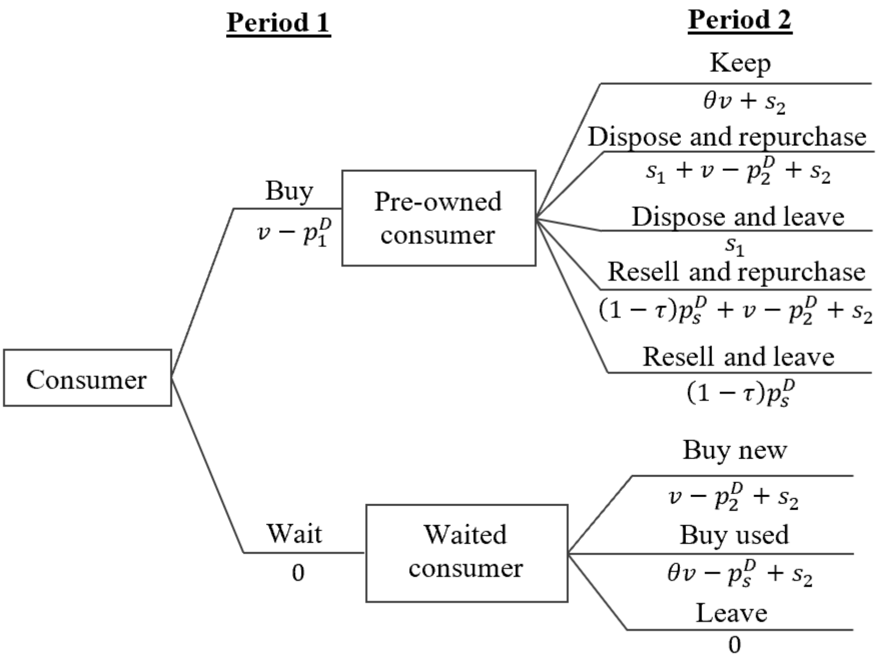


Figure 3.17: Decision sequence in the presence of CRP with disposal

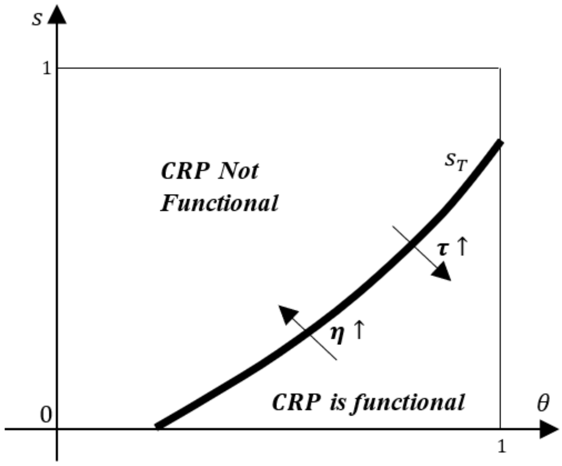
In the presence of a disposal option with a positive salvage value, the rise of CRP poses as a competing channel to disposal in dealing with used products. Specifically, a pre-owned consumer receives $(1-\tau)\, p_s^D$ by reselling a used product on the CRP and weighs it against the salvage value received by disposing of the used product. The retailer manages this competition between the CRP and the disposal option.

As the salvage value exceeds the income received by selling a used product on the CRP ($s_1 \geq (1-\tau)\, p_s^D$), disposal dominates reselling, reducing the system to the one without CRP. Otherwise, i.e., $s_1 < (1-\tau)\, p_s^D$, the CRP is the only channel for pre-owned consumers to rid of used products, reducing the system to the one with a negligible salvage value. The insights into the retailer's optimal pricing strategy, consumer surplus, social welfare, and environmental impact developed in the main analysis continue to be valid qualitatively.

The rise of CRP benefits the retailer only when the retailer manages to sustain used-product transactions on the platform. We find that compared to the situation with a negligible salvage value, the CRP is less likely to function and the retailer benefits less from this new market entity in the presence of the disposal option with a positive salvage value. It is due to the substitutability of the disposal option to selling on CRP, which overshadows the role of CRP in redistributing products. In addition to the condition stated in Lemma 3.1, with $s_1 = s$ and $s_2 = 0$, the salvage value has to be sufficiently low so that used-product transactions can be sustained on the CRP, i.e., $s < s_T$, where s_T is the threshold and defined in Appendix A.1. As Figure 3.18 illustrates, the CRP is less likely to function as it raises commission rate (value of τ increases), which curbs the supply, but it is more likely to function as a larger proportion of consumers perceive a peach (value of η increases), which drives in more demand. All this is consistent with the results stated in Lemma 3.1.

3.7 Model Extensions

This section encompasses several model extensions. We infuse three practical features to generate more insights. First, we consider the scenario where new consumers enter the market in period two. Second, we investigate the optimal commission rate levied by the CRP. Third, we access a multiple-CRP scenario.



Note. ↑ *indicates "increases".*

Figure 3.18: The condition for a functional CRP with disposal

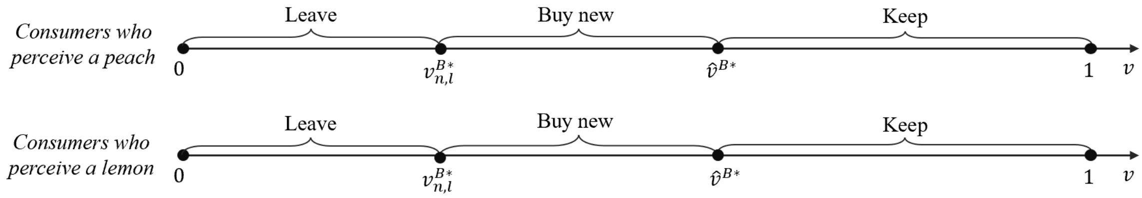
3.7.1 New-to-market Consumers

If considering that new consumers arrive in period two, we assume that the number of consumers in period one is one, and new consumers in a number of α arrive at the beginning of period two, i.e., the total number of consumers in period two is $1+\alpha$. The new consumers in period two have the same options as waited consumers. The retailer adjusts its prices in the two periods to adapt to the changes in market composition. Superscript A is added to indicate this setting. In the absence of CRP, as Figure 3.19(b) displays, new consumers either purchase new products from the retailer or leave without purchasing.

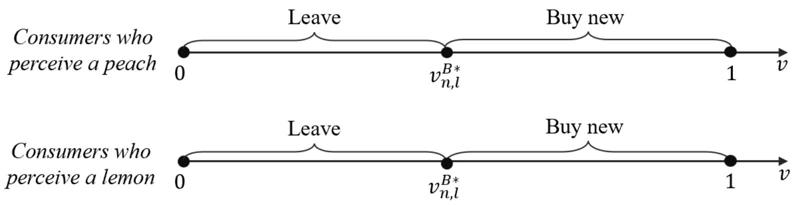
The new-product demand in period two, from the waited consumers and new consumers who purchase new products, is as follows:

$$d_2^{B,A^*} = \underbrace{\underbrace{\eta\left(\hat{v}^{B*} - v_{n,l}^{B*}\right)}_{perceive\ a\ peach} + \underbrace{(1-\eta)\left(\hat{v}^{B*} - v_{n,l}^{B*}\right)}_{perceive\ a\ lemon}}_{waited\ consumers} + \underbrace{\alpha\left(\underbrace{\eta\left(1 - v_{n,l}^{B*}\right)}_{perceive\ a\ peach} + \underbrace{(1-\eta)\left(1 - v_{n,l}^{B*}\right)}_{perceive\ a\ lemon}\right)}_{new\ consumers} \tag{3.9}$$

where $v_{n,l}^{B*} = p_2^{B*}$ and $\hat{v}^{B*}$ can be derived by Equation A.1.



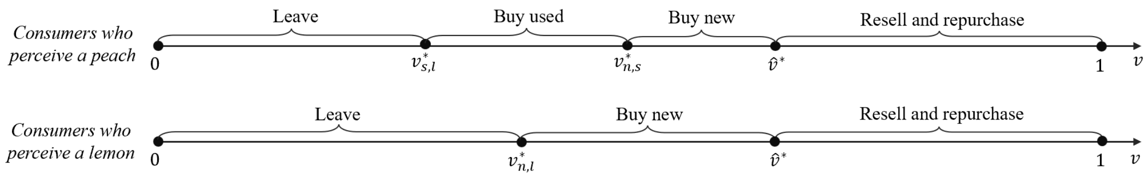
(a) Segmentation among existing consumers



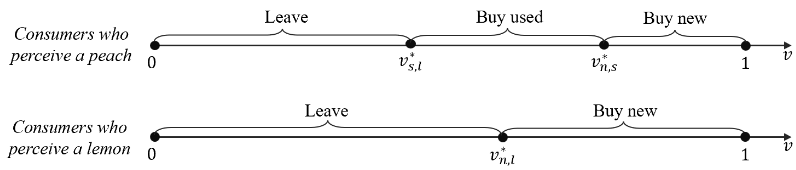
(b) Segmentation among existing consumers

Figure 3.19: Market segmentation in the absence of CRP with new entrants

In the presence of CRP, as Figure 3.20(b) illustrates, new consumers either purchase new products from the retailer, or purchase used products on the CRP, or leave without purchasing. Those new consumers who purchase used products form a source of demand on CRP.



(a) Segmentation among existing consumers



(b) Segmentation among existing consumers

Figure 3.20: Market segmentation in the presence of CRP with new entrants

The new-product demand in period two, from the pre-owned consumers who resell and repurchase and the waited consumers and new consumers who purchase new products, is:

$$
\begin{aligned}
d_2^{A*} = & \underbrace{\underbrace{\eta\left(1-v_{sn,k}^*\right)}_{perceive\ a\ peach} + \underbrace{(1-\eta)\left(1-\hat{v}^*\right)}_{perceive\ a\ lemon}}_{pre-owned\ consumers} + \underbrace{\underbrace{\eta\left(\hat{v}^*-v_{n,s}^*\right)}_{perceive\ a\ peach} + \underbrace{(1-\eta)\left(\hat{v}^*-v_{n,l}^*\right)}_{perceive\ a\ lemon}}_{waited\ consumers} \\
& + \underbrace{\alpha\left(\underbrace{\eta\left(1-v_{n,s}^*\right)}_{perceive\ a\ peach} + \underbrace{(1-\eta)\left(1-v_{n,l}^*\right)}_{perceive\ a\ lemon}\right)}_{new\ consumers}
\end{aligned}
\tag{3.10}
$$

where $v_{sn,k}^* = \frac{p_2^*-(1-\tau)p_s^*}{1-\theta}$, $v_{n,s}^* = \frac{p_2^*-p_s^*}{1-\theta}$, $v_{n,l}^* = p_2^*$, $v_{s,l}^* = \frac{p_s^*}{\theta}$ and $\hat{v}^*$ can be derived from Equation A.2.

On the CRP, the used-product supply comes from the pre-owned consumers who resell used products and has a number of $\underbrace{\eta\left(1-v_{sn,k}^*\right)}_{perceive\ a\ peach} + \underbrace{(1-\eta)\left(1-\hat{v}^*\right)}_{perceive\ a\ lemon}$, while the used-product demand comes from the waited consumers and new consumers who perceive and purchase a peach and has a number of $(1+\alpha)\eta\left(v_{n,s}^*-v_{s,l}^*\right)$. The number of waited consumers and new consumers who leave without purchasing is $d_{w,l}^{A*} = (1+\alpha)\left(\underbrace{\eta v_{s,l}^*}_{perceive\ a\ peach} + \underbrace{(1-\eta)\,v_{n,l}^*}_{perceive\ a\ lemon}\right)$.

To explicitly demonstrate the impact of new consumers, we study a peach-occupied market, i.e., $\eta = 1$. In the absence of CRP, the new-product demands in period one and period two are $d_1^{B,A^*} = 1-\hat{v}^{B*}$ and $d_2^{B,A^*} = \underbrace{\hat{v}^{B*}-v_{n,l}^{B*}}_{waited\ consumers} + \underbrace{\alpha\left(1-v_{n,l}^{B*}\right)}_{new\ consumers}$. In the presence of CRP, the number of supply and demand for used products on CRP are $d_{p,sn}^{A*} = 1-v_{sn,k}^*$ and $d_{w,s}^{A*} = (1+\alpha)\left(v_{n,s}^*-v_{s,l}^*\right)$, respectively, and new-product demand is $d_2^{A*} = \underbrace{1-v_{sn,k}^*}_{pre-owned\ consumers} + \underbrace{\hat{v}^*-v_{n,s}^*}_{waited\ consumers} + \underbrace{\alpha\left(1-v_{n,s}^*\right)}_{new\ consumers}$ in period two, while the new-product demand is $d_1^{A*} = 1-\hat{v}^*$ in period one. In either case, the retailer maximizes revenue by setting prices to generate demand across periods. Table 3.8 presents the scenarios for comparative analysis and Table 3.9 demonstrates the equilibrium demands in each scenario.

Table 3.8: Comparative matrix

	No new consumers arrive in period two	New consumers arrive in period two
With CRP	Main model (denoted by M)	Extended model (denoted by MA)
Without CRP	Benchmark (denoted by B)	Extended benchmark model (denoted by BA)

Table 3.9: Demands illustration

	No new consumers arrive in period two	New consumers arrive in period two
With CRP	$d_1^* = 1 - \hat{v}^*_{\eta=1}$	$d_1^{A*} = 1 - \hat{v}^*_{\eta=1}$
	$d_2^* = 1 - v^*_{sn,k} + \hat{v}^*_{\eta=1} - v^*_{n,s}$	$d_2^{A*} = 1 - v^*_{sn,k} + \hat{v}^*_{\eta=1} - v^*_{n,s} + \alpha\left(1 - v^*_{n,s}\right)$
	$d^*_{p,sn} = 1 - v^*_{sn,k}$	$d^{A*}_{p,sn} = 1 - v^*_{sn,k}$
	$d^*_{w,s} = v^*_{n,s} - v^*_{s,l}$	$d^{A*}_{w,s} = (1+\alpha)\left(v^*_{n,s} - v^*_{s,l}\right)$
	$d^*_{p,k} = v^*_{sn,k} - \hat{v}^*_{\eta=1}$	$d^{A*}_{p,k} = 0$
Without CRP	$d_1^{B*} = 1 - \hat{v}^{B*}$	$d_1^{B,A^*} = 1 - \hat{v}^{B*}$
	$d_2^{B*} = \hat{v}^{B*} - v^{B*}_{n,l}$	$d_2^{B,A^*} = \hat{v}^{B*} - v^{B*}_{n,l} + \alpha\left(1 - v^{B*}_{n,l}\right)$

In the presence of CRP, as new consumers arrive in period two, by comparing the results of scenarios M and MA, certain equilibrium outcomes do change. Specifically, the arrival of new consumers in period two prompts all pre-owned consumers to resell and repurchase products instead of keeping them, i.e., $d^{A*}_{p,k} = 0$ while $d^*_{p,k} = v^*_{sn,k} - \hat{v}^*_{\eta=1} > 0$. The CRP is always functional to sustain used-product transactions at a positive transaction price without satisfying the condition mentioned in Lemma 3.1, i.e., p_s^{A*} is always larger than zero while $p_s^* > 0$ when $\theta \geq \underline{\theta}_{\eta=1}(\tau)$.

However, our primary insights into the effects of CRP stem from the comparison between the situations with and without CRP. Specifically, the effects of CRP in the extended model (i.e., based on the comparison of scenarios MA and BA) remain largely consistent with those unveiled in Section 3.4 (i.e., based on the comparison of scenarios M and B). Particularly, when new consumers arrive in period two, the presence of CRP always increases demand in period one, i.e., $d_1^{A*} - d_1^{B,A^*} = \frac{2\theta(1-\theta(1-\tau))}{\Lambda_1(1+4\theta)} \geq 0$, and increases demand in period two except when consumers' perceived used-product value is extremely high, i.e., $d_2^{A*} - d_2^{B,A^*} > 0$ when $\theta < \theta_{d_2^A}(\tau)$. The proof is in Appendix A.5.1. This trend is consistent with that for the changes in demand in the main model, as demonstrated in Proposition 3.1. The rationale for the possible decrease of period-two demand is as follows: although the used products on the CRP appeal to new consumers, inducing them to make purchases on the platform ($d_{w,s}^{A*} > d_{w,s}^{*}$), the supply on CRP is limited ($d_{p,sn}^{A*} = d_{p,sn}^{*}$). Consequently, although all pre-owned consumers choose to resell rather than keep their products, the demand for new product in period two when CRP is present can still be lower than when CRP is absent, i.e., $d_2^{A*} - d_2^{B,A^*} < 0$ when $\theta > \theta_{d_2^A}(\tau)$. As the retailer maximizes revenue by setting prices to generate demand across periods, the patterns for prices and revenue are consistent with those in the main model. As such, the effects of CRP continue to be valid.

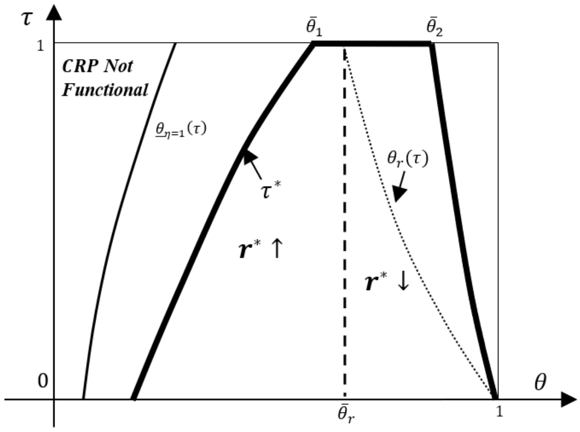
3.7.2 CRP's Endogenized Commission Pricing

Our main analysis is premised on the assumption that the commission rate charged by the CRP is exogenous. In practice, a CRP can decide its commission rate to maximize revenue. Proposition 3.8 states its optimal decisions. The proof can be found in Appendix A.5.2.

Proposition 3.8. *When the CRP sets the commission rate to maximize its revenue, let $\bar{\theta}_1$, $\bar{\theta}_2$ and $\bar{\theta}_r$ be defined in Appendix A.1:*

1. *The optimal commission rate is $\tau^* = 1$ when consumers perceive a moderate value from used products, i.e., $\theta \in \left[\bar{\theta}_1, \bar{\theta}_2\right]$, while $\tau^* = \tau(\theta)$ otherwise, i.e., $\theta \in \left[\underline{\theta}_{\eta=1}, \bar{\theta}_1\right)$ and $\theta \in \left(\bar{\theta}_2, 1\right]$;*

2. *The retailer's revenue improves as the CRP optimizes the commission rate when $\underline{\theta}_{\eta=1} \leq \theta < \bar{\theta}_r$, but it worsens otherwise.*



Note. ↓ *indicates "worsens" and* ↑ *indicates "improves".*

Figure 3.21: Optimal commission rate by CRP, with $\eta = 1$

In the presence of CRP, the volume of used products transacted on the platform equals the number of waited peach consumers who purchase used products or the number of pre-owned consumers - including both peach and lemon consumers - who resell used products and repurchase new ones. In setting the optimal commission rate, the CRP balances the tradeoff between commission rate and transaction volume. The outcome of this tradeoff is contingent on how consumers perceive used-product value.

When the consumers perceive a low value of used products ($\underline{\theta}_{\eta=1} \leq \theta < \bar{\theta}_1$), the retailer deters strategic consumer waiting by weakening intertemporal price discrimination. As θ increases, the number of pre-owned consumers increases and the waited consumers have a stronger incentive to purchase used products. It results in more transactions on the platform, enticing the CRP to levy a higher commission rate. Otherwise, when the consumers perceive a medium used-product value ($\bar{\theta}_1 \leq \theta \leq \bar{\theta}_2$), the CRP caps the commission rate at one to extract all the surplus from transactions. This result is partially in accordance with Mantin et al. (2014), L. Jiang et al. (2017), and Vedantam et al. (2021). Mantin et al. (2014) show that a retailer-owned platform integrating third-party sellers can extract all surplus from these sellers, effectively neutralizing all benefits to the supply chain partners. L. Jiang et al. (2017) find that the platform has the power to extract surplus from the consumers using its service, by tying transaction fee to the selling price of used product. Vedantam et al. (2021) provide evidence to indicate that the platform leaves no surplus to sellers for two purposes: one is to limit the number of sellers in the C2C market to preclude oversupply, and the other is to alleviate the cannibalization effect of new-product sales. Echoing Vedantam et al. (2021), our analysis identifies the situation where the CRP leaves no surplus to sellers. Note that Vedantam et al. (2021) assume that the CRP is owned by the retailer and argue that it alleviates the cannibalization of new-product sales to balance used-product sales. In our model, the CRP can extract all the surplus from used-product transactions to maximize its own revenue. Moreover, we find that the existence of CRP does not cannibalize new-product sales but increases it instead, in parallel to sustaining used-product sales.

Recall that the number of waited consumers, who form the demand on the CRP, is small as the consumers perceives a high value from used products. When the used-product value is sufficiently high ($\theta > \bar{\theta}_2$), the retailer aggravates intertemporal price difference, inducing more consumers to postpone purchases, relative to when the CRP is absent. As a tactic to compete with the retailer for demand, the CRP levies a commission rate to transfer part of the transaction revenue to the consumers, and the transferred proportion increases as the consumers perceive a higher value of used products (τ^* decreases with θ).

As Proposition 3.2 indicated, given an exogenous commission rate, the presence of CRP has a positive effect on the retailer's revenue when the consumers perceive a level of used-product value belongs to $\underline{\theta}_{\eta=1} \leq \theta < \bar{\theta}_r$. As stated in Proposition

3.6, the endogenized optimal commission rate is $\tau^* = 1$ for $\theta \in \left[\bar{\theta}_1, \bar{\theta}_2\right]$, where $\bar{\theta}_r \approx 0.64 > \bar{\theta}_1 \approx 0.63$. Compared to when the CRP is absent, revenue maximizing by the CRP improves the retailer's revenue when the consumers perceive a low used-product value ($\underline{\theta}_{\eta=1} \leq \theta < \bar{\theta}_r$). Nevertheless, it is detrimental to the retailer's revenue either when the CRP seizes all the transaction revenue in the situation where the level of used-product value is perceived to be medium, i.e., $\theta \in \left[\bar{\theta}_r, \bar{\theta}_2\right]$, or partial transaction revenue in the situation where the level of used-product deprecation is perceived to be low, i.e., $\theta > \bar{\theta}_2$.

3.7.3 Multiple Competitive CRPs

The introduction of multiple CRPs is bound to involve the competition among platforms in setting the revenue-maximizing commission rates. Extant studies in the setting of multiple platforms such as Binmore et al. (1986) and Rubinstein (1982) assume that platforms enter a game to make decisions, by anticipating the decisions made by one another and making best responses accordingly. Following that, we assume that there are K symmetric CRPs and the CRP k sets commission rate τ_k, where $k \in \{1, 2, \ldots, K\}$. Consumers have no intrinsic preferences toward these CRPs before participating in used-product transactions, and they transact at CRP k with resale revenue $(1 - \tau_k)p_s$, where p_s is the market-clearing price of used products. The game sequence of events in the presence of multiple CRPs is shown in Figure 3.22, is as follows. First, each CRP k commits to a commission rate τ_k to charge consumers for selling through the platform (Mantin et al. 2014; L. Jiang et al. 2017). Then, the retailer sets new-product prices for the two periods and consumers make utility-based purchase choices. In this game structure, the additional decision stage with respect to the main model is that CRPs make commitments about their commission rates prior to the new-product price setting by the retailer.

In the presence of multiple CRPs, forward-looking consumers choose the one

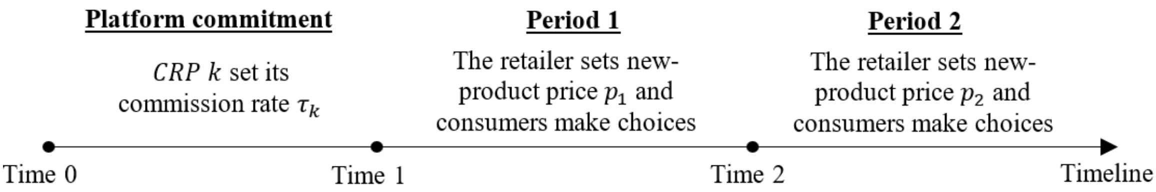


Figure 3.22: Timing of events with multiple CRPs

that brings them the highest resale revenue, i.e., $(1-\tau_k)\,p_s$. The CRP k receives revenue $\tau_k p_s d_k$, where d_k is the used-product demand handled by it. To compete with other platforms and maximize its own revenue, CRP k lowers commission rate τ_k to acquire more demand. In the equilibrium, the commission rates set by CRPs should be identical, i.e., τ_k^* is the same for $\forall k \in K$. Each CRP handles used-product demand in the volume of $d_k^* = \frac{d_s}{K}$, where d_s is the total used-product demand. Overall, multiple CRPs can be viewed similarly as a holistic monopolistic CRP, where τ_k^* in the multiple-CRP scenario equals τ in the main monopolistic-CRP scenario. As such, a multiple-CRP scenario does not change the fundamental qualitative nature of the results. In practice, C2C platforms' commission rates are posted online and rarely change. For example, eBay charges 15% for used branded apparel if the total sale amount is \$2,000 or less (eBay 2023), and ThredUP charges 20% when the selling price is \$200 or more (ThredUP 2023a). The commission rates for both CRPs are almost similar for used branded apparel.

3.8 Theoretical Contribution and Managerial Implication

Chapter 3 considers product characteristics such as depreciation and salvage value in secondhand products to analyze the retailer's optimal dynamic pricing strategy for new products in the presence of CRP. Theoretical contribution and managerial implication of this chapter are as follows.

(1) Theoretical Contribution

This chapter demonstrates that the intertemporal price discrimination adopted by retailers for new products is influenced by the extent of heterogeneity in used products. Our results differ from prior literature, which is against discriminate pricing over time in selling to strategic consumers. Existing literature assume a homogeneous and ex-ante known perceived value of used products among consumers (Yin et al. 2010; L. Jiang et al. 2017), which does not apply to the practices based on the C2C mode. Contrasting with extant studies, this work characterizes the heterogeneity of secondhand products in the presence of C2C resale markets. We find that when the heterogeneity of used products is high, the existence of C2C resale markets leads retailers to exacerbate intertemporal price discrimination for new products to encourage consumers' strategic waiting. This contrasts with prior literature, which discourage discriminatory pricing over time by a monopolist when selling to strategic consumers (Coase 1972; Stokey 1979; Besanko & Winston 1990; Liu & Zhang 2013). Our research incorporates consumers' heterogeneities in their valuations for both new and secondhand products. We emphasize the relationship between secondhand product heterogeneity and intertemporal price discrimination for new products. These findings enrich the literature on optimal dynamic pricing strategy for new products by offering novel insights in the context of C2C resale markets.

(2) Managerial Implication

In the presence of CRP, consumers can strategically play the role of individual suppliers, postponed demanders, or repeat purchasers. The interplay of these consumer behaviors causes the demands for new and used products to be correlated. The retailer tailors prices accordingly to manage the distribution of demands across periods and channels. The result suggests that retailers can profit from managing new-product selling over periods in parallel to support used-product transactions on CRPs, rather than competing with the platform for demand. It improves the efficiency of redistributing products and balances the demands for new and used products. We find that new-product demands in the two periods largely increase, giving rise to a demand-expansion effect. Retailers can benefit when consumers perceive certain discrepancies in the values of new and used products, whereas they may experience revenue loss if the CRP charges a high commission rate. It justifies the observations in the electronic, automotive, home furnishing, and branded apparel industries, where retailers have embraced CRPs that sets low commission rates to facilitate used-product transactions among consumers. Moreover, despite CRP can create a win-win situation for all market participants, the demand-expansion effect arising from the rise of CRP aggravates the environmental impact, which is against the original intention of creating an efficient and sustainable consumption mode to eliminate negative environmental impacts. Therefore, we suggest that retail practitioners can positively impact the environment and cultivate a green image by proactively adjusting their operations and focusing on long-term benefits.

3.9 Concluding Remarks

This chapter examines the characteristics of secondhand products, such as heterogeneity and salvage value, and analyzes the retailer's optimal dynamic pricing strategy in the presence of CRP. Brief answers to research questions proposed in Section 3.2 are as follows. First, the existence of CRP entices the retailer to aggravate intertemporal price discrimination to encourage strategic consumer waiting in most circumstances. Second, the retailer profits from the presence of CRP by exploiting strategic consumer behavior when consumers perceive a medium used-product value. Third, the presence of CRP can give rise to a win-win situation for all market participants at the expense of aggravated environmental impact. Moreover, we explore the situation where pre-owned consumers can dispose of used products to grab a positive salvage value to yield additional insights. We show that, in the absence of CRP, this option benefits the retailer but aggravates the environmental impact by generating more new-product sales, albeit exerting mixed effects on new-product prices across periods. Nevertheless, the availability of this option causes the retailer to benefit less from CRP, due to the competition between the disposal channel and the C2C resale channel for consumers to deal with used products. Furthermore, we discuss several practical market scenarios to enrich the analysis, including scenarios involving new entrants in the later period, the endogenization of the platform's commission rate, and multiple competitive CRPs. The findings of Chapter 3 provide valuable insights into the retailer's pricing operations in the presence of C2C resale markets, particularly concerning secondhand product characteristics.

Chapter 4

Dynamic Pricing Strategy for New Products Considering Consumers' Utility Dependence in the Presence of C2C Resale Market

4.1 Research Motivation

Chapter 3 examines the fundamental effects of C2C resale markets on the retailer's optimal dynamic pricing strategy for new products, with a specific focus on second-hand product characteristics. Building upon this framework, Chapter 4 introduces a new behavioral factor: utility dependence from consumers' repeat purchases when engaging in C2C resale transactions. After using a firm's product, consumers may find it easier to use other products offered by the same firm. For instance, repeatedly purchasing products from the same retailer enables consumers to save time and effort in familiarizing themselves with the sophisticated functions and possess the gratification from owning new products consecutively. Scholars have explained this "convenience" with the theory of state dependence (Guadagni & Little 1983; Gupta 1988; Krishnamurthi & Raj 1988), and defined a form of utility dependence to show that consumer loyalty is enhanced if recent purchases have been made (Erdem 1996; Moshkin & Shachar 2002). Business practices are ample to illustrate this phenomenon. Apple Inc. maintains consistent iOS interfaces across its product series to facilitate consumer use. A 2019 SellCell survey indicates that 90.5% of iPhone users continue purchasing its models when replacing smartphones (Statista 2019). Similarly, the experience that a consumer gains by driving vehicles can lead to repurchases in the automotive industry (J.D. Power 2020), turning consumers into habitual buyers. A report reveals that 80% of used-car and 76% of new-car owners repeatedly purchase the same car type in their next transaction (AutoTrader 2016).

As Table 4.1 demonstrated, our survey on consumers' repeat purchases shows that 50.23% of the respondents are inclined to repurchase from the same retailer if they have previously purchased and experienced the product. Similarly, 47.73% indicate a likelihood to repurchase from the same retailer after reselling the product originally purchased from it. Moreover, 55.8% of the respondents report experiencing an increase in value from repeatedly purchases with the same retailer. The main factors driving repeat purchases are "*Excellent experience*" (70.27%), "*Familiarity with sophisticated functions and reduced learning cost*" (39.06%), "*Habit formation*" (37.49%), and "*Loyal consumer*" (30.47%). Appendix D provides more details. We ensure the reliability and validity of the survey data through the following measures: (1) Prior to formal distribution, we conducted a small-scale pre-survey to improve accuracy; (2) We strictly controlled the selection of target respondents to ensure they met the study's criteria; (3) After collecting responses, we filtered out invalid results, such as surveys with unusually long or short completion times or those with repetitive, similar answers throughout. Moreover, as shown in Appendix E, our interviewees all commented that: "Repeat selling is vital for supply chain members especially retailers."

Table 4.1: Summary of the survey results on consumers' repeat purchases

Statement	Percentage of responses that agree
(A) The likelihood of repeat purchases from a same retailer if the product was purchased and experienced:	
- Likely	50.23%
- Unlikely	23.83%
(B) The likelihood of repeat purchases from a same retailer after reselling the retailer's product:	
- Likely	47.73%
- Unlikely	22.63%
(C) The extent of reaping additional value by repeat purchases from a same retailer:	
- Relatively high	42.94%
- Extremely high	12.83%
- Relatively low	6.93%
- Extremely low	5.36%
(D) The reason why purchases products repeatedly from the same retailer:	
- Excellent experience	70.27%
- Familiarity with sophisticated functions and reduced learning cost	39.06%
- Habit formation	37.49%
- Loyal consumer	30.47%
- Lack of substitution	20.22%
- Diversified choices (e.g., more colors or sizes)	9.70%

The feedback provides adequate evidence that consumers make repeat purchases due to their dependence on the retailer's products. In line with Moshkin & Shachar (2002), we characterize this dependence in the form of value increment and refer to it as utility dependence. By incorporating this essential feature, forward-looking consumers can gain both resale value and utility dependence when reselling and repurchasing simultaneously. This dual benefit motivates them to purchase early and become individual suppliers on the CRP (Risberg, 2014)Risberg (2014).

Forward-thinking retailers are adapting to the trend ushered in by the rise of CRPs to encourage repeat purchases and enhance consumer loyalty. The prevalent partnerships between retailers and CRPs in practice encompass various modes. First, as the brand-owned resale presented in Table 1.1, retailers opt to self-operate an internal platform, leveraging existing infrastructure by launching a dedicated section on their official website and utilizing established logistics networks. Second, retailers offer a price subsidy to consumers who participate in reselling and repeatedly purchase. For example, The North Face provide consumers who resell their products a \$10 discount on purchases of \$100 or more, incentivizing the circulation of their products (Cortez 2021). Third, retailers collaborate with an external platform that determines its own optimal commission rate. For instance, Swappa charges a commission rate of 3% of the sold price for sellers (Swappa 2024), while eBay sets varying commission rates according to product categories, such as 13.25% for consumer electronics and 15% for apparels (eBay 2023). However, there remains a lack of theoretical exploration on how retailers should collaborate with CRPs.

The remainder of this chapter is structured as follows. Section 4.2 provides the research questions. Section 4.3.1 introduces the model settings. Section 4.4 presents the retailer's optimal dynamic pricing strategy for new products within a fully covered market considering consumers' state-dependent utility, and subsequently examines the impact of CRP on retailer revenue, consumer surplus, and social welfare under these conditions. Section 4.5 explores how retailers should partner with CRP by investigating different collaboration strategies. Section 4.6 discusses approaches for enhancing the main model to broaden its applicability and examining the robustness of the results. Section 4.7 summarizes the theoretical contributions and managerial insights of this chapter. Section 4.8 concludes the chapter. The thresholds and proofs for the results are relegated to Appendix B.

4.2 Research Questions

The prevalence of C2C resale markets and the opportunity for repeat purchases inspire us to explore this phenomenon. While previous studies have examined the issues related to C2C resale (P. Desai et al. 2004; Gümüş et al. 2013; L. Jiang et al. 2017; Vedantam et al. 2021; Yin et al. 2010), utility dependence from repeat purchases has not been considered. Our work unveils the impacts of CRP on the performances of the retailer and forward-looking consumers, who experience utility dependence, and ultimately generates useful managerial insights. We investigate the following questions of practical relevance and academic value, as consumers experience state-dependent utility from repeat purchases:

1. How should retailers dynamically manage prices for new products to adapt to the rise of CRP?
2. Is it beneficial for retailers to embrace CRP, and if so, under what circumstance?
3. How can consumers and society benefit from CRP?
4. How should retailers collaborate with CRP?

To address these questions, we develop a stylized model in which a monopolistic retailer dynamically sets prices for the new products in the two periods. In period one, consumers can either purchase new products (to be active consumers) or postpone purchase to period two (to be reserved consumers). In period two, active consumers either keep used products or resell them on the CRP followed by repurchasing new ones from the retailer, while reserved consumers purchase either new products from the retailer or used products on the CRP. The CRP retains a commission for each transaction completed on its platform. Consumers are heterogeneous in perceiving the quality levels of used products and experiencing utility dependence by repeatedly purchasing new products from the same retailer. The retailer dynamically adjusts prices for new products to tailor to the market changes thus occur, leading to either a fully covered or partially covered market. We characterize three collaboration strategies: the retailer operates its own CRP, provides price subsidies to consumers who participate in resale, or allows the platform to set its optimal commission rate.

4.3 Model Framework

4.3.1 Model Description

We consider an e-commerce marketplace consisting of a monopolistic retailer, who sells new products to a market in two periods, and a CRP, who redistributes used products among consumers. Figure 4.1 illustrates the market structure. Under dynamic pricing, the retailer sets the new-product price p_1 (p_2) at the start of period one (two). Total market size is normalized to one. A consumer owns at most one unit of product at any time. The consumers who purchase new products in period one are active consumers, while the consumers who postpone purchases to period two are reserved consumers. Our current setting approximates the situation in which the new products sold across periods are not entirely identical but rather exhibit horizontal differences, such as variations in aspects like color, size, and appearance. The setting finds relevance in industries demanding a certain level of product usage knowledge, developing specific operating routines with the product, and delivering experiential value to consumers. These industries encompass appliances, automotive, consumer electronics, branded apparel, and furniture sectors. In Section 4.6.3, we discuss the scenario where products sold across periods exhibit vertical differentiation. The CRP provides a transaction venue for used-product supplies (from active consumers) and demands (from reserved consumers), and it retains a proportion $\tau \in [0,1]$ of the revenue for each transaction completed on its platform; we call τ the commission rate.

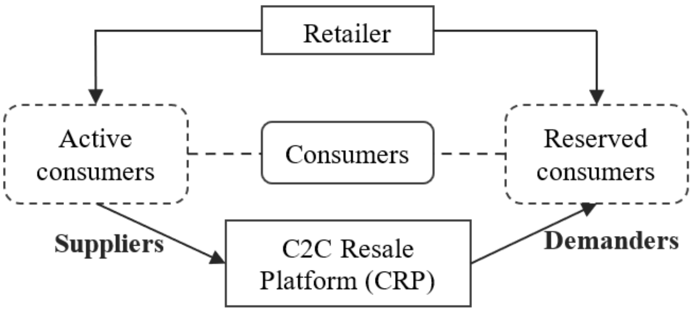


Figure 4.1: Market structure

Consumers are aware of the selling of new and used products alongside the existence of CRP. Each consumer values new product in a period at $v \in [0,1]$, which is homogeneous and time-invariant. While consumers hold the same base valuations of the new products offered in the two periods, they may still purchase repeatedly from the same retailer. Our survey results indicate that 50.2% of the respondents are likely to repeatedly purchase products if they have purchased and experienced products from the same retailer, even though the new products sold across periods exhibit no obvious differences in quality. To characterize this feature, we assume that an active consumer who repurchases a new product from the retailer after selling the used one on the CRP in period two values the newly owned product at $v + \varepsilon$, where ε is utility dependence and uniformly distributed on $[0,1]$. This assumption is consistent with Moshkin & Shachar (2002), who use a positive parameter to capture the magnitude of the dependence of utility on the previous choice and allow it to differ across consumers. We simply call ε consumer type. Our main model approximates the scenario where the product value is independent of utility dependence from repeat purchases. For instance, in the context of automobiles, the operational and driving habits cultivated by consumers during usage engender a notable level of utility dependence, which can be independent of the product's intrinsic value. Section

4.6.2 investigates the scenario in which utility dependence from repeat purchases is interrelated with new-product valuation, enhancing the depth of our study. We prove that the results derived in the main model qualitatively hold.

A new product purchased in period one depreciates at the end of the period and is valued at θv by consumers, where θ follows a uniform distribution on $[0, 1]$ to capture the heterogeneity among consumers in perceiving the quality levels of used products. Our survey also reveals that 59.2% of the respondents believe that they cannot accurately estimate the quality level of used product. Accordingly, we follow the practice to assume that θ is ex-ante unknown but is realized ex-post product usage. Consumers hold a priori belief about the distribution of θ in period one while the specific value of θ is realized in period two. Active consumers can observe the exact used-product value only after they have used or experienced the product, while reserved consumers can do so until active consumers post used products on the CRP.

Consumers are forward-looking and can accurately predict the new-product prices set by the retailer along with the transaction price on the CRP. The sequence of events occurs as follows. In period one, a consumer can purchase a new product from the retailer in period one (to be an active consumer) to receive utility $v - p_1$. Otherwise, a consumer forgoes the purchase in period one (to be a reserved consumer) to receive zero utility. All consumers remain in the market. In this chapter, we do not explicitly consider the arrival of new consumers at the beginning of period two. The reason is that this work primarily focuses on repeat purchases from consumers who have already purchased, and its impact with the rise of CRP, which redistributes and alters product ownership among existing consumers. In period two, an active consumer can resell the used product on the CRP, followed either by repurchasing a new product from the retailer to receive utility $u_{a,sn} = (1 - \tau) p_s + v + \varepsilon - p_2$, or by leaving the market to receive utility $u_{a,sl} = (1 - \tau) p_s$. Alternatively, an active consumer can keep using the product to receive utility $u_{a,k} = \theta v$. A reserved consumer can purchase a new product in period two to receive utility $u_{r,n} = v - p_2$ or purchase a used product to receive utility $u_{r,u} = \theta v - p_s$. Leaving without purchase yields utility $u_{r,l} = 0$. We normalize the discounting factor to one when valuing consumers' intertemporal utilities. The entire season of selling and transaction terminates at the end of period two, when all the products carry no salvage value and can be scrapped freely. Notations used in this chapter is summarized in Table 4.2.

In the main analysis, we assume the market is fully covered, where the new-product price in period two satisfies $p_2 \leq v$. Specifically, reserved consumers are left with two options in period two, "buy new" and "buy used", with the option "leave" being dominated. In contrast, active consumers never opt for the "resell and leave" option since it is dominated by the "resell and buy new" option. The new-product demand in period two comes from both active and reserved consumers. In Section 4.6.1, we extend the discussion to a partially covered market.

4.3.2 Equilibrium Analysis

Using backward induction, we first analyze the period-two subgame. Given period-one price p_1, we conjecture the existence of a marginal consumer type $\hat{\varepsilon}$, who is indifferent between purchasing a new product in period one or postponing the purchase to period two. As to be demonstrated, this conjecture holds in the equilibrium. A consumer with type in $(\hat{\varepsilon}, 1]$ purchases a new product in period one (active consumer), while a consumer with type in $[0, \hat{\varepsilon})$ postpones to period two (reserved consumer). The quantities of active and reserved consumers are $d_a = 1 - \hat{\varepsilon}$ and $d_r = \hat{\varepsilon}$, respectively. In period two, active and reserved consumers make respective utility-based purchase decisions. The active consumers who choose the "resell" option form the supply, while reserved consumers who choose the "buy used" option form the demand on the CRP. A general-equilibrium price is reached to match the supply with the demand for used products. All the used products sold on the CRP are cleared at p_s^* (P. S. Desai & Purohit 1998, 1999; B. Jiang & Tian 2018; Yin et al. 2010), a proportion $(1 - \tau)$ of

Table 4.2: List of notations

Notation	Description
v	Consumers' new-product valuation in each period
θ	Quality level of used product perceived by individual consumers
ε	Utility dependence reaped from repeat purchases
$\hat{\varepsilon}$	Indifferent consumer type
τ	CRP's commission rate
$i \in \{1, 2\}$	Time period
$j \in \{B, O, D\}$	Superscript indicating the benchmark setting without CRP, the self-managing platform strategy, and price subsidy strategy, respectively
c	Marginal operating cost of a self-managing platform
m	Price discount factor
δ	Consumers' value increment for an upgraded product
α	Product upgrade degree
a, r	Subscript indicating active or reserved consumers, respectively
k, sn, sl	Subscript indicating the options "keep", "resell and buy new", "resell and leave" respectively for active consumers
n, u, l	Subscript indicating the options "buy new", "buy used" or "leave" respectively for reserved consumers
u	Consumers' net utility
p_i	New-product retail price
d_i	New-product demand
p_s	Used-product market-clearing price
d_s	Used-product demand
r_i	Retailer's revenue
cs	Consumer surplus
sw	Social welfare

which is collected by active consumer who sells the used product while the remainder is retained by the CRP. The retailer sets the new-product price to maximize period-two revenue $r_2 = p_2 d_2$.

Lemma 4.1. *Given marginal consumer type $\hat{\varepsilon}$, in subgame equilibrium, the new-product price is $p_2^*(\hat{\varepsilon}) = \frac{\hat{\varepsilon}^2 - v(1-\tau)(1-\hat{\varepsilon})}{\hat{\varepsilon}\tau}$ and the transaction price for used products on the CRP is $p_s^*(\hat{\varepsilon}) = \frac{\hat{\varepsilon}^2 - v(1-\hat{\varepsilon})}{\hat{\varepsilon}\tau}$, with $p_s^*(\hat{\varepsilon}) = p_2^*(\hat{\varepsilon}) - \frac{1-\hat{\varepsilon}}{\hat{\varepsilon}} v$.*

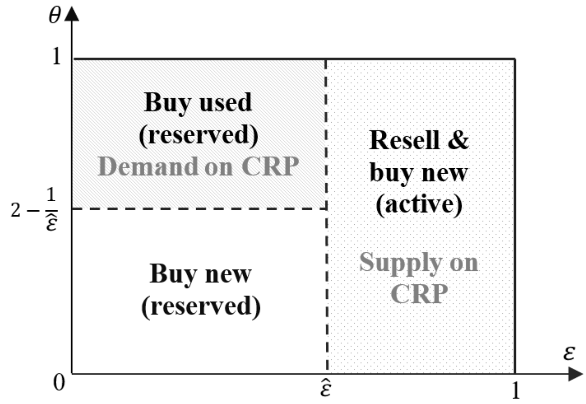


Figure 4.2: Market segmentation

The new-product price in period-two $p_2^*(\hat{\varepsilon})$ increases as more consumers postpone purchases to period two (value of $\hat{\varepsilon}$ increases). The transaction price for used products is below the price for new product, i.e., $p_s^* < p_2^*$, which is consistent with the intuition. An increase in the number of active consumers $(1-\hat{\varepsilon})$ relative to that of reserved consumers $(\hat{\varepsilon})$, implying an increase in the supply relative to the demand on the CRP, clamps down on the used-product transaction price relative to the new-product price. Notably, Lemma 4.1 implies the strategic complementarity of new-product market managed by the retailer and used-product market operated by the CRP.

Figure 4.2 details the segmentation among consumers contingent on the heterogeneities of used-product quality levels and utility dependence by repeatedly purchasing. In period two, a reserved consumer purchases a new product when the perceived used-product quality level satisfies $\theta \in \left[0, 2-\frac{1}{\hat{\varepsilon}}\right)$ but purchases a used product when $\theta \in \left[2-\frac{1}{\hat{\varepsilon}}, 1\right]$, i.e., perceiving a low extent of used-product quality level entices a reserved consumer to purchase a new product. Thus, the demands by reserved consumers for new and used products in period two are $d_{r,n} = \hat{\varepsilon}\left(2-\frac{1}{\hat{\varepsilon}}\right) = 2\hat{\varepsilon} - 1$ and

$d_{r,u} = \hat{\varepsilon}\left(\frac{1}{\hat{\varepsilon}} - 1\right) = 1 - \hat{\varepsilon}$, respectively, while no consumers leave, i.e., $d_{r,l} = 0$. All active consumers resell used products on the CRP and repurchase new products from the retailer, i.e., $d_{a,sn} = d_a = 1 - \hat{\varepsilon}$ and $d_{a,k} = d_{a,sl} = 0$. It is mainly because the presence of utility dependence prioritizes the choice "resell and buy new" over other options. The volume of used-product transaction on the CRP equals the number of active consumers. The total demand for new product in period two is $d_2 = d_{r,n} + d_{a,sn} = \hat{\varepsilon}$, which equals the number of reserved consumers, i.e., $d_r = d_{r,n} + d_{r,u} = \hat{\varepsilon}$. Importantly, the demand of reserved consumers taken away by the CRP returns to the retailer under the influence of utility dependence.

In period one, the retailer sets a new-product price to maximize total revenue $r = p_1 d_1 + r_2^*$, anticipating the revenue to receive in period two. Given new-product price p_1 and anticipating the retailer's selling in period two, a consumer purchases a new product when $u_a \geq \max\{u_r, 0\}$, but postpones purchasing to period two when $u_r \geq \max\{u_a, 0\}$, where u_a and u_r are, respectively, the utilities of purchasing a new product in period one and postponing the purchase to period two, as defined below:

$$u_a = \underbrace{v - p_1}_{buy\ new\ in\ period\ 1} + E_\theta\left(\max\left(\underbrace{\theta v}_{keep}, \underbrace{(1-\tau)\,p_s + v + \varepsilon - p_2}_{resell\ and\ buy\ new}, \underbrace{(1-\tau)\,p_s}_{resell\ and\ leave}\right)\right) \text{ and}$$
$$u_r = \underbrace{0}_{wait\ in\ period\ 1} + E_\theta\left(\max\left(\underbrace{\theta v - p_s}_{buy\ used}, \underbrace{v - p_2}_{buy\ new}, \underbrace{0}_{leave}\right)\right). \tag{4.1}$$

The marginal consumer is indifferent between purchasing a new product in period one and postponing to period two ($u_a = u_r$). Thus, the threshold utility dependence $\hat{\varepsilon}$ satisfies:

$$\hat{\varepsilon} = p_2^*(\hat{\varepsilon}) - p_s^*(\hat{\varepsilon})(1-\tau) - v + \sqrt{\left(p_2^*(\hat{\varepsilon}) - p_s^*(\hat{\varepsilon})\right)^2 + 2v\left(p_1 - p_2^*(\hat{\varepsilon})\right) - v^2}. \tag{4.2}$$

Lemma 4.2 and Table 4.3 state the outcomes. Please refer to Appendix B.2.1 for details. The retailer sets new-product prices over periods to manage the purchase decisions of consumers on when (period one vs period two) and what product (used product vs new product) to purchase.

Lemma 4.2. *The new-product prices in the two periods are* $p_1^* = \frac{2\hat{\varepsilon}^{*3} - \hat{\varepsilon}^{*2} v(\tau-2)}{2\hat{\varepsilon}^{*2}\tau} + \frac{2\hat{\varepsilon}^* v(2\tau-1) - v\tau)}{2\hat{\varepsilon}^{*2}\tau}$ *and* $p_2^* = v$ *respectively, and the market-clearing price for used products on the CRP is* $p_s^* = \frac{\hat{\varepsilon}^{*2} - v(1-\hat{\varepsilon}^*)}{\hat{\varepsilon}^*\tau}$, *where* $\hat{\varepsilon}^* = \frac{v(2\tau-1)+C_6}{2}$ *and* $\hat{\varepsilon}^* > \frac{1}{2}$.

Table 4.3: Equilibrium outcomes

	Period one	Period two
New-product price	$p_1^* = \frac{2\hat{\varepsilon}^{*3} - v\hat{\varepsilon}^{*2}(\tau-2) + 2v\hat{\varepsilon}^*(2\tau-1) - v\tau}{2\tau\hat{\varepsilon}^{*2}}$	$p_2^* = v$
New-product demand	$d_1^* = 1 - \hat{\varepsilon}^*$	$d_2^* = \hat{\varepsilon}^*$
Total demand	$d^* = 1$	
Used-product price and demand	$p_s^* = \frac{\hat{\varepsilon}^{*2} - v(1-\hat{\varepsilon}^*)}{\hat{\varepsilon}^*\tau}$ and $d_s^* = 1 - \hat{\varepsilon}^*$	
Revenue	$r_1^* = \frac{\left(2\hat{\varepsilon}^{*3} - v\hat{\varepsilon}^{*2}(\tau-2) + 2v\hat{\varepsilon}^*(2\tau-1) - v\tau\right)(1-\hat{\varepsilon}^*)}{2\tau\hat{\varepsilon}^{*2}}$	$r_2^* = \hat{\varepsilon}^* v$
Total revenue	$r^* = \frac{\hat{\varepsilon}^{*3}(2-\tau v) + v\hat{\varepsilon}^{*2}(2-3\tau) + v\hat{\varepsilon}^*(5\tau-2) - v\tau}{2\tau\hat{\varepsilon}^{*2}}$	

A notable issue is the functioning of CRP so that the used-product market can be maintained alongside the new-product market managed by the retailer. Similar to Lemma 3.1 in Chapter 3, Lemma 4.3 states that it crucially depends on the value of new-product consumption to consumers.

Lemma 4.3. *As consumers experience utility dependence, the transactions on the CRP exist only when consumers' new-product valuation satisfies that* $v \in \left(\frac{1}{2}, 1\right]$.

The CRP is functional to handle the transactions of used products only when new-product consumption yields a medium-to-high value, i.e., $v \in \left(\frac{1}{2}, 1\right]$. At a low new-product value, i.e., $v \leq \frac{1}{2}$, anticipating a lower price for new product and the chance of purchasing used product in period two, consumers have a weak incentive to purchase new products in period one, although they can reap utility dependence after repeat purchasing. Simultaneously, the number of reserved consumers, who either postpone the purchase of new product or intend to purchase used product on the

CRP in period two, is large. A low supply relative to a high demand results in an unbalanced used-product market, which regains balance only when consumers perceive a high value from new-product consumption. In this case, consumers are effectively segmented into purchase groups to sustain the matchup of supply and demand on the CRP. Examples include automotives, consumer electronics, and furniture. In the following analysis, we assume that $v \in \left(\frac{1}{2}, 1\right]$ holds, to ensure the validity of transactions on the CRP.

4.4 Dynamic Pricing Strategy for New Products Considering Consumers' Utility Dependence

Lemma 4.4. *As consumers experience utility dependence, in the presence of CRP:*

1. *The retailer adopts a skimming policy to set prices for new products across periods, i.e.,* $p_1^* > p_2^*$*.*
2. *As consumers' new-product valuation* v *increases,*
   (a) *the new-product prices in both periods increase, i.e.,* p_1^* *and* p_2^* *increase.*
   (b) *intertemporal price discrimination increases, i.e.,* $p_1^* - p_2^*$ *increases.*
   (c) *the used-product transaction price increases, i.e.,* p_s^* *increases.*
   (d) *the number of reserved (active) consumers increases (decreases), i.e.,* d_r *increases but* d_a *decreases.*

The presence of CRP provides consumers with a platform to transact used products, incubating the competition between used and new products in period two. Consumers' utility dependence brings higher surplus for consumers who purchase in both periods. Thus, the retailer charges a price for new product in period two that is lower than that in period one ($p_1^* > p_2^*$). The skimming pricing policy allows the retailer to compete with the CRP and attract more repeat purchases in period two. As new-product consumption yields a higher value to consumers, the retailer raises the new-product price in each period, which is intuitive, and, more importantly, it aggravates intertemporal price difference, i.e., $p_1^* - p_2^*$ increases with v. Consequently, consumers' incentive to purchase new products in period one weakens, reducing the new-product demand in period one, while more consumers postpone purchases, increasing the new-product demand in period two. The increase in the demand relative to the supply for used products on the CRP boosts the transaction price. As such, the retailer manages prices to shift new-product demand to period two but sustaining used-product transactions on the platform to cater to an increase in consumers' new-product valuation.

To isolate the impacts of CRP, we first analyze a benchmark setting in the absence of CRP. In this setting, consumers can only purchase new products from the retailer in the two periods, as there is no platform available for trading used products. We use superscript B on the quantities of interest to indicate this setting. Purchasing a new product in period one generates utility $v - p_1^B$ to a consumer, who keeps using the product in period two to receive utility $u_{a,k}^B = \theta v$, where θ is the quality level of used product perceived by the consumer. Then, the expected utility of purchasing a new product in period one is $u_a^B = v - p_1^B + E_\theta u_{a,k}^B$. Postponing purchasing a new product to period two yields utility $u_r^B = 0 + \max\left\{u_{r,n}^B, 0\right\}$, where $u_{r,n}^B = v - p_2^B$. A consumer prefers to purchase a new product in period one if $u_a^B > u_r^B \Leftrightarrow p_1^B - p_2^B < \frac{v}{2}$, prefers to postpone purchasing to period two if $u_a^B < u_r^B \Leftrightarrow p_1^B - p_2^B > \frac{v}{2}$, and is indifferent between the two options if $u_a^B = u_r^B \Leftrightarrow p_1^B - p_2^B = \frac{v}{2}$. The retailer sets new-product prices over periods to maximize total revenue.

Starting with the subgame in period two, under the assumption $p_2^B \leq v$, all reserved consumers buy new products rather than leaving the market, and the new-product demand is equal to the number of reserved consumers, i.e.,$d_2^B = d_r^B$. To extract all the surplus, the retailer sets $p_2^{B*} = v$ to maximize revenue, i.e., $\max_{p_2^B} r_2^B =$

$p_2^B d_2^B = p_2^B d_r^B$. In period one, the consumer purchases a new product if $v - p_1^B + E_\theta(\theta)v \geq v - p_2^{B*} \Rightarrow v - p_1^B + \frac{v}{2} \geq 0 \Rightarrow p_1^B \leq \frac{3v}{2}$. Thus, if the retailer sets $p_1^B < \frac{3v}{2}$, all consumers purchase in period one, and the retailer's revenue is $r^B = p_1^B d_1^B < \frac{3v}{2}$. If the retailer sets a period-one price $p_1^B > \frac{3v}{2}$, all consumers purchase in period two at $p_2^{B*} = v$, and the retailer's revenue is $r^B = p_2^{B*} d_2^B = v$. When $p_1^B = \frac{3v}{2}$, consumers are indifferent between purchasing in periods one and two. In this case, $d_1^B = d_2^B = \frac{1}{2}$, and the retailer's revenue is $r^B = p_1^B d_1^B + p_2^{B*} d_2^B = \frac{5v}{4}$. Therefore, maximizing the retailer's total revenue $r^B = p_1^B d_1^B + p_2^B d_2^B$ in the equilibrium, new-product prices are $p_1^{B*} = \frac{3v}{2}$, $p_2^{B*} = v$, new-product demands are $d_1^{B*} = \frac{1}{2}$, $d_2^{B*} = \frac{1}{2}$, and $d^{B*} = 1$, and revenues are $r_1^{B*} = \frac{3v}{4}$, $r_2^{B*} = \frac{v}{2}$, and $r^{B*} = \frac{5v}{4}$.

The retailer adheres to a skimming policy to set a new-product price in period one higher than that in period two, i.e., $p_1^{B*} - p_2^{B*} = \frac{v}{2} > 0$. Under this policy, half of the consumers purchase new products in period one and keep using them in period two, while the others wait to purchase new products in period two. Despite the difference in timing to finalize purchases, consumers receive the same expected utility, which is $\frac{v}{2}$. With the same demands for new product in the two periods, the higher price in period one generates a higher revenue that that in period two.

Compared to the situation without CRP, the presence of CRP affects consumers' choices of when, what and why to purchase, when consumers experience utility dependence. The number and composition of consumers who form new-product demands to the retailer across the two periods alter, forcing it to adapt prices. Table 4.4 presents the comparison results of performance outcomes with and without CRP.

In the presence of heterogeneities among consumers in perceiving the quality levels of used products and utility dependence from repeat purchases, we investigate the effects of CRP, which provides a venue for consumers to redistribute products and competes with the retailer for demand in the meanwhile. Proposition 4.1 summarizes the effects of CRP on the prices and demands for the retailer.

Table 4.4: Prices and demands in the absence and presence of CRP

	w/o CRP		w/ CRP
New-product price in period one	$\frac{3v}{2}$	$<$	$\frac{2\hat{\varepsilon}^{*3}-v\hat{\varepsilon}^{*2}(\tau-2)+2v\hat{\varepsilon}^{*}(2\tau-1)-v\tau}{2\tau\hat{\varepsilon}^{*2}}$
New-product price in period two	v	$=$	v
New-product intertemporal price discrimination	$\frac{v}{2}$	$<$	$\frac{v(\hat{\varepsilon}^{*2}+2\hat{\varepsilon}^{*}-1)}{2\hat{\varepsilon}^{*2}}$
New-product demand in period one	$\frac{1}{2}$	$>$	$1-\hat{\varepsilon}^{*}$
New-product demand in period two	$\frac{1}{2}$	$<$	$\hat{\varepsilon}^{*}$

Proposition 4.1. *As consumers experience utility dependence, compared with the situation without CRP, the presence of CRP:*

1. *increases new-product price in period one but keeps new-product price in period two unchanged, thus exacerbating intertemporal price discrimination adopted by the retailer, i.e.,* $p_1^* > p_1^{B*}$, $p_2^* = p_2^{B*}$, *and* $p_1^* - p_2^* > p_1^{B*} - p_2^{B*}$.

2. *decreases new-product demand in period one while increases new-product demand in period two, i.e.,* $d_1^* < d_1^{B*}$ *and* $d_2^* > d_2^{B*}$.

The CRP provides reserved consumers with the opportunity to purchase used products instead of new products from the retailer in period two, while it also provides active consumers with a venue to sell used products. With utility dependence from repeat purchases, active consumers prefer to resell used products and buy new ones in period two. The retailer's demand that is encroached by the CRP is compensated by repurchasing. It mitigates the direct competition between the new products provided by the retailer and used products provided by the CRP.

To cater to the change in consumers' purchase pattern, the retailer raises the new-product price in period one but maintains new-product price in period two, to balance the demands for new and used products across periods as consumers acquire utility dependence. The extant literature states that, in the presence of strategic consumers, skimming pricing policy is suboptimal to a monopolist, who should eliminate intertemporal price discrimination to deter strategic waiting by the consumers (Besanko & Winston 1990; Stokey 1979). In contrast, we find that, as consumers experience utility dependence, the rise of CRP allows the retailer to aggravate intertemporal price discrimination and encourage strategic waiting by the consumers. As such, market efficiency enhances through the redistribution of new-product demands over periods and matchup of suppliers (among active consumers) with demanders (among reserved consumers) for used products in period two.

L. Jiang et al. (2017) observe from numerical simulations that the retailer encourages consumers to engage in strategic waiting through intertemporal price discrimination when the platform poses a limited competitive threat to the retailer. In our model, reselling used products on the CRP by active consumers to reserved consumers enforces little pressure on the selling of new products to the retailer. It is because the presence of utility dependence entices active consumers to repurchase new products from the retailer after reselling and the total demand for new product remains unchanged. Our result identifies the concrete circumstances where the skimming pricing policy is optimal to the monopolistic retailer and how the retailer should manage prices to encourage strategic waiting by consumers.

4.4.1 Impacts on Retailer's Revenue

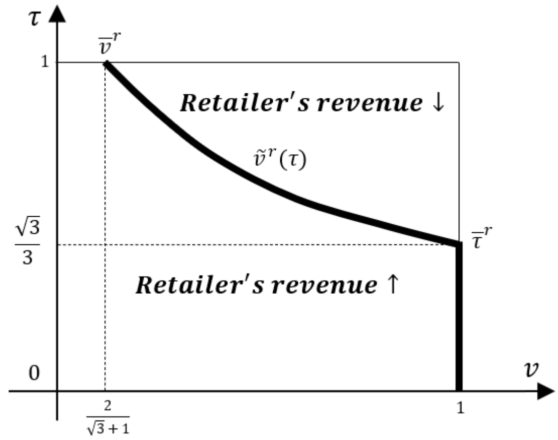
The price adaptations cause demand changes, exerting subtle impacts on the retailer's revenue over periods. On one hand, the new-product demand in period one decreases ($d_1^* < d_1^{B*}$) to worsen the retailer's revenue ($r_1^* < r_1^{B*}$), despite the increase in new-product price; we refer to it as the *cannibalization effect*. In contrast, in period two, all active consumers, instead of keeping used products as they would in the absence of the CRP, repurchase new products after reselling used ones. Together with the demand from reserved consumers who purchase new products, the new-product demand in period two increases relative to when CRP is absent ($d_2^* > d_2^{B*}$), where only reserved consumers would purchase new products. It results in an improvement in the retailer's revenue ($r_2^* > r_2^{B*}$); we call it the *enhancement effect*. Corollary 4.1 highlights the two effects arising from the presence of CRP on the revenue for the retailer.

Corollary 4.1. *As consumers experience utility dependence, the rise of CRP gives rise to two opposing effects on the retailer's revenue: a cannibalization effect that decreases the retailer's period-one revenue, and an enhancement effect that increases the retailer's period-two revenue.*

The coexistence of enhancement and cannibalization effects influences the retailer's total revenue from selling new products over the two periods. Proposition 4.2 states the consequence on the retailer's revenue as a result of the tradeoff of these two effects.

Proposition 4.2. *Referring to Figure 4.3, as consumers experience utility dependence, compared to the situation without CRP, in the presence of CRP, the enhancement effect outweighs the cannibalization effect to improve the retailer's total revenue when consumers' new-product valuation satisfies* $v < \min\{\tilde{v}^r(\tau), 1\}$ *for a given commission rate* τ*, where* $\tilde{v}^r(\tau)$ *is provided in Appendix B.1. Otherwise, the cannibalization effect outweighs the enhancement effect to undermine the retailer's total revenue.*

At a low commission rate by the CRP, i.e., $\tau \in \left[0, \frac{\sqrt{3}}{3}\right]$, active consumers retain a large proportion of the transaction value of used products. It entices consumers to purchase new products in period one, to receive surplus from the reselling of used products on the CRP and reap utility dependence by repeatedly purchasing from the retailer in period two. The cannibalization effect is weak against a strong enhancement effect, leading to an improvement in the retailer's total revenue. At a high commission rate by the CRP, i.e., $\tau \in \left(\frac{\sqrt{3}}{3}, 1\right]$, active consumers retain a



Notes. ↓ indicates "worsens" and ↑ indicates "improves".

Figure 4.3: Effects of CRP on the retailer's revenue considering consumers' utility dependence

small proportion of resale revenue for used products, and consumers' incentive to purchase new products in period one weakens. The net effect of CRP on the retailer's total revenue further depends on the consumers' new-product valuation v. Recall that intertemporal difference in new-product prices increases with v. At a high new-product valuation, i.e., $v \in (\tilde{v}^r, 1]$, the high new-product price in period one relative to that in period two induces consumers to postpone purchases, and the reduction in new-product sales produces a strong cannibalization effect. Meanwhile, since few active consumers repurchase from the retailer in period two, the enhancement effect is weak, despite the increase in the new-product demand by reserved consumers. Consequently, the retailer's revenue reduces. At a low new-product valuation, i.e., $v < \tilde{v}^r$, the new-product price in period one is not over-high so that the cannibalization effect arising from sales reduction in period one is contained, then the enhancement effect dominates to improve the retailer's total revenue.

The existing works state that the presence of a C2C resale market undermines the monopolist's profit (P. Desai et al. 2004; Yin et al. 2010). In contrast, our study indicates that the rise of CRP improves the retailer's revenue in many situations, despite its competition with the retailer for demand by providing used products at a lower price with a comparable quality level. This difference can be attributed to the heterogeneity among consumers in their perceived quality of used products and their utility dependence on repeat purchases. Prior studies assume that consumers hold homogeneous and exogenous used-product valuation and are aware of used-product quality levels prior to the start of the selling season. However, this assumption is not realistic for the used products sold on the CRP, which are provided by individuals without unified quality control and observed by reserved consumers in the later period. Meanwhile, active consumers are uncertain about the used-product quality level until they have used the product. Indeed, 59.2% of the respondents to our survey believe that they cannot accurately estimate the quality levels of the used products. All these drive us to assume that consumers are uncertain about the quality levels of the used products and make purchase decisions based on their expectations in period one. Furthermore, our survey reveals that 55.8% of the respondents have gained value increment by repeatedly purchasing from the same retailer, indicating the prevalence of utility dependence in practice. Consumer heterogeneity has substantial influences on demand formation, forcing the retailer to adapt prices to tailor to the market changes thus occur. By leveraging heterogeneities on consumers' side, the retailer practices intertemporal pricing discrimination to manage the demands for new products across periods.

Our results point to a decreasing trend for new-product prices ($p_1^* > p_2^*$) and an increasing trend for new-product demand ($d_1^* < d_2^*$), while new-product sales in period one are later converted into used-product transactions on the CRP in period two. In the presence of CRP when consumers experience utility dependence, dynamically managing the prices for new product across periods enables the retailer to align the matchup of supply and demand for used products with the new-product sales it manages. It can result in a more efficient distribution of demand to improve the retailer's revenue.

Corollary 4.2 states the comparative static results regarding the effects of the CRP's commission rate on the retailer's revenue.

Corollary 4.2. *The retailer's revenue increases as the CRP's commission rate increases when consumers' new-product valuation is low, i.e., $v \leq \tilde{v}_1^{r*}$; or the consumers' new-product valuation is medium and the commission rate is low, i.e., $v \in (\tilde{v}_1^{r*}, \tilde{v}_2^{r*}]$ and $\tau \in [0, \tilde{\tau}^{r*}]$, where $\tilde{v}_1^{r*}, \tilde{v}_2^{r*}$, and $\tilde{\tau}^{r*}$ are provided in Appendix B.1.*

The retailer receives revenue by selling new products in the two periods, while the commission rate determines the allocation of used-product transaction revenue between the platform and consumers. Corollary 4.2 identifies the circumstances where an increase in the commission rate on the CRP yields more revenue to the retailer. A higher commission rate implies that active consumers make less revenue from reselling on the platform. It weakens consumers' incentive to purchase new products in period one, decreasing the number of active consumers but increasing that of reserved consumers. The demand for new product in period one comes solely from active consumers, while that in period two comes from both reserved and active consumers and equals in quantity to that of reserved consumers. Thus, a higher commission rate decreases (increases) the demand for new product to the retailer in period one (period two).

Recall that intertemporal price discrimination ($p_1^* - p_2^*$) increases with the consumers' new-product valuation v. At a low new-product valuation, i.e., $v \leq \tilde{v}_1^{r*}$, the retailer sets a slightly higher price for new product in period one relative to that in period two. As the commission rate increases, the decrease in new-product sales leads to a reduction in revenue to the retailer in period one, which is less than the gain in sales revenue to the retailer in period two. As a result, the retailer is better off. At a medium new-product valuation, i.e., $v \in (\tilde{v}_1^{r*}, \tilde{v}_2^{r*}]$, the new-product price in period one is moderately higher than that in period two. Associated with an increase in the commission rate, the revenue drop in period one can be offset by the revenue gain in period two. It leads to an improvement in the retailer's total revenue, unless the commission rate is sufficiently high, i.e., $\tau > \tilde{\tau}^{r*}$, in which case, the retailer suffers revenue loss since the demand loss in period one cannot be compensated by the gain in period two. At a high new-product valuation, i.e., $v > \tilde{v}_2^{r*}$, intertemporal price discrimination is substantial, and the demand loss in period one attributed to an increase in the commission rate undermines the retailer's revenue.

4.4.2 Impacts on Consumer Surplus and Social Welfare

Consumer surplus integrates consumers' net utilities received by consuming new and used products across periods. In the absence of the CRP, consumer surplus is:

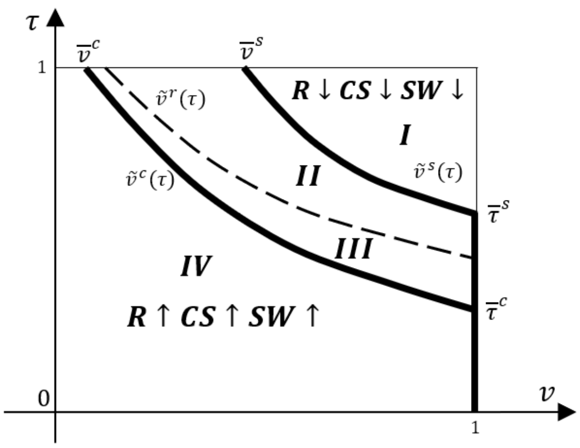
$$cs^B = \underbrace{\int_{\frac{1}{2}}^{1} \left(v - p_1^{B*} + \theta v\right) d\theta}_{active\ consumers} + \underbrace{\int_{0}^{\frac{1}{2}} \left(v - p_2^{B*}\right) d\theta}_{reserved\ consumers} = \frac{v}{8} \tag{4.3}$$

while in the presence of the CRP, it is:

$$\begin{aligned} cs = & \underbrace{\int_{\hat{\varepsilon}^*}^{1} \int_{0}^{1} \left(v - p_1^* + (1-\tau)\, p_s^* + v + \hat{\varepsilon}^* - p_2^*\right) d\theta d\varepsilon}_{active\ consumers} \\ & + \underbrace{\int_{0}^{\hat{\varepsilon}^*} \left(\int_{0}^{1-\frac{p_2^*-p_s^*}{v}} \left(v - p_2^*\right) d\theta + \int_{1-\frac{p_2^*-p_s^*}{v}}^{1} \left(\theta v - p_s^*\right) d\theta \right) d\varepsilon}_{reserved\ consumers} \\ = & \frac{\hat{\varepsilon}^{*4}\tau - 2\hat{\varepsilon}^{*3}(\tau+1) + \hat{\varepsilon}^{*2}\left(\tau\left(5v+1\right) - 2v\right) + 2v\hat{\varepsilon}^*\left(1-2\tau\right) + v\tau}{2\tau\hat{\varepsilon}^{*2}}. \end{aligned} \tag{4.4}$$

In the absence of CRP, social welfare aggregates the retailer's revenue and consumer surplus, i.e., $sw^B = r^{B*} + cs^B = \frac{11v}{8}$. In the presence of CRP, the transaction revenue on the CRP is accounted for as well, resulting in $sw = r^* + \tau p_s^* d_s^* + cs = \frac{\hat{\varepsilon}^*\left(6v - \hat{\varepsilon}^{*2} - 3\hat{\varepsilon}^* v + 1\right) - v}{2\hat{\varepsilon}^*}$. As consumers experience utility dependence, the rise of CRP entices the retailer to adapt the prices across periods to manage demand generation and satisfaction. Proposition 4.3 states the effects of CRP on consumers and society.

Proposition 4.3. *Referring to Figure 4.4, as consumers experience utility dependence, compared to the situation when CRP is absent, the presence of CRP improves* *consumer surplus only when* $v \leq \min\{\tilde{v}^c(\tau), 1\}$ *and improves social welfare only when* $v \leq \min\{\tilde{v}^s(\tau), 1\}$ *for a given commission rate* τ*, where* $\tilde{v}^c(\tau)$ *and* $\tilde{v}^s(\tau)$ *are provided in Appendix B.1.*



Notes. R stands for the retailer's revenue, CS stands for consumer surplus, and SW stands for social welfare.

R ↓ CS ↓ SW ↑ in area II; R ↑ CS ↓ SW ↑ in area III; ↓ indicates "worsens" and ↑ indicates "improves".

Figure 4.4: Effects of CRP on consumer surplus and social welfare considering consumers' utility dependence

Our intuition suggests that, with state-dependent utility, consumers benefit more than the retailer from the rise of CRP. It is because the CRP provides consumers with additional purchase choices, channels, and rewards, including resale value and utility dependence, but exposes the retailer to competition. Specifically, in the absence of CRP, consumers can only purchase new products from the retailer, with period-one demand from active consumers and period-two demand from reserved consumers. The rise of CRP enables active consumers to resell used products and purchase new ones from the retailer to receive additional values, and allows reserved consumers to postpone and purchase used products. Catering to such changes in consumers' purchase activities, the retailer dynamically adjusts prices to manage the demands for new product across periods alongside the transactions of used products on the CRP. As a result of this enhanced power in demand management, the retailer is more likely to benefit from the presence of CRP than consumers. That is, the retailer takes advantage of the enhanced purchase options granted to consumers due to the rise of CRP to profit by adapting prices over periods.

Recall that the retailer raises new-product price in period one but maintains new-product price in period two to aggravate price discrimination compared to that without CRP, leading to a decreased number of active consumers and an increased quantity of reserved consumers. When the CRP's commission rate is low, the transaction price for used products is low. The loss in consumer surplus in period one due to a higher price and a lower demand is outweighed by the utility dependence acquired from repeat purchases and the reselling revenue to active consumers. Meanwhile, the low transaction price for used products on the CRP benefits reserved consumers who purchase used products. All these result in an improved consumer surplus. Nevertheless, consumers are worse off with the rise of CRP when the commission rate is high and consumers' new-product valuation is high as well, in which case, the new-product price in period one is high and the used-product transaction price on the CRP in period two is high as well.

Notably, as consumers experience utility dependence, the rise of CRP benefits the retailer whenever it benefits consumers (area IV of Figure 4.4), i.e., the retailer and consumers can be better off simultaneously. By contrast, it harms consumers whenever it harms the retailer (areas I and II of Figure 4.4), i.e., the retailer and consumers can be worse off simultaneously. Only when consumers' new-product valuation and commission rate are medium-high (area III of Figure 4.4) does the CRP exert opposite effects on the retailer and consumers, benefiting the retailer but harming consumers in particular.

Taking into consideration the CRP's revenue made from used-product transactions, the aggregate effect of the CRP on social welfare is subtle. When the retailer and consumers are better off (area IV of Figure 4.4), the CRP's revenue improves social welfare, resulting in a win-win situation to benefit all market participants.

Otherwise, either the retailer, or consumers, or both are worse off with the rise of CRP. When new products yield a medium-high value (areas II and III of Figure 4.4), the commission revenue reaped by the CRP is high (due to a high transaction price) and can offset the reductions in the retailer's revenue or consumer surplus to increase social welfare. Nevertheless, when new-product consumption creates a high value (area I of Figure 4.4), the CRP makes a low revenue from used-product transactions (due to a low transaction volume), and social welfare worsens. It leads to a lose-lose outcome for all market participants. Additionally, we can conclude that the presence of CRP may lead to market participants being either simultaneously better off or worse off, as illustrated in areas I and IV of Figure 4.4.

4.5 Collaboration Strategy Between Retailer and CRP Considering Consumers' Utility Dependence

In this section, we infuse practical features to explore the retailer's optimal collaboration strategy with the CRP. This encompasses scenarios where the retailer self-manages an internal platform or provides price subsidies for consumers who repurchase. Additionally, we also analyze the platform's commission-rate pricing aimed at maximizing its own revenue.

4.5.1 Retailer's Self-Managing Platform Strategy

In reality, some retailers internally establish and operate CRPs rather than collaborating with external platforms to leverage consumers' utility dependence more effectively. For instance, IKEA has launched programs called "Circular Hub" and "Re-shop and Re-use" (IKEA 2024a,b), aiming to facilitate reselling and purchasing used IKEA products by their consumers and create spaces in consumers' homes for new IKEA items (Matzler et al. 2014). To explore the effects of such initiative, we consider the situation where the retailer self-manages a CRP by incurring a marginal operating cost c for each used-product transaction. We ignore fixed development cost since the retailer can rely on existing facilities to operate the CRP by, for instance, launching an entrance on the official website and utilizing extant logistics networks. The retailer's period-two revenue is $r_2^O = p_2^O d_2^O + \left(\tau p_s^O - c\right) d_s^O$, where superscript O indicates the scenario in which the retailer self-manages a CRP. The retailer sets new-product prices p_1^O and p_2^O to maximize the retailer's total revenue. The equilibrium outcomes is illustrated in Table 4.5. Please refer to Appendix B.4.1 for details.

Table 4.5: Equilibrium outcomes of strategy O

	Period one	Period two
Indifferent consumer type	$\hat{\varepsilon}^{O*} = \frac{v(2\tau-1)+C_6}{2}$	
New-product price	$p_1^{O*} = \frac{2\hat{\varepsilon}^{O*3} - v\hat{\varepsilon}^{O*2}(\tau-2) + 2v\hat{\varepsilon}^{O*}(2\tau-1) - v\tau}{2\tau\hat{\varepsilon}^{O*2}}$	$p_2^{O*} = v$
New-product demand	$d_1^{O*} = 1 - \hat{\varepsilon}^{O*}$	$d_2^{O*} = \hat{\varepsilon}^{O*}$
Total demand	$d^{O*} = 1$	
Used-product price and demand	$p_s^{O*} = \frac{\hat{\varepsilon}^{O*2} + v(\hat{\varepsilon}^{O*}-1)}{\hat{\varepsilon}^{O*}\tau}$ and $d_s^{O*} = 1 - \hat{\varepsilon}^{O*}$	
Revenue	$r_1^{O*} = \frac{\left(2\hat{\varepsilon}^{O*3} - v\hat{\varepsilon}^{O*2}(\tau-2) + 2v\hat{\varepsilon}^{O*}(2\tau-1) - v\tau\right)\left(1-\hat{\varepsilon}^{O*}\right)}{2\tau\hat{\varepsilon}^{O*2}}$	$r_2^{O*} = \frac{-\hat{\varepsilon}^{O*3} + \hat{\varepsilon}^{O*2}(1+c) + \hat{\varepsilon}^{O*}(2v-c) - v}{\hat{\varepsilon}^{O*}}$
Total revenue	$r^{O*} = \frac{-2(\tau+1)\hat{\varepsilon}^{O*4} + \hat{\varepsilon}^{O*3}(\tau(2c+v+2) - 2(v-1)) + \hat{\varepsilon}^{O*2}(4v - \tau(v+2c)) + v\hat{\varepsilon}^{O*}(3\tau-2) - v\tau}{2\tau\hat{\varepsilon}^{O*2}}$	

Proposition 4.4. *As consumers experience utility dependence, compared to when an external CRP handles used-product transactions, the retailer receives a higher revenue by self-managing a CRP when the marginal operating cost is low, i.e.,* $c \in [0, c^O)$, *where* $c^O = \frac{2\tau v(C_6 + v(2\tau-1) - 1)}{C_6 + v(2\tau-1)}$ *and* C_6 *is provided in Appendix B.1.*

Provided that the marginal operation cost is low, i.e., $c \in [0, c^O)$, a self-managing platform allows the retailer to further exploit the enhancement effect in period two, i.e., $r_2^{O*} > r_2^*$, and reap a higher total revenue.

4.5.2 Retailer's Price Subsidy Strategy

In practice, retailers often offer a subsidy to the consumers who repurchase new products after reselling used products. For instance, Stella McCartney's consumers who sell used products in The RealReal, an online apparel C2C platform, receive an instant \$100 credit to shop new products at Stella stores (ThredUP 2021). Consumers who have purchased Eileen Fisher products can bring their old products back and receive a \$5 reward for each item (Cortez 2021). In this section, we investigate the efficacy of the subsidy strategy. Superscript D is added on quantities of interest. Assuming the retailer implements a discounted price $(1-m)p_2^D$, where $m \in [0,1]$ is the discount factor, for active consumers who repurchase new products in period two. Consequently, the utility of an active consumer opting for the 'resell and buy new' option in period two becomes $v+\varepsilon-(1-m)p_2^D+(1-\tau)\,p_s^D$. The retailer's period-two revenue is $r_2^D = p_2^D d_2^D - mp_2^D d_s^D$, where $mp_2^D d_s^D$ represents the retailer's expenditure on subsidies. Conversely, reserved consumers continue to pay the regular new-product price p_2^D in period two. Given the discount factor m, the retailer sets new-product prices p_1^D and p_2^D to maximize revenue by managing consumer purchases. The equilibrium outcomes is illustrated in Table 4.6. Please refer to Appendix B.4.2 for details.

Proposition 4.5. *The retailer does not benefit from offering a price subsidy to consumers for repeat purchases. Implementing a price subsidy strategy does not alter the total demand for new products.*

Despite offering a subsidy for active consumers who repurchase aims to boost the demand for new product in period two, it undermines the revenue for the retailer, through its influences on the retailer's operations adjustments. Specifically, the retailer lowers the price for new product in period one ($p_1^{D*} \leq p_1^*$), which induces more consumers to purchase new products in period one ($d_1^{D*} \geq d_1^*$) and later repurchase new products after reselling used ones in period two. This is intuitive since the re-

Table 4.6: Equilibrium outcomes of strategy D

	Period one	Period two
Indifferent consumer type	$\hat{\varepsilon}^{D*} = \frac{v(2\tau-m-1)+\sqrt{v\left(v(m-2\tau+1)^2-4(\tau-1)\right)}}{2}$	
New-product price	$p_1^{D*} = \frac{\Lambda_{p_1^D}}{2(m-\tau)\hat{\varepsilon}^{D*2}}$	$p_2^{D*} = v$
New-product demand	$d_1^{D*} = 1 - \hat{\varepsilon}^{D*}$	$d_2^{D*} = \hat{\varepsilon}^{D*}$
Total demand	$d^{D*} = 1$	
Used-product price and demand	$p_s^{D*} = \frac{v(m-1)(\hat{\varepsilon}^{D*}-1)-\hat{\varepsilon}^{D*2}}{\hat{\varepsilon}^{D*}(m-\tau)}$ and $d_s^{D*} = 1 - \hat{\varepsilon}^{D*}$	
Revenue	$r_1^{D*} = \frac{\Lambda_{p_1^D}\left(1-\hat{\varepsilon}^{D*}\right)}{2(m-\tau)\hat{\varepsilon}^{D*2}}$	$r_2^{D*} = v\left(\hat{\varepsilon}^{D*}(1+m) - m\right)$
Total revenue	$r^{D*} = \frac{\Lambda_{p_1^D}\left(1-\hat{\varepsilon}^{D*}\right)}{2(m-\tau)\hat{\varepsilon}^{D*2}} + v\left(\hat{\varepsilon}^{D*}(1+m) - m\right)$	

Note. $\Lambda_{p_1^D} = -2\hat{\varepsilon}^{D*3} + v\hat{\varepsilon}^{D*2}(m+\tau-2) + 2v\hat{\varepsilon}^{D*}(m-2\tau+1) - v(m-\tau)$.

tailer makes less by selling to a active consumer who repurchases in period two and aims to make more sales to active consumers. Nevertheless, it reduces the number of reserved consumers, resulting in a reduction in total demand for new product in period two ($d_2^{D*} \leq d_2^*$), while the total demand for new product across periods remains unchanged. The retailer, by providing a subsidy for repeat purchasing, maintains the price for new product in period two ($p_2^{D*} = p_2^*$), but the number of consumers who pay full price drops. As a consequence of the sequential changes in the prices and demands for new product in the two periods, the retailer suffers a loss in total revenue. Thus, from the perspective of revenue generation, offering a subsidy for repeat purchase is not an effective instrument for the retailer.

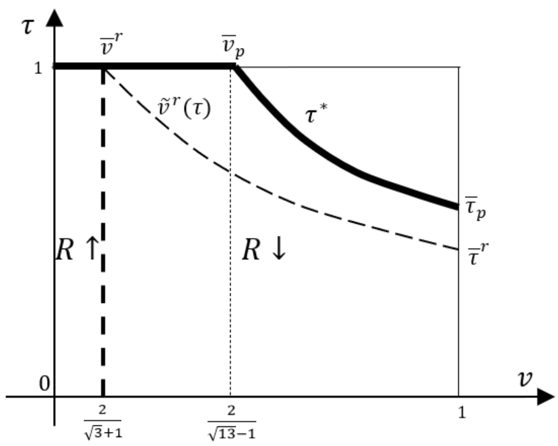
4.5.3 CRP's Optimal Commission Rate Strategy

Another practical collaboration strategy involves retailers partnering with an external CRP, which operates the platform and generates revenue by sustaining used-product transactions at an endogenously determined commission rate. For example, Swappa charges a commission rate of 3% of the sold price for sellers (Swappa 2024), while eBay sets varying commission rates according to product categories, such as 13.25% for consumer electronics and 15% for apparels (eBay 2023). Proposition 4.6 presents the results when the retailer allows the third-party CRP to set its optimal commission rate to maximize its revenue. The proof is in Appendix B.4.3.

Proposition 4.6. *As the CRP chooses the commission rate to maximize revenue:*

1. *the optimal commission rate is $\tau^* = 1$ when consumers' new-product valuation is low, i.e., $v \leq \frac{2}{\sqrt{13}-1}$; and $\tau^* = \frac{\left(2v^2+6v+1\right)C_5^2-\left(v^3-3v^2-10v\right)C_5+v^4+3v^3-5v^2-4v}{12v^2C_5^2+\left(6v^3+12v^2\right)C_5+6v^2}$ when consumers' new-product valuation is high, i.e., $v \in \left(\frac{2}{\sqrt{13}-1}, 1\right)$, where C_5 is provided in Appendix B.1.*

2. *the retailer's revenue improves when consumers' new-product valuation is low, i.e., $v \leq \frac{2}{\sqrt{3}+1}$, but is worsened otherwise.*



Notes. R stands for the retailer's revenue; ↓ indicates "worsens" and ↑ indicates "improves".

Figure 4.5: Optimal commission rate by CRP considering consumers' utility dependence

Recall that, in the presence of CRP, as consumers experience utility dependence, the volume of used-product transactions finalized on the platform equals the number of active consumers. The optimal commission rate depends heavily on consumers' new-product valuation. At a low new-product valuation, i.e., $v \leq \frac{2}{\sqrt{13}-1}$, the retailer sets a slightly high new-product price in period one, and the number of reserved consumers, some of whom are used-product demanders on the CRP, is low. The low transaction volume induces the CRP to set commission rate at $\tau^* = 1$ to extract all the surplus from transactions. While active consumers receive no income by selling used products, they reap utility dependence through repeat purchases. At a high new-product valuation, i.e., $v \in \left(\frac{2}{\sqrt{13}-1}, 1\right]$, the retailer substantially raises the new-product price in period one, inducing consumers to postpone purchases to period two. The CRP manages commission rate τ^* to balance the tradeoff between the marginal revenue from each transaction and transaction volume. The optimal rate decreases as consumers perceive a higher value from new-product consumption, i.e., τ^* decreases with v, to compensate for the reduction in transaction volume.

Figure 4.5 illustrates the effect of consumers' new-product valuation on the CRP's optimal commission rate, which influences the retailer's revenue compared to when the CRP is absent. Recall that by Proposition 4.2, the retailer benefits from the existence of CRP when consumers' new-product valuation satisfies $v < \min\{\tilde{v}^r(\tau), 1\}$ for a given commission rate τ, where $\tilde{v}^r(\tau)$ decreases with τ. With the optimal commission rate given in Proposition 4.6, $\tau^* = 1$ when $v \leq \bar{v}_p = \frac{2}{\sqrt{13}-1} > \bar{v}^r = \frac{2}{\sqrt{3}+1}$, and $\tau^* > \tilde{v}^{r^{-1}}(v)$, where $\tilde{v}^{r^{-1}}(\cdot)$ is the inverse function of $\tilde{v}^r(\cdot)$, when $v > \frac{2}{\sqrt{3}+1}$. It implies that the retailer can be better off even as the CRP sets the highest commission rate $\tau^* = 1$ when $v \leq \frac{2}{\sqrt{3}+1}$. However, its revenue reduces as the CRP retains all the transaction revenue when $v \in \left(\frac{2}{\sqrt{3}+1}, \frac{2}{\sqrt{13}-1}\right]$ or partial transaction revenue when $v \in \left(\frac{2}{\sqrt{13}-1}, 1\right]$. Thus, a revenue-maximizing CRP can cannibalize the retailer's revenue except when consumers' new-product valuation is low, i.e., $v \leq \frac{2}{\sqrt{3}+1}$, in which case, the retailer's revenue improves relative to that in the absence of CRP.

4.6 Model Robustness

In this section, we discuss three approaches to extend the main model, thus broadening its applicability. One examines a scenario with the partially covered market. One involves a scenario in which the product value and the utility dependence stemming from repeat purchases are interrelated. Another delves into the scenario in which products sold across periods exhibit vertical differentiation.

4.6.1 Partially Covered Market

In this section, we allow the market to be partially covered, where the new-product price in period two exceeds consumers' valuation, and we discuss the robustness of the results from the fully covered market.

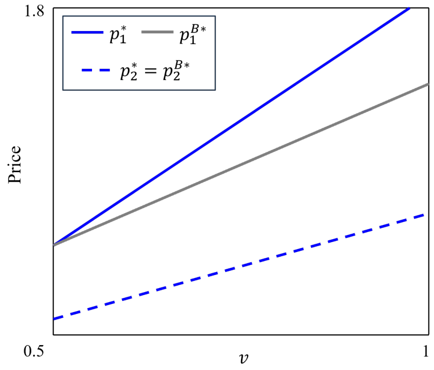
In the presence of CRP, under the condition $p_2 > v$, reserved consumers weigh the "buy used" option against the "leave the market" option in period two, but never tick the "buy new" option, which results in a negative utility. It causes the market to be partially covered since some consumers postpone purchases to period two but eventually leave without purchasing. Specifically, When $v + \varepsilon \geq p_2 > v$, reserved consumers decide between "buy used" and "leave" in period two, with the option "buy new" being dominated. Active consumers, are still presented with two alternatives: "keep" and "resell and buy new", with the option "resell and leave" being dominated. In this scenario, the demand for new products in period two originates exclusively from active consumers, i.e., $d_2 = d_{a,sn}$, with the market partially covered. The other scenario arises when $p_2 > v + \varepsilon$. In this case, the new-product demand in period two is zero, i.e., $d_2 = 0$, as both the option "buy new" for reserved consumers and the option "resell and buy new" for active consumers are dominated. The retailer who maximizes its period-two revenue ($r_2 = p_2 d_2$) in the subgame will not set a price that results in zero demand. Consequently, our focus is on the scenario where

$v + \varepsilon \geq p_2 > v$. Please refer to Appendix B.2.2 for details.

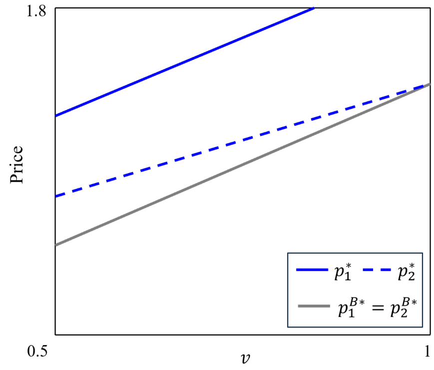
In the absence of CRP, as the retailer raises the new-product price above consumers' new-product valuation ($p_2^B > v$), all reserved consumers exit the market without purchase in period two since $v - p_2^B < 0$, resulting in no demand in this period, i.e., $d_2^B = 0$. It implies the ineffectiveness of the dynamic pricing in influencing its revenue $r_2^B = p_2^B d_2^B$ in period two. As a result, the retailer no longer dynamically adjusts period-two price. In period one, the consumer purchases a new product if $v - p_1^B + E_\theta(\theta)v \geq 0 \Rightarrow p_1^B \leq \frac{3v}{2}$. If the retailer sets $p_1^B < \frac{3v}{2}$, all consumers purchase in period one, i.e., $d_1^B = 1$, and the retailer's revenue is $r^B = p_1^B d_1^B < \frac{3v}{2}$. If the retailer sets a period-one price $p_1^B > \frac{3v}{2}$, all consumers will postpone and leave. The retailer receives zero revenue. When $p_1^B = \frac{3v}{2}$, consumers are indifferent between "purchasing in period one" and "postponing in period one then leaving in period two". In this case, the retailer sets new-product price in period one at $p_1^{B*} = \frac{3v}{2}$ to attract a demand of $d_1^{B*} = \frac{1}{2}$ but forgo the period-two market entirely. The total revenue is solely derived from the first period, yielding $r_1^{B*} = r^{B*} = \frac{3v}{4}$. Overall, in the equilibrium, new-product prices are $p_1^{B*} = \frac{3v}{2}$ and $p_2^{B*} > v$. One equilibrium outcome is to maintain its period-one price in period two, i.e., $p_1^B = p_2^B$. The new-product demands are $d_1^{B*} = \frac{1}{2}$, $d_2^{B*} = 0$, and $d^{B*} = \frac{1}{2}$, and revenues are $r_1^{B*} = \frac{3v}{4}$, $r_2^{B*} = 0$, and $r^{B*} = \frac{3v}{4}$.

We resort to a numerical study of the equilibrium outcomes when the market is partially covered and compare them with those when the market is fully covered. We use a reasonable commission rate, i.e., $\tau = 0.1$. In practice, CRPs retain a certain percentage of transaction revenue as commission. For instance, eBay charges 13.25% for most categories, including consumer electronics, furniture, appliances, and automobiles, and 15% for apparels (eBay 2023). Figure 4.6 illustrates the outcomes with and without CRP in scenarios with both full and partial market coverage.

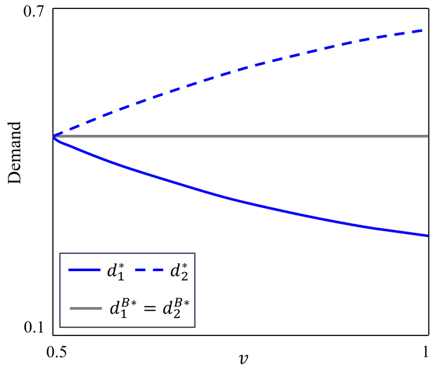
Lemma 4.5. *In the partially covered market, while the retailer raises prices in both periods, the substantial reduction in demand lowers revenue compared to that in the fully covered market.*



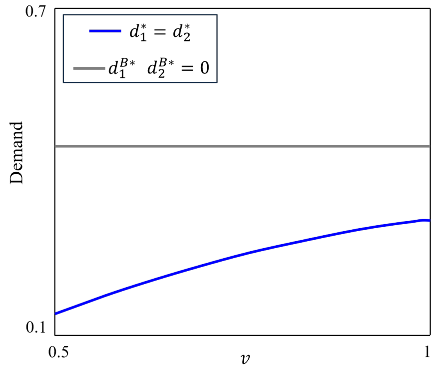
(a) Full coverage



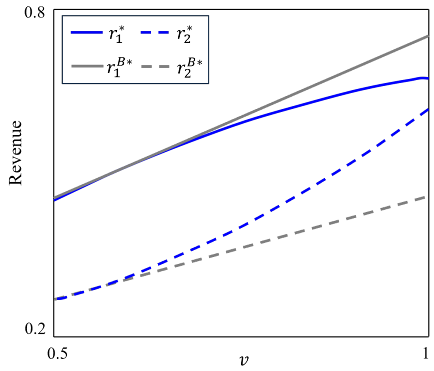
(b) Partial coverage



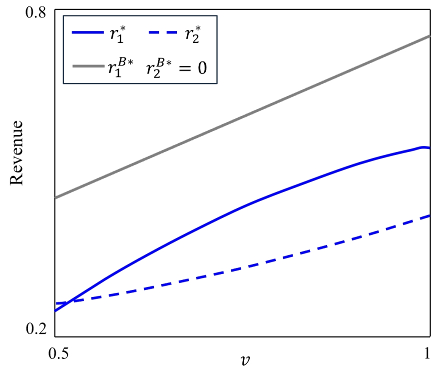
(c) Full coverage



(d) Partial coverage



(e) Full coverage



(f) Partial coverage

Note. $\tau = 0.1$

Figure 4.6: A numerical example under full and partial market coverage

If the retailer sets the period-two price higher than consumers' new-product valuation, the following dynamics unfold. Firstly, this price prompts a portion of reserved consumers to exit the market, resulting in a reduction in both new-product and used-product demands in period two compared to those in the main model. Meanwhile, some active consumers keep their purchased products, which is in contrast to the outcome in the main model, where all active consumers engage in reselling. Secondly, as consumers anticipate a decrease in used-product demand on the CRP, the likelihood of reselling on the CRP diminishes, leading to fewer consumers making purchases in period one. The new-product demand in period one also decreases compared to that in the main model. As depicted in Figures 4.6(c) and 4.6(d), in the presence of CRP, demands in both periods decrease in the case of partial market coverage. This reduction in demand exerts a negative impact on the retailer's revenue, as illustrated in Figures 4.6(e) and 4.6(f). Thus, we caution the retailer to carefully manage new-product pricing, since a too-high price can deter consumers from purchasing and expose the retailer to a revenue loss.

Nonetheless, we find that our key insights into the effects of CRP when consumers exhibit utility dependence remain robust in the partially covered market. Specifically, the retailer continues to aggravate intertemporal price discrimination and encourage strategic waiting by consumers. Comparing Figures 4.6(a) and 4.6(b), we observe that $p_1^* - p_2^* > p_1^{B*} - p_2^{B*}$ in both fully and partially covered markets. This phenomenon arises from the retailer's ability to attain higher revenue in the presence of CRP compared to the benchmark through managing prices in the two periods. It is crucial to note that, under partial market coverage, only those active consumers who resell used products opt for repeat purchases, to become the only source of new product demand and revenue for the retailer in period two. Intertemporal price discrimination enables the retailer to redistribute new-product demands over periods and regulate the matchup of suppliers (among active consumers who "resell and buy new") with demanders (among reserved consumers who "buy used") for used products in period two. Consequently, this strategic pricing strategy not only stimulates demand but also maximizes revenue for the retailer over the two periods.

Furthermore, the cannibalization and enhancement effects, which arise from the introduction of CRP, persist in the partially covered market. As demonstrated in Figures 4.6(e) and 4.6(f), $r_1^* < r_1^{B*}$ and $r_2^* > r_2^{B*}$. In a partially covered market, despite the adverse impact of the cannibalization effect on the retailer's revenue, the retailer has no incentive to stimulate a demand surge to avoid the cannibalization effect in period one. This rationale is grounded in two reasons. Firstly, allowing period-one demand to increase indiscriminately by raising the period-two price results in all reserved consumers leaving in period two. Consequently, there will be no source of demand on the CRP, and therefore no resale transactions. It causes the CRP to lose its functionality, reverting the market to that in the benchmark. However, we demonstrate that by strategically adjusting prices, the retailer can achieve a higher revenue than in the benchmark while sustaining the presence of CRP. Secondly, solely focusing on reducing the cannibalization effect leads to the elimination of the enhancement effect, thereby hurting the retailer's revenue. Under partial market coverage, only those active consumers who resell used products opt for repeat purchases, to become the only source of the new product demand and revenue for the retailer in period two. Hence, when there is no demand on the CRP, active consumers are unable to engage in resale activities, deterring them from pursuing repeat purchases and eliminating the enhancement effect.

4.6.2 Interrelated Utility Dependence and Product Valuation

We consider the situation where the utility dependence due to repeat purchases will not exceed the value of the product itself, i.e., $\varepsilon \in [0, v]$. Specifically, the utility dependence follows a uniform distribution with density $f(\varepsilon) = \frac{1}{v}$. Under the same decision sequence as before, given marginal consumer type $\hat{\varepsilon}$, in subgame equilibrium, the new-product price in period 2 is $p_2^*(\hat{\varepsilon}) = \frac{\hat{\varepsilon}^2 - v(1-\tau)(v-\hat{\varepsilon})}{\hat{\varepsilon}\tau}$ and the transaction price for used products on the CRP is $p_s^*(\hat{\varepsilon}) = \frac{\hat{\varepsilon}^2 - v(v-\hat{\varepsilon})}{\hat{\varepsilon}\tau}$, with $p_s^*(\hat{\varepsilon}) = p_2^*(\hat{\varepsilon}) - \frac{v-\hat{\varepsilon}}{\hat{\varepsilon}}v$. The market segmentation is shown in Figure 4.7.

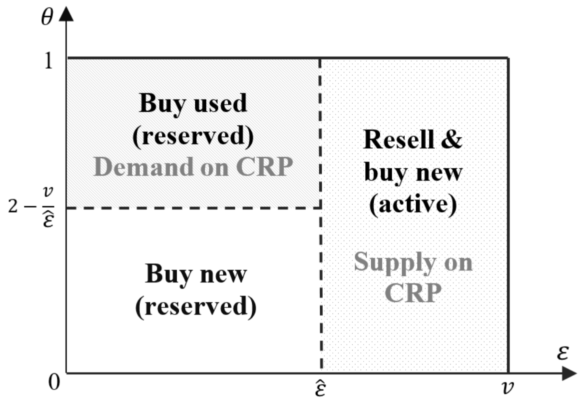


Figure 4.7: Market segmentation when $\varepsilon \in [0, v]$

As in the main model, the segmentation among consumers is contingent on the heterogeneities of used-product quality levels and utility dependence by repeatedly purchasing. The "resell and buy new" option always dominates the "keep" option and "resell and leave" option for active consumers; and reserved consumers only choose from two options, "buy used" and "buy new". No consumers leave without purchase and the market is fully covered. Nonetheless, the composition of segments changes compared to that in the main model. Specifically, the demands by reserved consumers for new and used products in period two are $d_{r,n} = \frac{\hat{\varepsilon}}{v}\left(2 - \frac{v}{\hat{\varepsilon}}\right) = \frac{2\hat{\varepsilon}}{v} - 1$ and $d_{r,u} = \frac{\hat{\varepsilon}}{v}\left(\frac{v}{\hat{\varepsilon}} - 1\right) = 1 - \frac{\hat{\varepsilon}}{v}$, respectively, while no consumers leave, i.e., $d_{r,l} = 0$. All active consumers resell used products on the CRP and repurchase new products from the retailer, i.e., $d_{a,sn} = d_a = 1 - \frac{\hat{\varepsilon}}{v}$ and $d_{a,k} = d_{a,sl} = 0$. It is mainly because the presence of utility dependence prioritizes the "resell and buy new" option over other options. The volume of used-product transaction on the CRP equals the number of active consumers. The total demand for the new product in period two is $d_2 = d_{r,n} + d_{a,sn} = \frac{\hat{\varepsilon}}{v}$, which equals the number of reserved consumers, i.e., $d_r = d_{r,n} + d_{r,u} = \frac{\hat{\varepsilon}}{v}$. The equilibrium outcomes are summarized in Table 4.7.

When utility dependence from repeat purchases is intertwined with consumers'

Table 4.7: Equilibrium outcomes when $\varepsilon \in [0, v]$

	Period one	Period two
Indifferent consumer type	$\hat{\varepsilon}^* = \frac{vC_7+2\tau-1}{2}$	
New-product price	$p_1^* = \frac{2\hat{\varepsilon}^3-v\hat{\varepsilon}^2(\tau-2)+2v^2\hat{\varepsilon}(2\tau-1)-v^3\tau}{2\tau\hat{\varepsilon}^2}$	$p_2^* = v$
New-product demand	$d_1^* = \frac{v-\hat{\varepsilon}^*}{v}$	$d_2^* = \frac{\hat{\varepsilon}^*}{v}$
Total demand	$d^* = 1$	
Used-product price and demand	$p_s^* = \frac{\hat{\varepsilon}^2-v(v-\hat{\varepsilon})}{\hat{\varepsilon}\tau}$ and $d_s^* = \frac{v-\hat{\varepsilon}^*}{v}$	
Revenue	$r_1^* = \frac{\left(2{\hat{\varepsilon}^*}^3-v{\hat{\varepsilon}^*}^2(\tau-2)+2v^2\hat{\varepsilon}(2\tau-1)-v^3\tau\right)(v-\hat{\varepsilon}^*)}{2\tau{\hat{\varepsilon}^*}^2v}$	$r_2^* = \hat{\varepsilon}^*$
Total revenue	$r^* = \frac{{\hat{\varepsilon}^*}^3(2-\tau)+v{\hat{\varepsilon}^*}^2(2-3\tau)+v^2\hat{\varepsilon}^*(5\tau-2)-v^3\tau}{2\tau{\hat{\varepsilon}^*}^2}$	

new-product valuation, in contrast to Lemma 4.3, the performance outcomes in the presence of CRP are no longer confined by the new-product valuation v. It consistently serves as a platform for managing used product transactions. Notably, through a comparative analysis of the equilibrium outcomes under the condition $\varepsilon \in [0, v]$ with the benchmark, we discover that all the results presented in Section 4.4 persist, especially the cannibalization and enhancement effects, albeit with minor differences outlined as follows. The number of reserved and active consumers, i.e., d_r and d_a, are insensitive to the new-product valuation v but exhibit variations solely to the changes in commission rate τ. Specifically, as the CRP's commission rate τ increases, d_r increases while d_a decreases. The proof is provided in Appendix B.5.1.

4.6.3 New Product Vertical Differentiation

In the main analysis, we focus on the horizontal differentiation between new products sold across periods, with particular attention given to the utility dependence experienced by consumers through repeat purchases. In this section, we shift our focus to vertical differentiation between new products sold across periods, with primary interest on the value increment perceived by consumers due to quality improvements.

Denote consumers' value increment for an upgraded product as δ, where δ is independently and uniformly distributed over $[0, \alpha]$ and $\alpha \in [0, 1]$ is the degree of product upgrade. For analytical simplicity, we assume that the retailer employs a single rollover strategy (Liang et al. 2014). Typically, when the retailer introduces an upgraded version in period two, the original version become obsolete and is no longer available for sale. This setting enables us to accentuate the direct competition occurring between distinct new-product versions across periods, in addition to the competition between new and used products.

The sequence of events is the same as that in the main model, except for consumers' period-two choices. In period two, an active consumer can resell the used original version on the CRP, followed either by purchasing an upgraded version from the retailer to receive utility $u_{a,sn} = (1 - \tau) p_s + v + \delta - p_2$, or by leaving the market to receive utility $u_{a,sl} = (1 - \tau) p_s$. Alternatively, an active consumer can keep using the original version to receive utility $u_{a,k} = \theta v$. A reserved consumer can purchase an upgraded version in period two to receive utility $u_{r,n} = v + \delta - p_2$ or purchase a used original version on the CRP to receive utility $u_{r,u} = \theta v - p_s$. Leaving without purchase yields utility $u_{r,l} = 0$. Importantly, unlike in our main model, where only active consumers who make repeat purchases experience utility increments, both active and reserved consumers now experience incremental utility.

Contrary to the findings in the main model, the retailer refrains from employing markdown pricing but instead sets a higher price for the upgraded version in period two when implementing product upgrade strategy. Such pricing strategy produces a distinct segmentation effect among consumers, effectively differentiating the market for the upgraded version from the market for the used original version. It results in the CRP playing a more pronounced role in redistributing demand within the market. In equilibrium, active consumers either keep the original version or resell it in favor of purchasing the upgraded version in period two. Conversely, reserved consumers, having deferred their purchase in period one, gravitate towards purchasing the used version on the CRP in period two. The demand for the new products in the two periods originates solely from active consumers, resulting in a different composition of the retailer's revenue compared to that in the main model. Moreover, when the transaction volume on the CRP is positive, a rise in the extent of upgrade degree intensifies the competitiveness of the upgraded version, resulting in a higher price for it along with a higher price for the used original version on the CRP. Counter-intuitively, the demands for upgraded version and used original version do not decrease, despite the elevated prices. In fact, both demands increase in response to the degree of product upgrade, since more active consumers choose to resell the original version and purchase the upgraded version. The proof can be found in Appendix B.5.2.

4.7 Theoretical Contribution and Managerial Implication

Chapter 4 introduces a new behavioral factor - consumers' utility dependence - into the research framework to analyze the retailer's optimal dynamic pricing strategy and collaboration strategy in the presence of CRP. Theoretical contribution and managerial implication of this chapter are as follows.

(1) Theoretical Contribution

This chapter incorporates consumers' utility-dependent behavior into the theoretical framework of C2C resale markets and uncovers the strategic role of consumers' utility dependence in the context of C2C resale markets, which is scarcely investigated in prior literature. Intuitively, with state-dependent utility, consumers benefit more than the retailer from the rise of CRP. It is because the CRP offers consumers with more opportunities, channels, and rewards, including resale value and utility dependence, but exposes the retailer to competition. Extant literature states that the C2C resale market has mixed effects on consumer surplus and social welfare (L. Jiang et al. 2017). As a complement to the literature, we find that the retailer and consumers can be influenced in the same manner by the rise of CRP. Utility dependence grants the retailer enhanced power in demand management, making it more likely for the retailer to benefit from the presence of CRP than consumers. This contradicts the convention wisdom, which suggests that CRPs cannibalizes firms' profits (P. Desai et al. 2004; Yin et al. 2010). Additionally, the rise of CRP is more likely to benefit the society than individual consumers and the retailer. Our findings clarify the intricate impacts of C2C resale markets on consumers, retailers, platforms, and society in the presence of utility dependence. Our work contributes to the literature on secondary markets by conducting a comprehensive investigation into the C2C mode.

(2) Managerial Implication

This chapter provides operational-level managerial guidance for retailers on adjusting prices and on collaborating with CRPs in response to consumers' utility dependence. The presence of utility dependence helps mitigate the direct competition between the retailer and the CRP, since it drives consumers to repurchase new products after ridding of used ones, which compensates for the demand that the platform takes away from the retailer. We encourage retailers to leverage the heterogeneities in consumers' perceptions of the quality levels of used products, as well as their utility dependence, to practice intertemporal price discrimination and improve revenue. Exacerbated intertemporal price discrimination produces a cannibalization effect to harm the retailer's revenue in the early period but an enhancement effect to improve it in the later period. In most situations, the enhancement effect dominates, enabling the retailer to benefit from the rise of CRP. However, if consumers perceive a high value in consuming new products and the CRP's commission rate is high, the cannibalization effect is strong to cause a revenue loss to the retailer. For collaboration strategies, we recommend that retailers adopt a self-managing CRP when the marginal operating cost is low. However, offering a discount to repeat consumers is not an efficient revenue-enhancing instrument because it curbs the sales to waited consumers to harm the retailer's revenue. Furthermore, when collaborating with a third-party CRP that sets the revenue-maximizing commission rate, retailers can still benefit from consumers who perceive a low value in new-product consumption.

4.8 Concluding Remarks

This chapter considers consumers' utility-dependent behavior and analyzes the retailer's optimal dynamic pricing strategy in the presence of CRP. To summarize this chapter and answer the research questions raised in 4.2, first, as consumers experience utility dependence, the emergence of CRP allows the retailer to raise the new-product price in period one but maintain the new-product price in period two unchanged, which influences the distribution of demands across periods and channels. The retailer intensifies intertemporal price competition to enhance market efficiency in the coexistence of new and used products. Second, while the CRP introduces direct competition for the retailer, the existence of consumers' utility dependence alters their purchase choices and mitigates competition, enabling the retailer to benefit from embracing it. We identify a cannibalization effect and an enhancement effect on the retailer's revenue. The enhancement effect is dominant to improve the retailer's revenue except when consumers perceive a high value in new-product consumption and the CRP's commission rate is high. Third, as consumers acquire utility dependence, the rise of CRP improves (worsens) consumer surplus when it improves (worsens) the retailer's revenue, aligning the preferences of the retailer and consumers over the establishment of CRP. The addition of the CRP's revenue from used-product transactions suggests that social welfare is likely to improve with the presence of this entity. Fourth, the retailer can benefit from self-managing a CRP when the marginal operating cost is low, whereas offering a discount to repeat purchasers proves to be an inefficient instrument for improving the retailer's revenue. Additionally, the retailer can be better off when an external CRP sets the commission rate to maximize its own revenue. Moreover, we explore three extensions to prove the robustness of our findings: a partially covered market, the interrelatedness of product value and utility dependence, and vertical differentiation across products. Overall, this chapter offers meaningful insights into the retailer's dynamic pricing strategies for new products in the presence of C2C resale markets, involving consumers' utility dependence.

Chapter 5

Dynamic Pricing Strategy for New Products Considering Consumers' Time Inconsistency in the Presence of C2C Resale Market

5.1 Research Motivation

Chapter 3 and Chapter 4 are grounded in consumers' rational expectations regarding the payment and payoff of their choices. By contrast, Chapter 5 diverges from this setting to explore the situation where consumers' intertemporal choices exhibit time inconsistency. Consumers often make quick purchasing decisions of new experience products, driven by immediate gratification, while later realize that the purchased product has limited usage value or requires effort to fully utilize. This phenomenon, as argued by Meyer et al. (2008) and D. V. Thompson et al. (2005), highlights a disparity between consumers' value of product features at the time of purchase and their actual utility upon usage. Referred to as 'valuation-usage disparity' by Meyer et al.

(2008) or 'preference reversal' by Ülkü et al. (2012), this discrepancy can be explained by the theory of time inconsistency. Time-inconsistent individuals, as described in studies such as Gilpatric (2009) and Hoch & Loewenstein (1991), tend to prioritize current benefits over future ones, reflecting dynamic and inconsistent preferences over time. This behavior manifests in a temporal distribution of payoffs and payments, where the payments of an action are immediate, but any payoffs are delayed through consumption over time. It leads to consumers' misestimation of their utilities across periods, resulting in inconsistencies in their intertemporal decision-making.

Due to consumers' misestimation of product utilities, a significant number of underutilized products find their way into C2C resale market where consumers can align with their time-inconsistent tendencies. On one hand, in anticipation of the availability of such an outlet channel provided by CRPs for dealing with underutilized products, consumers can mitigate the risks associated with impulsive purchasing and product uncertainty. On the other hand, consumers can spend less by purchasing used products. 38% of consumers state that they shop secondhand to afford higher-end brands in 2023 (ThredUP 2024). Whether the existence of C2C resale markets exacerbates or mitigates consumers' time-inconsistent behavior is worth to conduct a comprehensive investigation.

Incumbent manufacturers typically employ two strategies to accommodate consumers' time-inconsistent preferences. Firstly, they dynamically set their pricing strategy for new products over time. Secondly, they continuously introduce upgraded versions sequentially as part of their innovation agenda. However, these strategies lead to a trade-off. On one hand, the existence of C2C resale market reduces consumers' purchase uncertainty caused by time inconsistency and allows them to enjoy intermediate benefits (resale revenue) by reselling underused products. Consumers can consistently pursue the latest version, and the manufacturer can leverage the CRP to mitigate the negative impact of consumers' misestimation of utilities, thereby increasing instantaneous sales and profitability. On the other hand, the existence of time inconsistency discourages potential consumers from purchasing, as they fail to correctly anticipate future behavior. This phenomenon is exacerbated by the presence of CRPs, which poses a threat to the manufacturer as they compete for consumers, hence harming the manufacturer's profitability.

The remainder of this chapter is structured as follows. Section 5.2 proposes several research questions. Section 5.3 outlines the model setting and presents the equilibrium. In Section 5.4, we analyze the manufacturer's optimal dynamic pricing strategy for new products considering consumers' time inconsistency. Section 5.5 demonstrates the manufacturer's optimal release strategy of product upgrade when consumers exhibit time inconsistency. Section 5.6 states the theoretical and managerial contributions of this chapter, while Section 5.7 provides the concluding remarks. The proofs for this chapter are summarized in Appendix C.

5.2 Research Questions

This chapter aims to analyze the decision-making process of consumers who behave in a time-inconsistent manner and address the following research questions, as consumers are time-inconsistent:

1. How does time inconsistency influence the market segmentation across periods in the presence of CRP?
2. How should the manufacturer dynamically adapt its selling prices for new products with the existence of CRP, and what are the implications for its profit?
3. What is the manufacturer's optimal release strategy of product upgrade in the existence of CRP?

To answer these questions, we expand upon the modeling framework introduced in Chapter 3 by incorporating a time-inconsistent discounting scheme in this chapter.

Specifically, we consider a two-period setting in which a monopolistic manufacturer directly sells two versions (the original version and the upgraded version) of a new experience product to a same batch of consumers by dynamically setting prices. Consumers are forward-looking and time-inconsistent. Specifically, they take into consideration the anticipated utility of period-two action when making period-one decision, and they discount their utilities time-inconsistently. In each of the periods, the manufacturer sets its optimal selling price by maximizing profit. A CRP is established in period two, which allows consumers to transact used items individually. Consumers decide on when to purchase - period one or period two; what and where to purchase - the original version or the upgraded version from the manufacturer or used items on the CRP. This chapter uniquely incorporates consumers' time inconsistency into the study of secondary markets within the C2C framework.

5.3 Model Framework

5.3.1 Model Description

A monopolistic manufacturer offers products with a set of experiential features to the market in a two-period setting. Consumers recognize experiential features as a measure of the product's usage utility v. As an example, contemporary smart washing machines available in the market offer a wide range of experiential features, including functionalities such as washer-dryer combo, specialized cycles for wool sweater washing, and down jacket cleaning. These experiential features contribute to consumers' utilization of a smart washing machine. We assume that each consumer is endowed with a heterogeneous but time-independent usage utility v in evaluating the product in a period, where v is uniformly distributed on $[0, \bar{v}]$. Here, $\bar{v}$ can be interpreted as the maximal usage utility that a consumer can derive from all experiential features.

The manufacturer follows a sequential launch strategy, introducing the original version (referred to as V1) and the upgraded version (referred to as V2) at the beginning of period one and two, respectively. The upgraded version integrates additional experiential features that influence consumers' usage utility for the product. We assume that the consumer obtains αv by experiencing V2 in a period, where α captures the extent of differentiation in experiential features of V2 relative to V1. We consider the case where $\alpha \geq 1$. For instance, the manufacturer strategically positions V1 as a trial version to gather consumer feedback and enhance the subsequent version by incorporating additional experiential features to satisfy consumers' needs. Moreover, we exclude from consideration simultaneous selling of new V1 and new V2, that is, the manufacturer employs single rollover strategy to launch products across periods (Liang et al. 2014).

All V1 sold in period one wind up as used ones in period two. A consumer values the usage utility provided by a used V1 in one period at θv, where $\theta \in [0, 1]$ scales the usage utility of a used V1 relative to a new V1. A CRP is present in period two to sustain transactions of used V1 among consumers, with a commission fee τ for each transaction. In equilibrium, at the market-clearing price p_s^*, supply is matched with demand on the CRP (Anderson & Ginsburgh 1994; Yin et al. 2010). Consumers are aware of the manufacturer's launch schedule for new products V1 and V2 in the two periods and the existence of a CRP for transacting used V1 in period two.

Importantly, consumers exhibit time inconsistency in making purchase decisions. There exists a temporal distinction between payments and payoffs for time-inconsistent consumers. Specifically, any payments are immediate, while the generated payoffs are delayed. As illustrated in Figure 5.1, the expenses associated with purchasing products are incurred immediately at the time of decision in each period. In contrast, the usage utility gained through fully accessing the product's experiential features unfolds over a period of time. According to the present-biased preference model proposed by O'Donoghue & Rabin (1999), for all time period t, a consumer's intertemporal preference is $U^t(u_t, u_{t+1}, \ldots, u_T) = \delta^t u_t + \beta \sum_{t+1}^{T} \delta^{t+1} u_{t+1}$, where $\delta \leq 1$

denotes the objective and exponential discount rate and β signifies the subjective, linear, and time-inconsistent discount rate. We assume $\delta = 1$ to exclude the effect of exponential time discounting and explicitly examine the discount caused by time inconsistency. The extent of time inconsistency is expressed as $1 - \beta$.

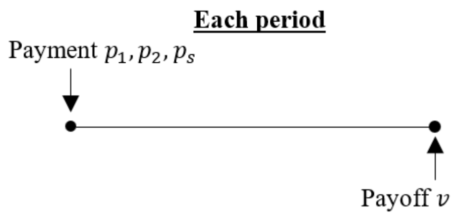


Figure 5.1: Temporal distinction of payment and payoff

In the setting of a two-period framework applying the present-biased preference model, we label three nodes (time 0, 1, 2) as depicted in Figure 5.2. Consumers make purchase decisions at the beginning of each period (time 0 and 1). Those who make purchases at time 0 incur an immediate payment (p_1 of V1), with other payments or payoffs at time 1 and 2 subject to discounting by time-inconsistent parameter β. Consumers who purchase at time 1 incur immediate payments (p_2 of V2 and p_s of used V1), with the payoffs at Time 2 discounted by β. A consumer who behave in a time-inconsistent manner is modeled as a separate agent at each decision node, aiming to maximize discounted present utilities. Consumers are forward-looking and are able to accurately anticipate prices across periods. As evidenced in prior works (Galperti & Strulovici 2014; L. Li & Jiang 2022), the disparity of intertemporal preferences stemming from time inconsistency does not hinder consumers from forming accurate expectations regarding equilibrium outcomes, thus exemplifying forward-looking behavior.

The manufacturer is rational. By dynamically setting prices, the manufacturer optimizes its operations to maximize profit $\max \pi = \sum_t^2 (p_t - c_t)\, d_t - c_I$ in the two periods, where c_t is the marginal cost of production and selling, c_I is the investment cost for the upgraded version, and $t \in \{1, 2\}$ denotes period. Without loss of general-

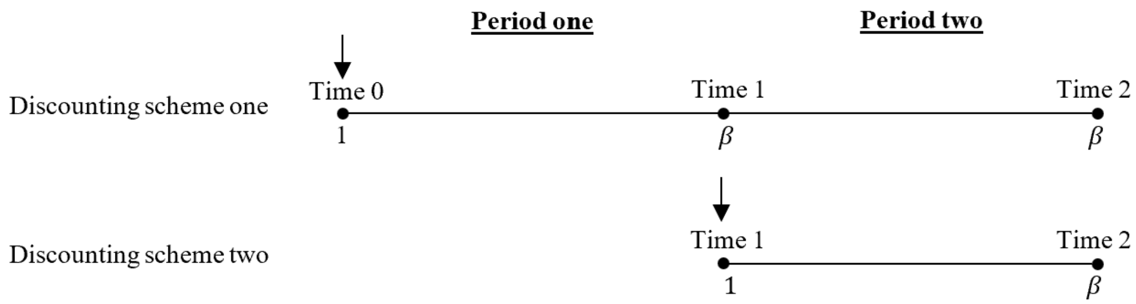


Figure 5.2: Discounting scheme

ity, we normalize c_t to zero. The investment cost $c_I = \frac{K(\alpha^2-1)}{2}$ is a convex increasing function depending on the differentiation degree α and scaled by K. This setting is widely used in the literature (P. S. Desai 1997; Yin et al. 2010).

The timeline of the events is as follows. In the beginning of period one (time 0), the manufacturer decides on the price p_1 for V1. Since product design and investment are long-term decisions, the manufacturer incurs c_I at time 0. Consumers can either purchase a V1 at time 0 or postpone the purchase to time 1. We refer to a consumer who purchases V1 (postpones purchase) at time 0 as an early-adopter (follower). All consumers remain in the market. In the beginning of period two (time 1), an early-adopter can keep used V1 and continue using it (termed 'Keep V1' option), resell used V1 on the CRP and purchase V2 from the manufacturer (termed 'Resell V1 and purchase V2' option), or leave after reselling used V1 (termed 'Resell V1 and leave' option). Followers have three options: one is to purchase V2 from the manufacturer (termed 'Purchase V2' option), another is to purchase used V1 on the CRP (termed 'Purchase V1' option), and the third is to leave without purchasing (termed 'Leave' option). Consumers are present for both periods. Each consumer holds at most one-unit demand for the product. The entire selling and reselling season concludes at the end of period two, when all products are freely scrapped. Note that the assumption of two periods is not critical to our results. Instead, what are critical are (i) the consumer's choice in the prior period limits the options in the latter period due to their ongoing engagement with the product, and (ii) there exists a temporal distinction of payments and payoffs when the consumer make choices across periods. Figure 5.3 shows the model dynamics.

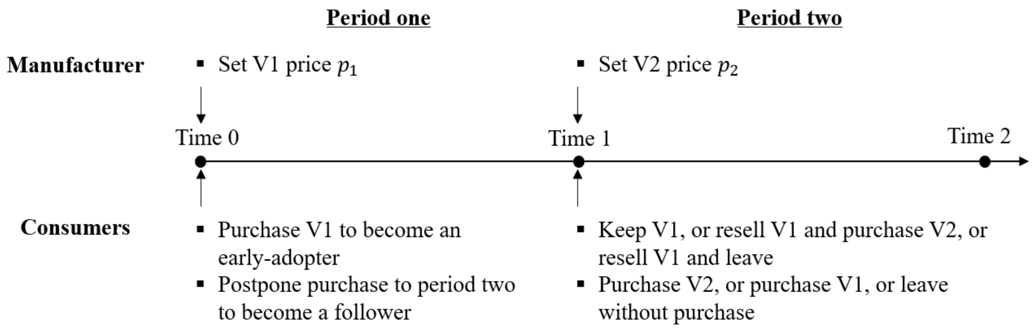


Figure 5.3: Model dynamics

The CRP provides consumers with more options of what and where to purchase. Early-adopters can resell used V1 and followers can purchase used V1 on the CRP, i.e., early-adopters (followers) form supply (demand) on the platform. The existence of time inconsistency alters consumers' perceptions on whether and when to purchase. Consumers may deviate from their anticipated choices due to misestimations of their actual utilities. The number and the composition of consumers purchasing products in the two periods alter, necessitating the manufacturer to adjust prices and strategically plan the launch of different versions to accommodate shifts in the marketplace.

Notation-wise, subscripts E and F denote early-adopters and followers, respectively; subscripts $e \in \{k, rp, rl\}$ denote, respectively, 'Keep V1', 'Resell V1 and purchase V2', and 'Resell V1 and leave' options for early-adopters; and subscripts $f \in \{n, s, l\}$ denote, respectively, 'Purchase V2', 'Purchase V1', and 'Leave' options for followers; $\tilde{u}$ and u denote consumers' anticipated and actual net utility, respectively. For easy reference, we summarize notations used in this chapter in Table 5.1.

At time 0, consumers decide whether to purchase now or postpone the purchase to time 1 based on the sum of anticipated net utilities of the two periods, employing the 'Discounting scheme one' in Figure 5.2. Specifically, a consumer's net utility

Table 5.1: List of notations

Notation	Definition
v	Consumers' usage utility of the original product's experiential features in each period
$\bar{v}$	Maximal usage utility
θ	The usage utility factor of a used product
α	The differentiation degree of V2 relative to V1
β	Time-inconsistent parameter
$1-\beta$	Extent of time inconsistency
τ	CRP's commission rate
$t \in \{1,2\}$	Time period
E, F	Subscript indicating early-adopters or followers, respectively
$e \in \{k, rp, rl\}$	Subscript indicating 'Keep V1', 'Resell V1 and purchase V2', 'Resell V1 and leave' options, respectively, for early-adopters
$f \in \{n, s, l\}$	Subscript indicating 'Purchase V2', 'Purchase V1' or 'Leave' options, respectively, for followers
$\tilde{u}_{\{E,F\},\{e,f\}}$	Consumers' anticipated utility
$u_{\{E,F\},\{e,f\}}$	Consumers' actual utility
p_t	New product price in period t
d_t	New product demand in period t
p_s	Used product market-clearing price
d_s	Used product demand
c_I	Investment cost
K	Investment cost parameter
π	Manufacturer's profit
R, N, O	Superscripts indicating the scenario with rational consumers, the scenario without product upgrade, and the scenario without product upgrade when consumers are rational, respectively

of purchasing V1 at present (to become an early-adopter), anticipating period-two decision, is:

$$\tilde{u}_E = \beta v - p_1 + \max\{\tilde{u}_{E,k}, \tilde{u}_{E,rp}, \tilde{u}_{E,rl}\} \tag{5.1}$$

where $\tilde{u}_{E,k} = \beta\theta v$ is the anticipated utility of 'Keep V1', $\tilde{u}_{E,rp} = \beta(1-\tau)p_s - \beta p_2 + \beta\alpha v$ is that of 'Resell V1 and purchase V2', and $\tilde{u}_{E,rl} = \beta(1-\tau)p_s$ is that of 'Resell V1 and leave'. The immediate payment for purchasing V1 at time 0 is p_1. Consumers utilize V1, experiencing its features from time 0 to time 1, to acquire a payoff of usage utility v. Therefore, the observed payoff at time 0 is discounted as βv. Subsequent payments are also linearly discounted by the time-inconsistent parameter β. This includes the payment p_2 for purchasing V2 and the reward $(1-\tau)p_s$ for reselling V1 at time 1, which are both discounted by β. The discounted payoff obtained at Time 2 by utilizing V2 in period two is $\beta\alpha v$.

Following the same logic, a consumer's net utility of postponing the purchase to time 1 (to become a follower), anticipating its period-two option, is:

$$\tilde{u}_F = 0 + \max\{\tilde{u}_{F,n}, \tilde{u}_{F,s}, \tilde{u}_{F,l}\} \tag{5.2}$$

where $\tilde{u}_{F,n} = \beta\alpha v - \beta p_2$ is the anticipated utility of 'Purchase V2', $\tilde{u}_{F,s} = \beta\theta v - \beta p_s$ is that of 'Purchase V1', and $\tilde{u}_{F,l} = 0$ is that of 'Leave'.

A consumer prefers purchasing than postponing at time 0 when $\tilde{u}_E \geq \tilde{u}_F$. A threshold usage utility $\hat{v}_{e,f}$ exists to equate $\tilde{u}_E$ and $\tilde{u}_F$, thus to regulate consumers' purchase behavior in period one, where $e \in \{k, rp, rl\}$ and $f \in \{n, s, l\}$. Consumers' choices at time 0, i.e., 'Purchase V1' or 'Postpone purchase', segment them into two purchase groups: early-adopters and followers. A consumer with a usage utility above $\hat{v}_{e,f}$ purchases V1 at time 0, while a consumer with a usage utility below $\hat{v}_{e,f}$ postpones purchase to time 1. The thresholds $\hat{v}_{e,f}$ are summarized in Table 5.2.

In general, an increased extent of time inconsistency (value of β increases), an increased usage utility of V2 relative to V1 (value of α increases), or a decreased usage utility of used V1 (value of θ decreases) decreases the threshold $\hat{v}_{e,f}$, boosting

Table 5.2: Thresholds at time 0

Condition	Threshold $\hat{v}_{e,f}$
Purchases V1 and anticipates keeping V1 than:	
• Postpones and anticipates purchasing V2 $\beta v - p_1 + \tilde{u}_{E,k} \geq 0 + \tilde{u}_{F,n}$	$v \geq \hat{v}_{k,n} = \frac{p_1 - \beta p_2}{\beta(1-(\alpha-\theta))}$ if $1-(\alpha-\theta) > 0$
• Postpones and anticipates purchasing V1 $\beta v - p_1 + \tilde{u}_{E,k} \geq 0 + \tilde{u}_{F,s}$	$v \geq \hat{v}_{k,s} = \frac{p_1 - \beta p_s}{\beta}$
• Postpones and anticipates leaving $\beta v - p_1 + \tilde{u}_{E,k} \geq 0 + \tilde{u}_{F,l}$	$v \geq \hat{v}_{k,l} = \frac{p_1}{\beta(1+\theta)}$
Purchases V1 and anticipates reselling V1 then purchasing V2 than:	
• Postpones and anticipates purchasing V2 $\beta v - p_1 + \tilde{u}_{E,rp} \geq 0 + \tilde{u}_{F,n}$	$v \geq \hat{v}_{rp,n} = \frac{p_1 - \beta(1-\tau)p_s}{\beta}$
• Postpones and anticipates purchasing V1 $\beta v - p_1 + \tilde{u}_{E,rp} \geq 0 + \tilde{u}_{F,s}$	$v \geq \hat{v}_{rp,s} = \frac{p_1 + \beta p_2 - \beta(2-\tau)p_s}{\beta(1+\alpha-\theta)}$
• Postpones and anticipates leaving $\beta v - p_1 + \tilde{u}_{E,rp} \geq 0 + \tilde{u}_{F,l}$	$v \geq \hat{v}_{rp,l} = \frac{p_1 + \beta p_2 - \beta(1-\tau)p_s}{\beta(1+\alpha)}$
Purchases V1 and anticipates reselling V1 then leaving than:	
• Postpones and anticipates purchasing V2 $\beta v - p_1 + \tilde{u}_{E,rl} \geq 0 + \tilde{u}_{F,n}$	$v \leq \hat{v}_{rl,n} = \frac{\beta p_2 - p_1 + \beta(1-\tau)p_s}{\beta(\alpha-1)}$
• Postpones and anticipates purchasing V1 $\beta v - p_1 + \tilde{u}_{E,rl} \geq 0 + \tilde{u}_{F,s}$	$v \geq \hat{v}_{rl,s} = \frac{p_1 - \beta(2-\tau)p_s}{\beta(1-\theta)}$
• Postpones and anticipates leaving $\beta v - p_1 + \tilde{u}_{E,rl} \geq 0 + \tilde{u}_{F,l}$	$v \geq \hat{v}_{rl,l} = \frac{p_1 - \beta(1-\tau)p_s}{\beta}$

consumer's incentive to purchase at time 0. One exception is $\hat{v}_{k,l}$ which increases with a lowered θ.

At time 1, early-adopters decide whether to replace used V1 with new V2, while followers decide whether to make a purchase and, if so, which product version to purchase. At this juncture, consumers' actions may deviate from what they anticipated at time 0. By employing the 'Discounting scheme two' in Figure 5.2, an early-adopter's present utilities are $u_{E,k} = \beta\theta v$ by 'Keep V1', $u_{E,rp} = (1-\tau)p_s + \beta\alpha v - p_2$ by 'Resell V1 and purchase V2', but $u_{E,rl} = (1-\tau)p_s$ by 'Resell V1 and leave'. In this case, the immediate payment for purchasing V2 at time 1 is p_2, and the immediate reward for reselling V1 on the CRP is $(1-\tau)p_s$. The discounted payoff for used V1 and new V2 observed at time 1 is $\beta\theta v$ and $\beta\alpha v$, respectively. Following the same logic, a follower's present utilities are $u_{F,n} = \beta\alpha v - p_2$ by 'Purchase V2', $u_{F,s} = \beta\theta v - p_s$ by 'Purchase V1', but $u_{F,l} = 0$ by 'Leave'.

Comparing the anticipated and actual utility from time 1 choices, as shown in Table 5.3, we find that consumers can either precise-estimate or over-estimate their time 1 utilities. Note that the column labeled 'Anticipated' refers to the amount that consumers anticipate to receive from time 1 choices at the point of time 0, i.e., $\frac{\tilde{u}}{\beta}$. The column labeled 'Actual' refers to the amount that consumers actually receives from time 1 choices at the point of time 1, i.e., u. Specifically, concerning consumers' precise estimation, the example is that an early-adopter anticipates the utility from the time 1 choice 'Resell V1 and leave' at time 0 to be $(1-\tau)p_s$. This anticipated amount is consistent with the actual utility $(1-\tau)p_s$ received at time 1. Alternatively, in terms of consumers' overestimation, an illustrative example is that the anticipated amount of the time 1 choice 'Resell V1 and purchase V2' at time 0 for an early-adopter is $(1-\tau)p_s + \alpha v - p_2$. By contrast, the actual utility of this option at time 1 is $(1-\tau)p_s + \beta\alpha v - p_2$. Consumers over-estimate the utility since $(1-\tau)p_s + \alpha v - p_2$ is larger than $(1-\tau)p_s + \beta\alpha v - p_2$. Likewise, consumers opting for the choices 'Keep', 'Purchase V2', and 'Purchase V1' also overestimate their utilities at time 0. An intensified extent of time inconsistency (value of β decreases) results in a larger disparity between the perceived and actual utilities. It, in turn, amplifies consumers' choice inconsistencies.

Consumers' misestimation of intertemporal utilities leads to inconsistent actions. The manufacturer can leverage consumers' time-inconsistent behavior to adapt its pricing and product launch strategies, in addition to competing with the CRP for consumer demands.

Table 5.3: Consumers' estimation of intertemporal utilities

Choices at time 1	Anticipated		Actual	
Resell V1 and leave	$(1-\tau)p_s$	$=$	$(1-\tau)p_s$	Precise-estimate
Keep	θv		$\beta\theta v$	
Resell V1 and purchase V2	$(1-\tau)p_s + \alpha v - p_2$	$>$	$(1-\tau)p_s + \beta\alpha v - p_2$	Over-estimate
Purchase V2	$\alpha v - p_2$		$\beta\alpha v - p_2$	
Purchase V1	$\theta v - p_s$		$\beta\theta v - p_s$	

5.3.2 Equilibrium Analysis

Using backward induction, we first solve the period-two subgame equilibrium. At time 1, consumers have been segmented into early-adopters and followers by the threshold $\hat{v}_{e,f}$, as illustrated in 5.2, with the early-adopters holding usage utilities in $[\hat{v}_{e,f}, \bar{v}]$ and followers holding usage utilities in $[0, \hat{v}_{e,f}]$. Further segmentation within early-adopters and followers are based on the individual rationality (IR) and incentive compatibility (IC) constraints mentioned in Table 5.4.

A weakened extent of time inconsistency (value of β increases), a higher usage utility of V2 (value of α increases), or a lower usage utility of used V1 (value of θ decreases) decreases the IR and IC constraints, affecting the market segmentation in period two. One critical assumption $\frac{p_2}{p_s} > \frac{\alpha}{\theta}$ must hold to ensure the existence of demand on the CRP.

By the thresholds provided in Table 5.4, among the early-adopters, those with high usage utilities $\max\{v_{E,rp}, v_{rp,k}\} \leq v \leq \bar{v}$ resell V1 and purchase V2 and the others with usage utilities $\max\{\hat{v}_{e,f}, v_{E,k}\} \leq v < \max\{v_{E,rp}, v_{rp,k}\}$ keep V1. Followers purchase V2 from the manufacturer, purchase V1 on the CRP, and leave when their usage utilities are high with $\max\{v_{F,n}, v_{n,s}\} \leq v < \hat{v}_{e,f}$, intermediate with $\max\{v_{F,s}, v_{s,l}\} \leq v < \max\{v_{F,n}, v_{n,s}\}$, and low with $0 \leq v < \max\{v_{F,s}, v_{s,l}\}$, respectively.

Table 5.4: Thresholds at time 1

Segments	Choices	Thresholds	
		IR constraints	IC constraints
Early-adopters	Keep V1	$u_{E,k} \geq 0$	$u_{E,k} \geq u_{E,rp} \Rightarrow v \leq v_{rp,k} = \frac{p_2-(1-\tau)p_s}{\beta(\alpha-\theta)}$ $u_{E,k} \geq u_{E,rl} \Rightarrow v \geq v_{k,rl} = \frac{(1-\tau)p_s}{\beta\theta}$
	Resell V1 and purchase V2	$u_{E,rp} \geq 0 \Rightarrow v \geq v_{E,rp} = \frac{p_2-(1-\tau)p_s}{\beta\alpha}$	$u_{E,rp} \geq u_{E,k} \Rightarrow v \geq v_{rp,k} = \frac{p_2-(1-\tau)p_s}{\beta(\alpha-\theta)}$ $u_{E,rp} \geq u_{E,rl} \Rightarrow v \geq v_{rp,rl} = \frac{p_2}{\beta\alpha}$
	Resell V1 and leave	$u_{E,rl} \geq 0$	$u_{E,rl} \geq u_{E,k} \Rightarrow v \leq v_{k,rl} = \frac{(1-\tau)p_s}{\beta\theta}$ $u_{E,rl} \leq u_{E,rp} \Rightarrow v \leq v_{rp,rl} = \frac{p_2}{\beta\alpha}$
Followers	Purchase V2	$u_{F,n} \geq 0 \Rightarrow v \geq v_{F,n} = \frac{p_2}{\beta\alpha}$	$u_{F,n} \geq u_{F,s} \Rightarrow v \geq v_{n,s} = \frac{p_2-p_s}{\beta(\alpha-\theta)}$ $u_{F,n} \geq u_{F,l} \Rightarrow v \geq v_{n,l} = \frac{p_2}{\beta\alpha}$
	Purchase V1	$u_{F,s} \geq 0 \Rightarrow v \geq v_{F,s} = \frac{p_s}{\beta\theta}$	$u_{F,s} \geq u_{F,n} \Rightarrow v \leq v_{n,s} = \frac{p_2-p_s}{\beta(\alpha-\theta)}$ $u_{F,s} \geq u_{F,l} \Rightarrow v \geq v_{s,l} = \frac{p_s}{\beta\theta}$
	Leave	$u_{F,l} = 0$	$u_{F,l} \geq u_{F,n} \Rightarrow v \leq v_{n,l} = \frac{p_2}{\beta\alpha}$ $u_{F,l} \geq u_{F,s} \Rightarrow v \leq v_{s,l} = \frac{p_s}{\beta\theta}$

Based on the aforementioned thresholds for segmenting the market, the manufacturer maximizes the profit in period two:

$$\max \pi_2 = p_2 d_2 \tag{5.3}$$

where d_2 comes from both the early-adopters who resell V1 and purchase V2 (which equals in quantity to that of followers who purchase used V1 on the CRP) and the followers who purchase V2, i.e., $d_2 = \underbrace{\frac{\bar{v} - v_{rp,k}}{\bar{v}}}_{early-adopters} + \underbrace{\frac{\hat{v} - v_{n,s}}{\bar{v}}}_{followers}$. On the CRP, the supply for used V1 comes from early-adopters, in a quantity of $\frac{\bar{v}-v_{rp,k}}{\bar{v}}$, and the demand for used V1 comes from followers, in a quantity of $\frac{v_{n,s}-v_{s,l}}{\bar{v}}$. The number of followers who leave without purchasing is $\frac{v_{s,l}}{\bar{v}}$. Lemma 5.1 presents the subgame equilibrium outcomes. The proof is shown in C.1.

Lemma 5.1. *Given the threshold $\hat{v}_{e,f}$ (abbreviated as $\hat{v}$ in the formulas), in subgame equilibrium, the price for the upgraded version is $p_2^*(\hat{v}) = \frac{\beta(\hat{v}(\alpha+\theta(1-\tau))+\bar{v}(\alpha-\theta))}{4}$, and the* *market-clearing price for the used original product is* $p_s^*(\hat{v}) = \frac{\beta\theta(\theta(\hat{v}(1-\tau)+\bar{v})-\alpha(\bar{v}-\hat{v}))}{2(\alpha+\theta(1-\tau))}$*. Moreover, the demand for the upgraded version is* $d_2^*(\hat{v}) = \frac{\alpha(\bar{v}+\hat{v})+\theta(\hat{v}(1-\tau)-\bar{v})}{2\bar{v}(\alpha+\theta(1-\tau))}$ *and the profit is* $\pi_2^*(\hat{v}) = \frac{\beta(\hat{v}(\alpha+\theta(1-\tau))+\bar{v}(\alpha-\theta))^2}{8\bar{v}(\alpha+\theta(1-\tau))}$.

In subgame equilibrium, we find that the price of V2, the market-clearing price of used V1, and the manufacturer's period-two profit all increase monotonically with β. In essence, as the extent of time inconsistency intensifies (value of β decreases), the heightened misestimation of choices renders consumers more sensitive to prices. The manufacturer experiences a loss of pricing power on the upgraded version, resulting in a lower profit. The consumers' improved usage utility for the upgraded version (value of α increases) entices the manufacturer to raise price at time 1, thereby benefiting from increased profit.

Back to period one, in anticipation of the profit to receive in period two, the manufacturer sets the price for the original version to manipulate the time 0 threshold $\hat{v}_{e,f}$ (See Table 5.2), maximizing the total profit over the two periods:

$$\pi(\hat{v}) = p_1(\hat{v})d_1(\hat{v}) + \pi_2^*(\hat{v}) - \frac{K\left(\alpha^2-1\right)}{2} \tag{5.4}$$

where $d_1(\hat{v}) = \frac{\bar{v}-\hat{v}}{\bar{v}}$. Lemma 5.2 and Table 5.5 state the equilibrium. Please refer to Appendix C.1 for details.

Lemma 5.2. *The optimal threshold at time 0 is*

$$\hat{v}^* = \frac{5\bar{v}\begin{pmatrix} \frac{\theta^2}{5}\left(\tau-1\right)\left(\beta\left(\tau+2\right)+1\right) - \\ \theta\left(\alpha\left(\frac{2\beta}{5}-\tau\left(1+\frac{3\beta}{5}\right)+\frac{4}{5}\right)-\frac{4}{5}\left(\tau-1\right)\right)-\alpha^2-\frac{4\alpha}{5}\end{pmatrix}}{2\left(\alpha+\theta(1-\tau)\left(\theta\left(\beta-\frac{1}{2}\right)\left(\tau-1\right)+\alpha\left(\beta-\frac{7}{2}\right)-4\right)\right)}.$$

The optimal market segmentation is illustrated in Figure 5.4. At the initial purchase at time 0, the threshold $\hat{v}^* = v_{rp,l}$ regulates segmentation in period one. Specifically, a consumer with usage utility above $\hat{v}^*$ purchases V1 and anticipates 'Resell V1 and purchase V2' at time 1, while a consumer with usage utility below $\hat{v}^*$ postpones the purchase and anticipates 'Leave the market without making any

Table 5.5: Equilibrium outcomes

	Period one	Period two
New-product price	$p_1^* = \frac{\beta\Lambda_{p_1}}{4(\alpha+\theta(1-\tau))}$	$p_2^* = \frac{\beta(\hat{v}^*(\alpha+\theta(1-\tau))+\bar{v}(\alpha-\theta))}{4}$
New-product demand	$d_1^* = \frac{\bar{v}-\hat{v}^*}{\bar{v}}$	$d_2^* = \frac{\beta(\hat{v}^*(\alpha+\theta(1-\tau))+\bar{v}(\alpha-\theta))}{2\bar{v}(\alpha+\theta(1-\tau))}$
Total demand	$d^* = \frac{\theta(\bar{v}(1-2\tau)-\hat{v}^*(1-\tau))+\alpha(3\bar{v}-\hat{v}^*)}{2\bar{v}(\alpha+\theta(1-\tau))}$	
Used-product price	$p_s^* = \frac{\beta\theta(\hat{v}^*(\alpha+\theta(1-\tau))-\bar{v}(\alpha-\theta))}{2(\alpha+\theta(1-\tau))}$	
Used-product demand	$d_s^* = \frac{\theta^2(\tau-1)(\bar{v}+\hat{v}^*(\tau-1))-\alpha\theta\bar{v}(\tau+2)+\alpha^2(3\bar{v}-\hat{v}^*)}{4\bar{v}(\alpha-\theta)(\alpha+\theta(1-\tau))}$	
Profit	$\pi_1^* = \frac{\beta\Lambda_{p_1}(\bar{v}-\hat{v}^*)}{4\bar{v}(\alpha+\theta(1-\tau))}$	$\pi_2^* = \frac{\beta(\hat{v}^*(\alpha+\theta(1-\tau))+\bar{v}(\alpha-\theta))^2}{8\bar{v}(\alpha+\theta(1-\tau))}$
Total Profit	$\pi^* = \frac{\beta\Lambda_{p_1}(\bar{v}-\hat{v}^*)}{4\bar{v}(\alpha+\theta(1-\tau))} + \frac{\beta(\hat{v}^*(\alpha+\theta(1-\tau))+\bar{v}(\alpha-\theta))}{4} - \frac{K(\alpha^2-1)}{2}$	

Note. $\Lambda_{p_1} = \beta\theta^2(\tau-1)\left(\hat{v}^*(\tau-1)-3\bar{v}\right)-\theta\left(4\hat{v}^*(\tau-1)(\alpha+1)-3\alpha\beta\bar{v}\left(\tau-\frac{2}{3}\right)\right)-\alpha\left(\hat{v}^*\left(\alpha\beta-4(\alpha+1)\right)-\alpha\beta\bar{v}\right)$.

purchase' at time 1. Thus, the demand for V1 in period one is $d_1^* = \frac{\bar{v}-\hat{v}^*}{\bar{v}}$. When time 1 arrives, consumers may deviate from their anticipated choices. Some early-adopters opt to keep V1 (in a quantity of $\frac{v_{rp,k}^*-\hat{v}^*}{\bar{v}}$) instead of replacing used V1 with V2; we refer to it as the *demand vanishing* effect. Followers, initially expecting to exit the market in period two, shift to purchasing V1 (in a quantity of $\frac{v_{n,s}^*-v_{s,l}^*}{\bar{v}}$) or purchasing V2 (in a quantity of $\frac{\hat{v}^*-v_{n,s}^*}{\bar{v}}$); we refer to them the *demand migration* effect and the *demand expansion* effect, respectively. Lemma 5.3 summarizes these effects.

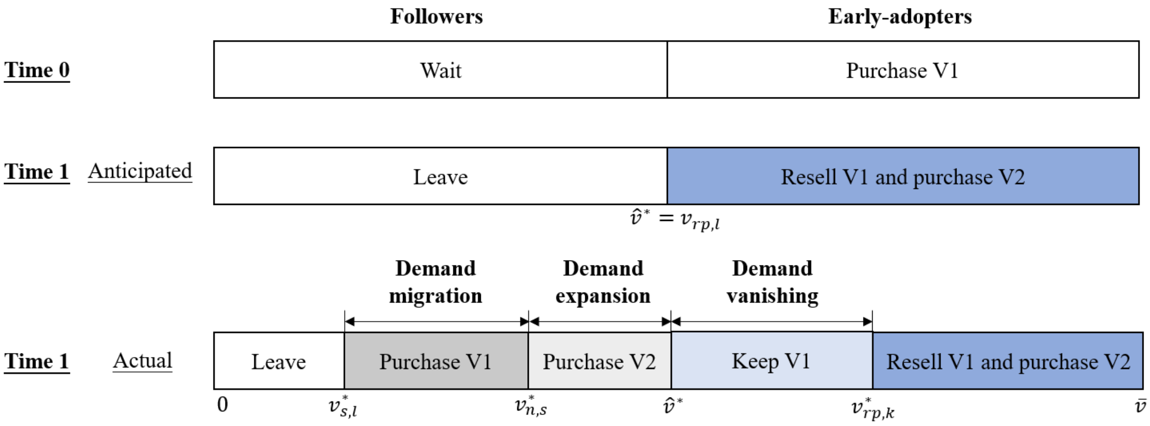


Figure 5.4: Anticipated and actual market segmentation

Lemma 5.3. *In the presence of CRP, the presence of time inconsistency results in three effects on the demand to the manufacturer: demand vanishing, demand migration, and demand expansion.*

The demand migration effect represents the segment of followers who diverge from their anticipated choice of 'Leave' and choose to make a purchase from the CRP. Intuitively, due to the existence of vertical competition introduced by the C2C resale market, the demand migration effect is disadvantageous to the manufacturer's demand. However, it exerts a positive influence on the manufacturer. Specifically, this segment, functioning as the demand side of the CRP, not only generates demand for the platform but also fosters purchases of the upgraded version for the manufacturer by facilitating the replacement of product versions for resellers among early-adopters. On the contrary, the demand expansion effect and the demand vanishing effect each have a direct positive and negative impact on the manufacturer's demand, respectively.

Lemma 5.4. *The manufacturer adheres to a decreasing pricing trajectory in the two periods when consumers exhibit time inconsistency.*

Intuitively, the manufacturer will set a higher price for the upgraded version compared to the original version, given our assumption that the usage utility of the upgraded version is larger for each consumer, i.e., $\alpha > 1$. However, intriguingly, we find that the manufacturer lacks the incentive to depart from a decreasing price trajectory ($p_1^* \geq p_2^*$) even with the introduction of an upgraded version at time 1 when consumers are time-inconsistent. The rationale is as follows. The existence of CRP offers consumers a venue to upgrade product versions while earning resale income. This leads to more impulsive purchasing among time-inconsistent consumers in period one. Consequently, the manufacturer can strategically raise the price for the original version to extract more surplus from consumers. As illustrated in Figure 5.4, all early-adopters initially anticipate choosing 'Resell V1 and purchase V2' at time

1. Nevertheless, consumers' time-inconsistent behavior induces a demand vanishing effect, leading some early-adopters to forgo resale and opt to keep the product. Simultaneously, the manufacturer reduces the price at time 1 compared with the price at time 0 to attract more followers, persuading them to shift from their initial intention of leaving the market to making a purchase. This induces demand migration and demand expansion effects, resulting in benefits for the manufacturer.

Lemmas 5.5 and 5.6, respectively, demonstrate the effects of the extent of time inconsistency and the degree of differentiation between product versions on market outcomes.

Lemma 5.5. *As time inconsistency strengthens (value of β decreases):*

1. *the selling prices decrease;*
2. *the extent of intertemporal price discrimination decreases;*
3. *the number of early-adopters (followers) increases (decreases);*
4. *the market-clearing price of used original products decreases, while the transaction volume on the CRP increases;*
5. *demand vanishing increases, while demand migration and demand expansion decrease;*
6. *less consumers leave without purchasing.*

The heightened extent of time inconsistency results in lower anticipated and actual utilities for consumers. It weakens the manufacturer's ability to set prices in both periods. Moreover, heightened time inconsistency leads to greater discrepancies in consumers' misestimation of intertemporal utilities. This causes more consumers to make inconsistent choices between time 0 and time 1, prompting the manufacturer to reduce intertemporal price discrimination to mitigate the negative impacts of time inconsistency. The pricing outcome weighs on consumers' purchase incentives in each period. In period one, the simultaneous decrease in the selling price and intertemporal price discrimination leads to more consumers making purchases, i.e., the number of early-adopters increases while the number of followers decreases. In period two, the reduced utilities make both early adopters and followers to refrain from purchasing. Consequently, the demand vanishing effect increases, while the demand migration and demand expansion effects decrease. Simultaneously, the market-clearing price of used original products on the CRP decreases with heightened time inconsistency, indicating that increased time inconsistency fuels the price competition between the CRP and the manufacturer.

Lemma 5.6. *As the degree of differentiation between product versions increases (value of α increases):*

1. *the selling prices increase;*
2. *the extent of intertemporal price discrimination increases;*
3. *the number of early-adopters (followers) decreases (increases);*
4. *the market-clearing price of used original products decreases, while the transaction volume on the CRP increases;*
5. *demand vanishing decreases, while demand migration and demand expansion increase.*
6. *less consumers leave without purchasing.*

The increased differentiation between product versions provides the manufacturer with a competitive advantage over the CRP, as consumers perceive higher usage utility from the new upgraded version compared to the used original version. This allows the manufacturer to raise prices in both periods while decreasing the market-clearing price for used original products on the CRP. Moreover, as the differences between new products released in the two periods increase, the manufacturer tends to exacerbate intertemporal price discrmination to create more distinct market segmentation. These pricing adjustments significantly affect consumers' choices in each period. In period one, the simultaneous increase in the selling price and intertemporal price discrimination leads to more consumers delaying their purchases, i.e., the number of early-adopters decreases whereas the number of followers increases. In period two, the increased usage utility of upgraded products leads more early adopters to participate in resale and purchase the upgraded version. Thus, the demand vanishing effect decreases. Moreover, the enhanced competitiveness of upgraded products and the reduced prices of used original products induces more followers to purchase from the manufacturer or the CRP rather than exiting the market. As such, the demand migration and demand expansion effects increase.

A critical issue pertains to the sustainability of transactions on the CRP, ensuring the viability of the used original version. Similar to Lemma 3.1 in Chapter 3, Lemma 5.7 demonstrates the necessary condition for the CRP to sustain transactions of used original products.

Lemma 5.7. *When consumers are time-inconsistent, the transactions of used original products on the CRP are sustained if the usage utility of a used original version is high, i.e.,* $\theta \geq \underline{\theta}(\beta, \alpha, \tau)$*, where* $\underline{\theta}(\beta, \alpha, \tau)$ *is defined in C.5.*

Followers, perceiving high usage utility from used original products, are more likely to make purchases on the CRP, ensuring a sufficient volume of demand. Moreover, if the perceived usage utility of the used original version is high, a sizable number of early adopters will still opt to resell rather than keep the used product, ensuring a sufficient volume of supply on the CRP. This decision is driven by the resale income and the opportunity to upgrade to a newer product version. Thus, the CRP achieves balance by effectively matching supply with demand. In the subsequent analysis, we assume that the usage utility of a used original version is high enough to ensure the existence of transactions on the CRP.

5.4 Dynamic Pricing Strategy for New Products Considering Consumers' Time Inconsistency

This section assesses the impact of time inconsistency on the manufacturer's optimal dynamic pricing strategy in the presence of CRP. To conduct a comparative investigation, we construct a benchmark scenario wherein consumers form rational (completely correct) expectations about future payments and payoffs, and their perceptions and preferences remain unchanged over time, i.e., $\beta = 1$. Other model settings remain unchanged. Superscript R is added to make a difference.

When consumers behave rationally, the utility of purchasing at time 0 is $u_E^R = v - p_1^R + \max\left\{u_{E,k}^R, u_{E,rp}^R, u_{E,rl}^R\right\}$. Here, the utilities for the options 'Keep V1', 'Resell V1 and purchase V2', and 'Resell V1 and leave' are $u_{E,k}^R = \theta v$, $u_{E,rp}^R = (1-\tau)\, p_s^R + \alpha v - p_2^R$, and $u_{E,rl}^R = (1-\tau)\, p_s^R$, respectively. A consumer's utility of postponing at time 0 is $u_F^R = 0 + \max\left\{u_{F,n}^R, u_{F,s}^R, u_{F,l}^R\right\}$, where the utilities for the options 'Purchase V2', 'Purchase V1', and 'Leave' are given by $u_{F,n}^R = \alpha v - p_2^R$, $u_{F,s}^R = \theta v - p_s^R$, and $u_{F,l}^R = 0$. Consumers opt to purchase the original version at time 0 if $u_E^R \geq u_F^R$. At time 1, for early-adopters, the decision to purchase the upgraded version is determined by $u_{E,rp}^R \geq \max\left\{u_{E,k}^R, u_{E,rl}^R\right\}$, while for followers, it is contingent on $u_{F,n}^R \geq \max\left\{u_{F,s}^R, u_{F,l}^R\right\}$.

Using backward induction, we first solve the period-two subgame equilibrium of scenario R. A threshold $\hat{v}_{e,f}^R$ segments the market into early-adopters and followers in scenario R, with the early-adopters holding usage utilities in $[\hat{v}_{e,f}^R, \bar{v}]$ and followers holding usage utilities in $[0, \hat{v}_{e,f}^R]$. Further segmentation of scenario R within early-adopters and followers are based on the IR and IC constraints mentioned in Table 5.6.

By the thresholds provided in Table 5.6, among early-adopters, those with high usage utilities $\max\left\{v_{E,rp}^R, v_{rp,k}^R\right\} \leq v \leq \bar{v}$ resell V1 and purchase V2 and the others with usage utilities $\max\left\{\hat{v}_{e,f}^R, v_{E,k}^R\right\} \leq v < \max\left\{v_{E,rp}^R, v_{rp,k}^R\right\}$ keep V1. Followers

Table 5.6: Thresholds at time 1 of scenario R

Segments	Choices	Thresholds	
		IR constraints	IC constraints
Early-adopters	Keep V1	$u^R_{E,k} \geq 0$	$u^R_{E,k} \geq u^R_{E,rp} \Rightarrow v \leq v^R_{rp,k} = \frac{p^R_2-(1-\tau)p^R_s}{\alpha-\theta}$ $u^R_{E,k} \geq u^R_{E,rl} \Rightarrow v \geq v^R_{k,rl} = \frac{(1-\tau)p^R_s}{\theta}$
	Resell V1 and purchase V2	$u^R_{E,rp} \geq 0 \Rightarrow v \geq v^R_{E,rp} = \frac{p^R_2-(1-\tau)p^R_s}{\alpha}$	$u^R_{E,rp} \geq u^R_{E,k} \Rightarrow v \geq v^R_{rp,k} = \frac{p^R_2-(1-\tau)p^R_s}{\alpha-\theta}$ $u^R_{E,rp} \geq u^R_{E,rl} \Rightarrow v \geq v^R_{rp,rl} = \frac{p^R_2}{\alpha}$
	Resell V1 and leave	$u^R_{E,rl} \geq 0$	$u^R_{E,rl} \geq u^R_{E,k} \Rightarrow v \leq v^R_{k,rl} = \frac{(1-\tau)p^R_s}{\theta}$ $u^R_{E,rl} \leq u^R_{E,rp} \Rightarrow v \leq v^R_{rp,rl} = \frac{p^R_2}{\alpha}$
Followers	Purchase V2	$u^R_{F,n} \geq 0 \Rightarrow v \geq v_{F,n} = \frac{p^R_2}{\alpha}$	$u^R_{F,n} \geq u^R_{F,s} \Rightarrow v \geq v^R_{n,s} = \frac{p^R_2-p^R_s}{\alpha-\theta}$ $u^R_{F,n} \geq u^R_{F,l} \Rightarrow v \geq v^R_{n,l} = \frac{p^R_2}{\alpha}$
	Purchase V1	$u^R_{F,s} \geq 0 \Rightarrow v \geq v^R_{F,s} = \frac{p^R_s}{\theta}$	$u^R_{F,s} \geq u^R_{F,n} \Rightarrow v \leq v^R_{n,s} = \frac{p^R_2-p^R_s}{\alpha-\theta}$ $u^R_{F,s} \geq u^R_{F,l} \Rightarrow v \geq v^R_{s,l} = \frac{p^R_s}{\theta}$
	Leave	$u^R_{F,l} = 0$	$u^R_{F,l} \geq u^R_{F,n} \Rightarrow v \leq v^R_{n,l} = \frac{p^R_2}{\alpha}$ $u^R_{F,l} \geq u^R_{F,s} \Rightarrow v \leq v^R_{s,l} = \frac{p^R_s}{\theta}$

purchase V2 from the manufacturer, purchase used V1 on the CRP, and leave when their usage utilities are high with $\max\left\{v^R_{F,n}, v^R_{n,s}\right\} \leq v < \hat{v}^R_{e,f}$, intermediate with $\max\left\{v^R_{F,s}, v^R_{s,l}\right\} \leq v < \max\left\{v^R_{F,n}, v^R_{n,s}\right\}$, and low with $0 \leq v < \max\left\{v^R_{F,s}, v^R_{s,l}\right\}$, respectively.

Based on the aforementioned thresholds for segmenting the market in scenario R, the manufacturer optimizes the period-two profit:

$$\max \pi^R_2 = p^R_2 d^R_2 \tag{5.5}$$

where $d^R_2 = \underbrace{\frac{\bar{v} - v^R_{rp,k}}{\bar{v}}}_{early-adopters} + +\underbrace{\frac{\hat{v}^R - v^R_{n,s}}{\bar{v}}}_{followers}$. On the CRP, the supply for used V1 comes from early-adopters, in a quantity of $\frac{\bar{v}-v^R_{rp,k}}{\bar{v}}$, and the demand for used V1 comes from followers, in a quantity of $\frac{v^R_{n,s}-v^R_{s,l}}{\bar{v}}$. The number of followers who leave without purchasing is $\frac{v^R_{s,l}}{\bar{v}}$. The market segmentation of scenario R is depicted in Figure 5.5. The proof is shown in C.2.

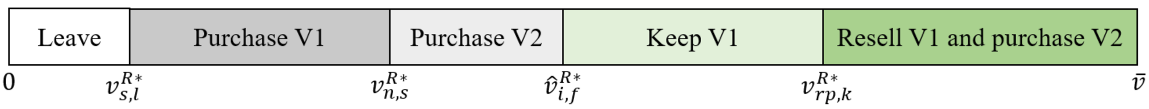


Figure 5.5: Market segmentation of scenario R

Back to period one, in anticipation of the profit to receive in period two in scenario R, the manufacturer maximizes the total profit over the two periods:

$$\pi(\hat{v}^R) = p_1(\hat{v}^R)d_1(\hat{v}^R) + \pi_2^*(\hat{v}^R) - \frac{K\left(\alpha^2-1\right)}{2} \tag{5.6}$$

where $d_1(\hat{v}^R) = \frac{\bar{v}-\hat{v}^R}{\bar{v}}$. The equilibrium outcomes of scenario R is summarized in Table 5.7, where the optimal threshold is $\hat{v}^{R*} = \frac{\bar{v}(\theta(\tau-5)+3\alpha-4)}{\theta(\tau-9)+7\alpha-8}$. One necessary condition for the existence of equilibrium in scenario R is $\alpha < \bar{\alpha} = \frac{8+\theta(9-\tau)}{7}$. Note that when consumers are rational, the condition for sustaining the transactions of used original products on the CRP is $\theta \geq \underline{\theta}^R(\alpha,\tau)$. Moreover, our findings reveal that time inconsistency constrains the range in which the CRP operates for consumers engaging in secondhand transactions, i.e., $\underline{\theta} > \underline{\theta}^R$, where $\underline{\theta}$ is defined in Lemma 5.7. Please refer to Appendix C.2 for details.

Table 5.7: Equilibrium outcomes of scenario R

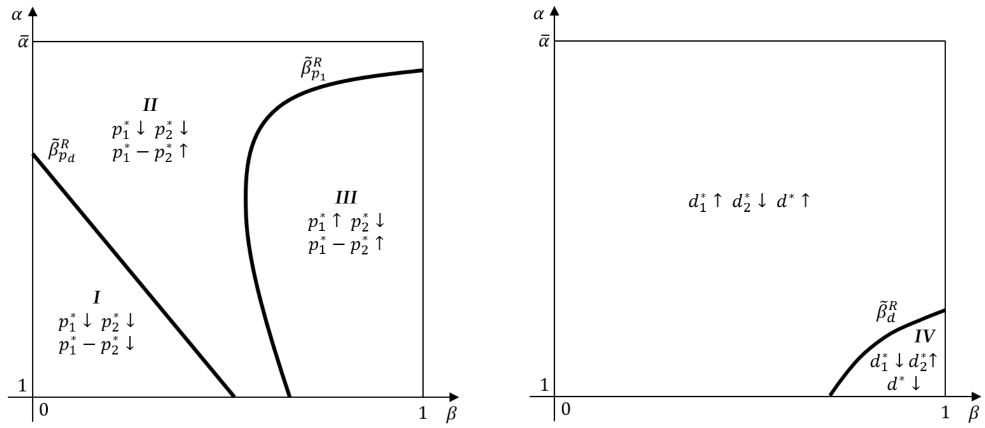
	Period one	Period two
New-product price	$p_1^{R*} = \frac{\hat{v}^{R*}(\theta(5-\tau)-3\alpha+4)+\bar{v}(\alpha-\theta)}{4}$	$p_2^{R*} = \frac{\hat{v}^{R*}(\alpha+\theta(1-\tau))+\bar{v}(\alpha-\theta)}{4}$
New-product demand	$d_1^{R*} = \frac{\bar{v}-\hat{v}^{R*}}{\bar{v}}$	$d_2^{R*} = \frac{\hat{v}^{R*}(\alpha+\theta(1-\tau))+\bar{v}(\alpha-\theta)}{2\bar{v}(\alpha+\theta(1-\tau))}$
Total demand	$d^{R*} = \frac{\theta\left(\bar{v}(1-2\tau)-\hat{v}^{R*}(1-\tau)\right)+\alpha\left(3\bar{v}-\hat{v}^{R*}\right)}{2\bar{v}(\alpha+\theta(1-\tau))}$	
Used-product price	$p_s^{R*} = \frac{\theta\left(\hat{v}^{R*}(\alpha+\theta(1-\tau))-\bar{v}(\alpha-\theta)\right)}{2(\alpha+\theta(1-\tau))}$	
Used-product demand	$d_s^{R*} = \frac{\theta^2(\tau-1)\left(\bar{v}+\hat{v}^{R*}(\tau-1)\right)-\alpha\theta\bar{v}(\tau+2)+\alpha^2\left(3\bar{v}-\hat{v}^{R*}\right)}{4\bar{v}(\alpha-\theta)(\alpha+\theta(1-\tau))}$	
Profit	$\pi_1^{R*} = \frac{\left(\bar{v}-\hat{v}^{R*}\right)\left(\hat{v}^{R*}(\theta(5-\tau)-3\alpha+4)+\bar{v}(\alpha-\theta)\right)}{4\bar{v}} - \frac{K\left(\alpha^2-1\right)}{2}$	$\pi_2^{R*} = \frac{\left(\hat{v}^{R*}(\alpha+\theta(1-\tau))+\bar{v}(\alpha-\theta)\right)^2}{8\bar{v}(\alpha+\theta(1-\tau))}$
Total Profit	$\pi^{R*} = \frac{\left(\bar{v}-\hat{v}^{R*}\right)\left(\hat{v}^{R*}(\theta(5-\tau)-3\alpha+4)+\bar{v}(\alpha-\theta)\right)}{4\bar{v}} + \frac{\left(\hat{v}^{R*}(\alpha+\theta(1-\tau))+\bar{v}(\alpha-\theta)\right)^2}{8\bar{v}(\alpha+\theta(1-\tau))} - \frac{K\left(\alpha^2-1\right)}{2}$	

By comparing the equilibrium outcomes of the systems with time-inconsistent consumers (main model) and with rational consumers (scenario R), we examine the impact of time inconsistency in the presence of CRP. Proposition 5.1 demonstrates the influence of time inconsistency on the manufacturer's price and demand.

Proposition 5.1. *When consumers exhibit time-inconsistent behavior than rational behavior, in the presence of CRP, the manufacturer's:*

1. *period-one price increases if the extent of time inconsistency is low, i.e.,* $\beta \geq \tilde{\beta}^R_{p_1}(\theta, \alpha, \tau)$*, but decreases otherwise.* $\tilde{\beta}^R_{p_1}(\theta, \alpha, \tau)$ *is defined in C.5;*
2. *period-two price decreases;*
3. *intertemporal price discrimination exacerbates if the extent of time inconsistency is low, i.e.,* $p_1^* - p_2^* \geq p_1^{R*} - p_2^{R*}$ *when* $\beta \geq \tilde{\beta}^R_{p_d}(\theta, \alpha, \tau)$*, but mitigates otherwise.* $\tilde{\beta}^R_{p_d}(\theta, \alpha, \tau)$ *is defined in C.5;*
4. *period-one demand increases while period-two demand decreases except in cases where the extent of time inconsistency is sufficiently low, i.e.,* $\beta \geq \tilde{\beta}^R_d(\theta, \alpha, \tau)$*, but period-one demand decreases and period-two demand increases otherwise.* $\tilde{\beta}^R_d(\theta, \alpha, \tau)$ *is defined in C.5;*
5. *total demand increases except for when the extent of time inconsistency is sufficiently low, i.e.,* $\beta \geq \tilde{\beta}^R_d(\theta, \alpha, \tau)$*, but decreases otherwise.*

Compared to rational consumers, time-inconsistent consumers apply a linear discount to the payments and payoffs associated with their choices, which results in misestimation of their intertemporal utilities and alters their intertemporal behavior. As demonstrated in Lemma 5.3, three demand effects emerge. When the extent of time inconsistency surpasses a certain threshold, $\beta < \tilde{\beta}^R_{p_1}$, consumers display pronounced misestimation of their utilities in intertemporal choices. The impact of demand vanishing is significant, while the effects of demand migration and expansion are relatively limited. Consequently, the manufacturer experiences a diminished power to set prices in both periods, resulting in a decrease in p_1^* and p_2^*, as areas I and II shown in Figure 5.6(a). Only when the time inconsistency level is low, i.e., $\beta \geq \tilde{\beta}^R_{p_1}$, can the manufacturer increase the period-one price for the original version p_1^* to exploit consumers' time-inconsistent behavior, as area III shown in Figure 5.6(a).



(a) Price (b) Demand

Note. ↓ *indicates "worsens" and* ↑ *indicates "improves";* $\theta = 0.6$ *and* $\tau = 0.1$

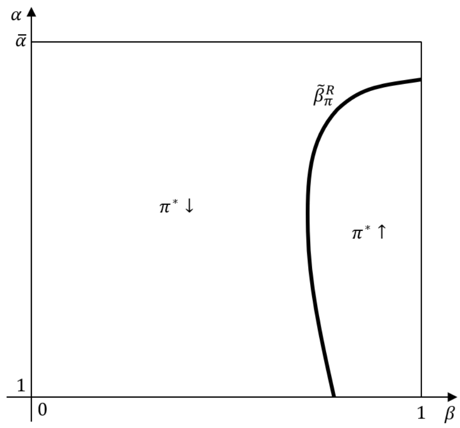
Figure 5.6: Effects of time inconsistency on price and demand in the presence of CRP

However, the manufacturer reduces p_2^* compared to the scenario where consumers are rational. The presence of time inconsistency intensifies competition from the CRP, compelling the manufacturer to lower the period-two price to regulate demand effects. Simultaneously, a low level of time inconsistency also exacerbates intertemporal price discrimination compared to scenario R, i.e., $p_1^* - p_2^* \geq p_1^{R*} - p_2^{R*}$ when $\beta \geq \tilde{\beta}^R_{p_d}$.

The adjustments made to the manufacturer's pricing strategy across the two periods yield changes in its demand. Surprisingly, when the condition holds such that $\beta \in \left[\tilde{\beta}^R_{p_1}, \tilde{\beta}^R_d\right]$, an increased in period-one price does not result in a decrease in period-one demand. This counter-intuitive outcome stems from time-inconsistent consumers' impulse purchasing behavior in period one. In equilibrium, at time 0, all early-adopters anticipate reselling the product and then purchasing V2 at time 1. The existence of CRP instills confidence in them to acquire resale revenue, thus motivating purchases in period one. Consequently, the manufacturer can raise period-one price without sacrificing sales volume. Furthermore, we find that period-one demand and period-two demand manifest opposite trends in the same area, while period-one demand and total demand manifest similar trends in the same area, as area IV illustrated in Figure 5.6(b). The increase in period-one demand serves as the main source of the rise in total demand.

5.4.1 Impacts on Manufacturer's Profit

Proposition 5.2. *In the presence of CRP, when consumers are time-inconsistent, the manufacturer's profit improves compared to the situation with rational consumers if the extent of time inconsistency and the differentiation level between product versions is low, i.e.,* $\beta \geq \tilde{\beta}_\pi^R(\theta, \alpha, \tau)$*, where* $\tilde{\beta}_\pi^R(\theta, \alpha, \tau)$ *is defined in C.5. Otherwise, the manufacturer's profit diminishes.*



Notes. $\downarrow$ *indicates "worsens" and* $\uparrow$ *indicates "improves";* $\theta = 0.6$ *and* $\tau = 0.1$.

Figure 5.7: Effects of time inconsistency on manufacturer's profit in the presence of CRP

Existing works mainly highlight the negative role of consumer biases on business operations. For instance, Rust et al. (2006) demonstrate that manufacturers exploiting consumer biases is detrimental to their long-term interests. Gilpatric (2009) states that the effectiveness of rebate programs in capitalizing on present-biased consumers is limited, especially in settings characterized by substantial variance in the degree of consumers' present biases. In contrast, our study indicates that the manufacturer can profitably leverage consumers' time-inconsistent behavior when the extent of time inconsistency and the differentiation level between product versions is low, i.e., $\beta \geq \tilde{\beta}_{\pi}^{R}$, as illustrated in Figure 5.7. According to Proposition 5.1, in comparison with the situation with rational consumers, the manufacturer increases period-one price and decreases period-two price when the extent of time inconsistency is low. This pricing strategy exacerbates intertemporal price discrimination, leading to more distinct market segmentation. Moreover, Lemma 5.5 indicates that the negative demand vanishing effect is small when time inconsistency is low, whereas the positive demand migration and demand expansion effects are high under the same condition. In this case, the manufacturer can profitably leverage the existence of CRP to mitigate the negative impact of consumers' time-inconsistent behavior. Our findings contribute to the literature by identifying specific circumstances under which the incumbent can benefit from consumers' subjective biases - time-inconsistent behavior, particularly within the context of C2C resale markets.

Importantly, the manufacturer's profit increases as the extent of time inconsistency decreases (value of β increases), i.e., $\frac{\partial \pi^*}{\partial \beta} > 0$, despite a decrease in the total demand. Prior literature suggests that employing precommitment strategies or self-control devices can effectively address consumers' impulsive behavior, thereby increasing β (Kivetz & Simonson 2002; Thaler & Shefrin 1981; S. Jain 2012). For instance, S. Jain (2012) proposes a self-control instrument such as delaying payment. Therefore, we alert incumbents to strategically exploit consumer's time-inconsistent behavior by managing the magnitude of β.

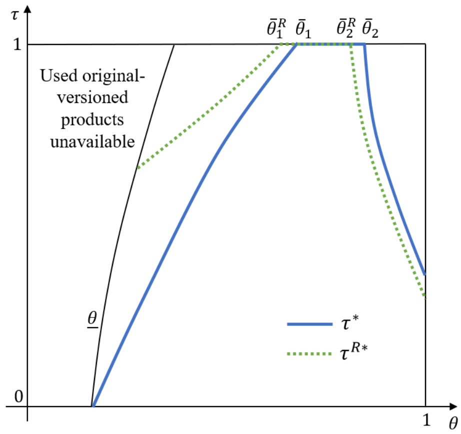
5.4.2 Impacts on CRP's Optimal Commission Rate

Our analysis has been based on the assumption that the commission rate imposed by the CRP is exogenous. In practice, a CRP has the ability to endogenously determine its commission rate to maximize revenue. In this section, we consider a scenario where the CRP can strategically choose its optimal commission rate at any time before time

0. Lemma 5.8 states the CRP's optimal decisions regarding the commission rate when consumers exhibit either time-inconsistent or rational behavior.

Lemma 5.8. *When the CRP sets the commission rate to maximize its revenue, let* $\bar{\theta}_1^R$, $\bar{\theta}_2^R$, $\bar{\theta}_1$, *and* $\bar{\theta}_2$ *be defined in Appendix C.5, the optimal commission rate is:*

1. *when consumers are time-inconsistent,* $\tau^* = \tilde{\tau}(\beta, \theta, \alpha)$ *except when the usage utility of a used original version is moderate, i.e.,* $\theta \in [\underline{\theta}, \bar{\theta}_1)$ *and* $\theta \in (\bar{\theta}_2, 1]$, *while* $\tau^* = 1$ *otherwise, i.e.,* $\theta \in [\bar{\theta}_1, \bar{\theta}_2]$;
2. *when consumers are rational,* $\tau^{R*} = \tilde{\tau}^R(\theta, \alpha)$ *except when the usage utility of a used original version is moderate, i.e.,* $\theta \in [\underline{\theta}, \bar{\theta}_1^R)$ *and* $\theta \in (\bar{\theta}_2^R, 1]$, *while* $\tau^{R*} = 1$ *otherwise, i.e.,* $\theta \in [\bar{\theta}_1^R, \bar{\theta}_2^R]$.



Notes. $\alpha = 1.2$ *and* $\beta = 0.6$.

Figure 5.8: Effects of time inconsistency on CRP's optimal commission rate

In setting the optimal commission rate to maximize revenue, the CRP strikes a balance between the commission rate and the transaction volume of used original products. Despite it may seem beneficial for the CRP to set a higher commission rate, an excessively high rate can have negative consequences. It can reduce the revenue early-adopters earn from reselling the original version, consequently reducing the participation of early-adopters in resale. This, in turn, leads to a decrease in the quantity of used original products for followers to purchase. The outcome of this trade-off is contingent on the usage utility of a used original version (See Figure 5.8). Whether consumers are time-inconsistent or rational, if the usage utility of a used original version falls within a moderate range, i.e., $\theta \in \left[\bar{\theta}_1, \bar{\theta}_2\right]$ or $\theta \in \left[\bar{\theta}_1^R, \bar{\theta}_2^R\right]$, the CRP adopts the highest commission rate $\tau^* = \tau^{R*} = 1$ to extract entire surplus from consumers' resale transactions. This result is consistent with Proposition 3.8 in Chapter 3, which provides further discussions on setting a commission rate to extract all resale revenue from consumers. However, if the usage utility of a used original version lies outside this range, the CRP adjusts its commission rate to ensure the transaction volume, i.e., $\tau^* = \tilde{\tau}(\beta, \theta, \alpha)$ if $\theta \in \left[\underline{\theta}, \bar{\theta}_1\right)$ and $\theta \in \left(\bar{\theta}_2, 1\right]$; $\tau^{R*} = \tilde{\tau}^R(\theta, \alpha)$ if $\theta \in \left[\underline{\theta}, \bar{\theta}_1^R\right)$ and $\theta \in \left(\bar{\theta}_2^R, 1\right]$. Proposition 5.3 discusses the impact of time inconsistency on the endogenized commission rate set by the revenue-maximizing CRP.

Proposition 5.3. *When consumers behave time-inconsistently, compared to the scenario where consumers behave rationally, the revenue-maximizing CRP sets a higher commission rate if the usage utility of a used original version is high, i.e., when* $\theta > \bar{\theta}_2^R$, $\tau^* > \tau^{R*}$. *Otherwise, the revenue-maximizing CRP sets a lower commission rate, i.e., when* $\theta < \bar{\theta}_1$, $\tau^* < \tau^{R*}$.

Through a comparison of the optimal commission rates in the main model and scenario R, we find that when the usage utility of a used original version is high, the CRP sets a higher commission rate when consumers exhibit time inconsistency, i.e., $\tau^* > \tau^{R*}$ when $\theta > \bar{\theta}_2^R$. In this case, the existence of time inconsistency empowers the CRP to enhance its revenue derived from resale transactions of used original products. Nevertheless, if the usage utility of a used original version θ is lower than the threshold $\bar{\theta}_1$, consumers' time-inconsistent behavior forces the CRP to relinquish parts of its competitive edge in determining its own commission rate, i.e., $\tau^* < \tau^{R*}$. To summarize, time inconsistency alters the CRP's position in setting the commission rate to maintain a balanced C2C resale market. Therefore, we suggest that CRPs, when dealing with time-inconsistent consumers, should ensure the quality of used products, thereby increasing θ among consumers, to earn higher commission revenue.

5.5 Product Upgrade Strategy Considering Consumers' Time Inconsistency

This section delves into the manufacturer's product upgrade strategy when consumers are time-inconsistent. We construct a benchmark scenario N, where the manufacturer refrains from introducing the upgraded version to the market in period two, i.e., $\alpha = 1$, to conduct a comparative investigation. Other model settings remain unchanged. Superscript N indicates this setting.

If the manufacturer launches the same versions across the two periods, consumers who purchase the product in period one are no longer incentivized to engage in second-hand resale in period two for the purpose of updating product versions. Instead, their motivation shifts towards replacing the old product in their possession with an equally new one. In contrast, consumers who deferred their purchases in the previous period seek to acquire a product at a lower price in the later period. Specifically, the option 'Resell used V1 and purchase V2' for early-adopters transforms into 'Resell used V1 and repurchase new V1', and the option 'Purchase new V2' for followers transforms into 'Purchase new V1'. At this case, a consumer's net utility of purchasing V1 at time 0, anticipating period-two decision, is $\tilde{u}_E^N = \beta v - p_1^N + \max\left\{\tilde{u}_{E,k}^N, \tilde{u}_{E,rp}^N, \tilde{u}_{E,rl}^N\right\}$, where $\tilde{u}_{E,k}^N = \beta\theta v$ is the anticipated utility of 'Keep V1', $\tilde{u}_{E,rp}^N = \beta(1-\tau)p_s^N + \beta v - \beta p_2^N$ is that of 'Resell V1 and repurchase V1', and $\tilde{u}_{E,rl}^N = \beta(1-\tau)p_s^N$ is that of 'Resell V1 and leave'. Otherwise, a consumer's net utility of postponing the purchase at time 0, anticipating its period-two option, is $\tilde{u}_F^N = 0 + \max\left\{\tilde{u}_{F,n}^N, \tilde{u}_{F,s}^N, \tilde{u}_{F,l}^N\right\}$, where $\tilde{u}_{F,n}^N = \beta v - \beta p_2^N$ is the anticipated utility of 'Purchase new V1', $\tilde{u}_{F,s}^N = \beta\theta v - \beta p_s^N$ is that of 'Purchase used V1', and $\tilde{u}_{F,l}^N = 0$ is that of 'Leave'.

At time 0, consumers are willing to purchase if $\tilde{u}_E^N \geq \tilde{u}_F^N$. A threshold $\hat{v}_{e,f}^N$ segments the market into early-adopters and followers, with the early-adopters holding usage utilities in $[\hat{v}_{e,f}^N, \bar{v}]$ and followers holding usage utilities in $[0, \hat{v}_{e,f}^N]$. The thresholds $\hat{v}_{e,f}^N$ are summarized in Table 5.8.

Table 5.8: Thresholds at time 0 of scenario N

Condition	Threshold $\hat{v}_{e,f}^N$
Purchases V1 and anticipates keeping V1 than:	
• Postpones and anticipates purchasing new V1 $\beta v - p_1^N + \tilde{u}_{E,k}^N \geq 0 + \tilde{u}_{F,n}^N$	$v \geq \hat{v}_{k,n}^N = \frac{p_1^N - \beta p_2^N}{\beta\theta}$
• Postpones and anticipates purchasing used V1 $\beta v - p_1^N + \tilde{u}_{E,k}^N \geq 0 + \tilde{u}_{F,s}^N$	$v \geq \hat{v}_{k,s}^N = \frac{p_1^N - \beta p_s^N}{\beta}$
• Postpones and anticipates leaving $\beta v - p_1^N + \tilde{u}_{E,k}^N \geq 0 + \tilde{u}_{F,l}^N$	$v \geq \hat{v}_{k,l}^N = \frac{p_1^N}{\beta(1+\theta)}$
Purchases V1 and anticipates reselling V1 then repurchasing V1 than:	
• Postpones and anticipates purchasing new V1 $\beta v - p_1^N + \tilde{u}_{E,rp}^N \geq 0 + \tilde{u}_{F,n}^N$	$v \geq \hat{v}_{rp,n}^N = \frac{p_1^N - \beta(1-\tau)p_s^N}{\beta}$
• Postpones and anticipates purchasing used V1 $\beta v - p_1^N + \tilde{u}_{E,rp}^N \geq 0 + \tilde{u}_{F,s}^N$	$v \geq \hat{v}_{rp,s}^N = \frac{p_1^N + \beta p_2^N - \beta(2-\tau)p_s^N}{\beta(2-\theta)}$
• Postpones and anticipates leaving $\beta v - p_1^N + \tilde{u}_{E,rp}^N \geq 0 + \tilde{u}_{F,l}^N$	$v \geq \hat{v}_{rp,l}^N = \frac{p_1^N + \beta p_2^N - \beta(1-\tau)p_s^N}{2\beta}$
Purchases V1 and anticipates reselling V1 then leaving than:	
• Postpones and anticipates purchasing new V1 $\beta v - p_1^N + \tilde{u}_{E,rl}^N \geq 0 + \tilde{u}_{F,n}^N$	if $\beta \geq \frac{p_1^N}{p_2^N + p_s^N(1-\tau)}$
• Postpones and anticipates purchasing used V1 $\beta v - p_1^N + \tilde{u}_{E,rl}^N \geq 0 + \tilde{u}_{F,s}^N$	$v \geq \hat{v}_{rl,s}^N = \frac{p_1^N - \beta(2-\tau)p_s^N}{\beta(1-\theta)}$
• Postpones and anticipates leaving $\beta v - p_1^N + \tilde{u}_{E,rl}^N \geq 0 + \tilde{u}_{F,l}^N$	$v \geq \hat{v}_{rl,l}^N = \frac{p_1^N - \beta(1-\tau)p_s^N}{\beta}$

Note. $\hat{v}_{rl,n}^N$ *is not available in scenario N.*

At time 1, an early-adopter's present utilities for the options 'Keep V1', 'Resell V1 and repurchase V1', and 'Resell V1 and leave' are $u_{E,k}^N = \beta\theta v$, $u_{E,rp}^N = (1-\tau)\,p_s^N + \beta v - p_2^N$, and $u_{E,rl}^N = (1-\tau)\,p_s^N$, respectively. A follower's present utilities for the options 'Purchase new V1', 'Purchase used V1', and 'Leave' are given by $u_{F,n}^N =$

$\beta v - p_2^N$, $u_{F,s}^N = \beta\theta v - p_s^N$, and $u_{F,l}^N = 0$. Early-adopters opt to repurchase if $u_{E,rp}^N \geq \max\left\{u_{E,k}^N, u_{E,rl}^N\right\}$, whereas for followers, the decision to purchase depends on $u_{F,n}^N \geq \max\left\{u_{F,s}^N, u_{F,l}^N\right\}$.

Using backward induction, we first solve the period-two subgame equilibrium of scenario N. The period-two segmentation of scenario N are based on the IR and IC constraints mentioned in Table 5.9.

Table 5.9: Thresholds at time 1 of scenario N

Segments	Choices	Thresholds	
		IR constraints	IC constraints
Early-adopters	Keep V1	$u_{E,k}^N \geq 0$	$u_{E,k}^N \geq u_{E,rp}^N \Rightarrow v \leq v_{rp,k}^N = \frac{p_2^N-(1-\tau)p_s^N}{\beta(1-\theta)}$ $u_{E,k}^N \geq u_{E,rl}^N \Rightarrow v \geq v_{k,rl}^N = \frac{(1-\tau)p_s^N}{\beta\theta}$
	Resell V1 and purchase V1	$u_{E,rp}^N \geq 0 \Rightarrow v \geq v_{E,rp}^N = \frac{p_2^N-(1-\tau)p_s^N}{\beta}$	$u_{E,rp}^N \geq u_{E,k}^N \Rightarrow v \geq v_{rp,k}^N = \frac{p_2^N-(1-\tau)p_s^N}{\beta(1-\theta)}$ $u_{E,rp}^N \geq u_{E,rl}^N \Rightarrow v \geq v_{rp,rl}^N = \frac{p_2^N}{\beta}$
	Resell V1 and leave	$u_{E,rl}^N \geq 0$	$u_{E,rl}^N \geq u_{E,k}^N \Rightarrow v \leq v_{k,rl}^N = \frac{(1-\tau)p_s^N}{\beta\theta}$ $u_{E,rl}^N \leq u_{E,rp}^N \Rightarrow v \leq v_{rp,rl}^N = \frac{p_2^N}{\beta}$
Followers	Purchase new V1	$u_{F,n}^N \geq 0 \Rightarrow v \geq v_{F,n} = \frac{p_2^N}{\beta}$	$u_{F,n}^N \geq u_{F,s}^N \Rightarrow v \geq v_{n,s}^N = \frac{p_2^N-p_s^N}{\beta(1-\theta)}$ $u_{F,n}^N \geq u_{F,l}^N \Rightarrow v \geq v_{n,l}^N = \frac{p_2^N}{\beta}$
	Purchase used V1	$u_{F,s}^N \geq 0 \Rightarrow v \geq v_{F,s}^N = \frac{p_s^N}{\beta\theta}$	$u_{F,s}^N \geq u_{F,n}^N \Rightarrow v \leq v_{n,s}^N = \frac{p_2^N-p_s^N}{\beta(1-\theta)}$ $u_{F,s}^N \geq u_{F,l}^N \Rightarrow v \geq v_{s,l}^N = \frac{p_s^N}{\beta\theta}$
	Leave	$u_{F,l}^N = 0$	$u_{F,l}^N \geq u_{F,n}^N \Rightarrow v \leq v_{n,l}^N = \frac{p_2^N}{\beta}$ $u_{F,l}^N \geq u_{F,s}^N \Rightarrow v \leq v_{s,l}^N = \frac{p_s^N}{\beta\theta}$

By the thresholds provided in Table 5.9, among early-adopters, those with high usage utilities $\max\left\{v_{E,rp}^N, v_{rp,k}^N\right\} \leq v \leq \bar{v}$ resell V1 and repurchase V1 and the others with usage utilities $\max\left\{\hat{v}_{e,f}^N, v_{E,k}^N\right\} \leq v < \max\left\{v_{E,rp}^N, v_{rp,k}^N\right\}$ keep V1. Followers purchase new V1 from the manufacturer, purchase used V1 on the CRP, and leave when their usage utilities are high with $\max\left\{v_{F,n}^N, v_{n,s}^N\right\} \leq v < \hat{v}_{e,f}^N$, intermediate with $\max\left\{v_{F,s}^N, v_{s,l}^N\right\} \leq v < \max\left\{v_{F,n}^N, v_{n,s}^N\right\}$, and low with $0 \leq v < \max\left\{v_{F,s}^N, v_{s,l}^N\right\}$, respectively.

Based on the aforementioned thresholds for segmenting the market in scenario

N, the manufacturer maximizes the profit in period two:

$$\max \pi_2^N = p_2^N d_2^N \tag{5.7}$$

where $d_2 = \underbrace{\frac{\bar{v} - v_{rp,k}^N}{\bar{v}}}_{early-adopters} + \underbrace{\frac{\hat{v}^N - v_{n,s}^N}{\bar{v}}}_{followers}$. On the CRP, the supply for used V1 comes from early-adopters, in a quantity of $\frac{\bar{v}-v_{rp,k}^N}{\bar{v}}$, and the demand for used V1 comes from followers, in a quantity of $\frac{v_{n,s}^N - v_{s,l}^N}{\bar{v}}$. The number of followers who leave without purchasing is $\frac{v_{s,l}^N}{\bar{v}}$. The proof is shown in C.3.

Back to period one, in anticipation of the profit to receive in period two in scenario N, the manufacturer sets selling prices to manipulate the time 0 threshold $\hat{v}_{e,f}^N$ (See Table 5.8), maximizing the total profit over the two periods:

$$\pi(\hat{v}^N) = p_1(\hat{v}^N) d_1(\hat{v}^N) + \pi_2^*(\hat{v}^N) \tag{5.8}$$

where $d_1(\hat{v}^N) = \frac{\bar{v}-\hat{v}^N}{\bar{v}}$. Lemma 5.9 and Table 5.10 state the equilibrium of scenario N. Note that the condition for sustaining the transactions of used original products on the CRP in scenario N is $\theta \geq \underline{\theta}^N(\beta, \tau)$. Additionally, when consumers are time-inconsistent, the manufacturer's product upgrade strategy limits the available area for the platform to sustain transactions of used original products, i.e., $\underline{\theta} > \underline{\theta}^N$, where $\underline{\theta}$ is defined in Lemma 5.7. The proof of scenario N is outlined in C.3.

Lemma 5.9. *The optimal threshold at time 0 in scenario N is*

$$\hat{v}^{N*} = \frac{\bar{v}\left(\theta^2(\tau-1)\left(\beta\left(\tau+2\right)+1\right)+\theta\left(\beta(2-3\tau)-9\tau+8\right)\right)}{2(\theta(\tau-1)-1)\left(\theta\left(\beta-\frac{1}{2}\right)(\tau-1)+\beta-\frac{15}{2}\right)}.$$

Similar to the main model, the presence of time inconsistency also induces the demand vanishing, demand migration, and demand expansion effects in scenario N, as depicted in Figure 5.9. At time 0, a consumer with usage utility above $\hat{v}^{N*}$ purchases V1 and anticipates reselling and repurchasing V1 at time 1. Conversely, a consumer with usage utility below $\hat{v}^{N*}$ postpones the purchase and anticipates leaving the market without making any purchase at time 1. At time 1, a proportion of

Table 5.10: Equilibrium outcomes of scenario N

	Period one	Period two
New-product price	$p_1^{N*} = \frac{\beta\Lambda_{p_1^N}}{4(1+\theta(1-\tau))}$	$p_2^{N*} = \frac{\beta\left(\hat{v}^{N*}(1+\theta(1-\tau))+\bar{v}(1-\theta)\right)}{4}$
New-product demand	$d_1^{N*} = \frac{\bar{v}-\hat{v}^{N*}}{\bar{v}}$	$d_2^{N*} = \frac{\beta\left(\hat{v}^{N*}(1+\theta(1-\tau))+\bar{v}(1-\theta)\right)}{2\bar{v}(1+\theta(1-\tau))}$
Total demand	$d^{N*} = \frac{\theta\left(\bar{v}(2\tau-1)-\hat{v}^{N*}(\tau-1)\right)-3\bar{v}+\hat{v}^{N*}}{2\bar{v}(\theta(\tau-1)-1)}$	
Used-product price	$p_s^{N*} = \frac{\theta\left(\hat{v}^{N*}(\alpha+\theta(1-\tau))-\bar{v}(\alpha-\theta)\right)}{2(\alpha+\theta(1-\tau))}$	
Used-product demand	$d_s^{N*} = \frac{\theta^2(\tau-1)\left(\bar{v}+\hat{v}^{N*}(\tau-1)\right)-\theta\bar{v}(\tau+2)+3\bar{v}-\hat{v}^{N*}}{4\bar{v}(1-\theta)(1+\theta(1-\tau))}$	
Profit	$\pi_1^{N*} = \frac{\beta\Lambda_{p_1^N}\left(\bar{v}-\hat{v}^{N*}\right)}{4\bar{v}(1+\theta(1-\tau))}$	$\pi_2^{N*} = \frac{\beta\left(\hat{v}^{N*}(1+\theta(1-\tau))+\bar{v}(1-\theta)\right)^2}{8\bar{v}(1+\theta(1-\tau))}$
Total Profit	$\pi^{N*} = \frac{\beta\Lambda_{p_1^N}\left(\bar{v}-\hat{v}^{N*}\right)}{4\bar{v}(1+\theta(1-\tau))} + \frac{\beta\left(\hat{v}^{N*}(1+\theta(1-\tau))+\bar{v}(1-\theta)\right)^2}{8\bar{v}(1+\theta(1-\tau))}$	

Note. $\Lambda_{p_1^N} = \beta\theta^2(\tau-1)\left(\hat{v}^{N*}(\tau-1)-3\bar{v}\right)+\theta\left(\beta\bar{v}\left(3\tau-2\right)-8\hat{v}^{N*}(\tau-1)\right)-\beta\left(\bar{v}+\hat{v}^{N*}\right)+8\hat{v}^{N*}$.

early-adopters, quantified as $\frac{v_{rp,k}^{N*}-\hat{v}^{N*}}{\bar{v}}$, choose to keep V1, an outcome referred to as the demand vanishing effect. The magnitudes of the demand migration effect (followers who initially anticipated leaving the market but instead purchase used V1) and the demand expansion effect (followers who anticipated leaving but instead purchase new V1) are $\frac{v_{n,s}^{N*}-v_{s,l}^{N*}}{\bar{v}}$ and $\frac{\hat{v}^{N*}-v_{n,s}^{N*}}{\bar{v}}$, respectively.

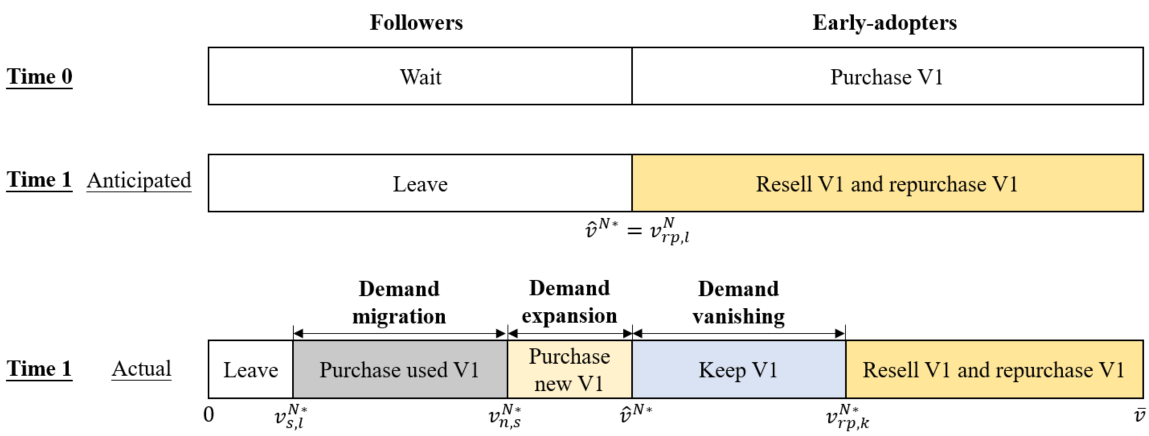


Figure 5.9: Anticipated and actual market segmentation of scenario N

5.5.1 Impacts on Manufacturer's Profit

Based on the performance outcomes of two situations - one in which the manufacturer releases the upgraded version (main model) and the other in which it does not (scenario N) - we conduct a comparative investigation to examine the impact of the manufacturer's product upgrade strategy. Lemma 5.10 presents the changes in demand effects when comparing the main model with scenario N.

Lemma 5.10. *In the presence of CRP, if consumers are time-inconsistent, the demand effects change when the manufacturer sequentially launches different versions compared to consistently launching the same version as follows:*

1. *demand vanishing decreases, i.e.,* $d_{vanishing} < d^N_{vanishing}$*;*

2. *demand expansion increases when the extent of time inconsistency is low, i.e.,* $d_{expansion} > d^N_{expansion}$ *if* $\beta > \tilde{\beta}^N_{expansion}(\bar{v}, \theta, \alpha, \tau)$*; otherwise, demand expansion decreases;*

3. *demand migration increases, i.e.,* $d_{migration} > d^N_{migration}$*.*

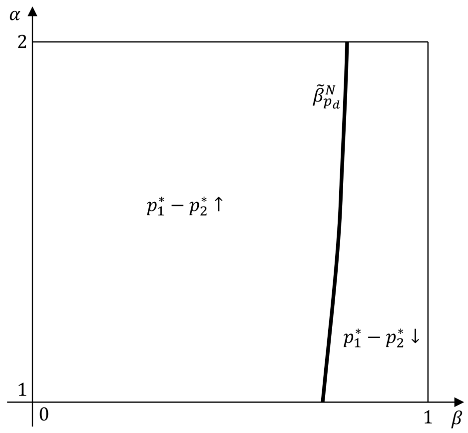
In contrast to the scenario where the manufacturer consistently launches the same version, the impact of time inconsistency is more positive when the manufacturer sequentially introduces different versions. Specifically, we note a reduction in the demand vanishing effect and an increase in the demand migration effect. Recall that the demand vanishing effect refers to early-adopters who anticipate reselling V1 at time 0 but transfer to keeping it at time 1. It is intuitive that repurchasing V1 is less attractive compared to purchasing V2 after reselling. As such, the demand vanishing effect in scenario N is more pronounced than it in the main model. Moreover, the demand migration effect refers to followers who anticipate the outside option at time 0 but transfer to purchasing used V1 on the CRP at time 1. In scenario N, used V1 on the CRP competes with new V1 provided by the manufacturer, whereas in the main model, it competes with new V2 provided by the manufacturer. In the latter case, higher vertical differentiation gives V2 a competitive advantage over used V1, leading to a lower transaction price on the CRP for used V1, i.e., $p_s^* < p_s^{N*}$. Consequently, the demand migration effect increases in the main model compared to scenario N.

Furthermore, the demand expansion effect increases when the extent of time inconsistency is low, i.e., $\beta > \tilde{\beta}^N_{expansion}$. Note that the demand expansion effect refers to followers who anticipate the outside option at time 0 but transfer to purchasing from the manufacturer at time 1. For followers, it is intuitive that purchasing V1 is less attractive compared to purchasing V2, resulting in a more pronounced demand expansion effect in the main model. However, if the extent of time inconsistency is high, i.e., $\beta \leq \tilde{\beta}^N_{expansion}$, intensified disparities in intertemporal utilities among consumers lead them to prefer the lower-priced option - purchasing V1 in scenario N compared to purchasing V2 in the main model, as detailed in the following Proposition. Proposition 5.4 demonstrates the influence of the product upgrade strategy on the manufacturer's pricing and demand when consumers are time-inconsistent.

Proposition 5.4. *In the presence of CRP, if consumers are time-inconsistent, when the manufacturer launches different versions compared to when it consistently launches the same version, the manufacturer's:*

1. *prices in the two periods both increase;*
2. *intertemporal price discrimination exacerbates if the extent of time inconsistency is high, i.e.,* $p_1^* - p_2^* \geq p_1^{N*} - p_2^{N*}$ *when* $\beta < \tilde{\beta}^N_{pd}(\theta, \alpha, \tau)$ *and* $\tilde{\beta}^N_{pd}(\theta, \alpha, \tau)$ *is defined in Appendix C.5, but mitigates otherwise;*
3. *period-one demand decreases and period-two demand increases;*
4. *total demand increases.*

Recall that if the manufacturer introduces an upgraded version in the later period, the market witnesses a threefold vertical product competition. Firstly, compe-



Notes. $\downarrow$ *indicates "worsens" and* $\uparrow$ *indicates "improves";* $\theta = 0.6$ *and* $\tau = 0.1$.

Figure 5.10: Effects of product upgrade on price discrimination in the presence of CRP

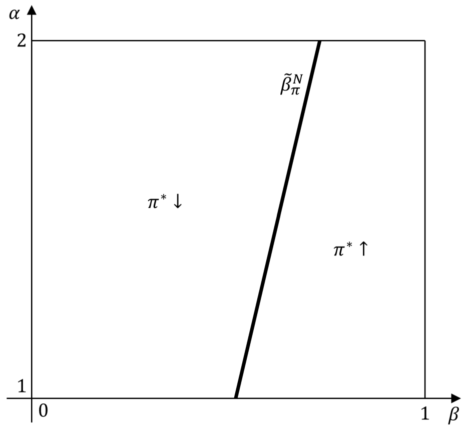
tition emerges between different versions of new products across periods, namely the original version and the upgraded version. Secondly, competition arises between used original version and new upgraded version in period two. Lastly, there is competition between used and new original products across periods. On the contrary, if the manufacturer consistently releases the same version, competition is confined to the realm of used and new original version.

Our result shows that, the presence of time-inconsistent behavior among consumers allows the manufacturer to raise prices in both periods while receiving higher total demand. As indicated by Lemma 5.10, the manufacturer can alleviate the negative impact of time inconsistency by leveraging the release of the upgraded version as a buffer against consumers' time-inconsistent behavior. To effectively exploit the demand effects arising from time inconsistency, the manufacturer exacerbates price discrimination when the extent of time inconsistency is high, i.e., $\beta < \tilde{\beta}^N_{p_d}$, as illustrated in Figure 5.10. Simultaneously, the competitive advantage of the upgraded version also prompts more consumers to postpone their purchases in period one and opt for the upgraded version in period two. These factors contribute to lower period-one demand and higher period-two demand in the main model compared to scenario

N.

Proposition 5.5 states the manufacturer's product upgrade strategy on its profitability.

Proposition 5.5. *In the presence of CRP, if consumers are time-inconsistent, the manufacturer's profit improves when it launches different versions across periods compared to when it launches the same version, given a low level of time inconsistency, i.e.,* $\beta \geq \tilde{\beta}_{\pi}^{N}(\bar{v}, \theta, \alpha, \tau, K)$*, where* $\tilde{\beta}_{\pi}^{N}(\bar{v}, \theta, \alpha, \tau, K)$ *is defined in Appendix C.5. Otherwise, the manufacturer's profit diminishes.*



Notes. $\downarrow$ *indicates "worsens" and* $\uparrow$ *indicates "improves";* $\bar{v} = 1$*,* $\theta = 0.6$*,* $\alpha = 1.2$*, and* $\tau = 0.1$*.*

Figure 5.11: Effects of product upgrade on manufacturer's profit in the presence of CRP

Referring to Lemma 5.10, it is observed that demand expansion reduces with strengthened extent of time inconsistency. In instances where the time inconsistency level is high, i.e., $\beta < \tilde{\beta}_{\pi}^{N}$, the excessive reduction in demand expansion outweighs the decrease in demand vanishing and the increase in demand migration. This results from the exacerbated intertemporal price discrimination, which consequently leads to a significant reduction in period-one demand. Thus, it negatively impacts the manufacturer's profit. As Figure 5.11 illustrated, only when the time inconsistency level is above the threshold $\tilde{\beta}_{\pi}^{N}$, the manufacturer's profit increases. At this point, the demand effects influenced by the existence of time inconsistency are shifting in a positive direction due to the manufacturer's product upgrade strategy.

5.5.2 Optimal Release Strategy of Product Upgrade

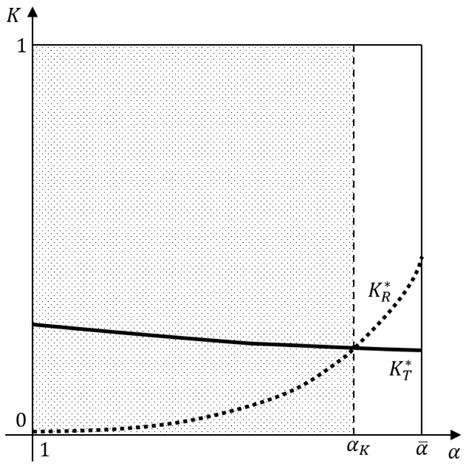
This section investigates whether the manufacturer should release the upgraded version in response to consumers' time-inconsistent purchasing behavior with the existence of CRP. We construct a benchmark scenario O to investigate the equilibrium outcomes when the manufacturer introduces same versions to the market in two consecutive periods, and consumers are rational, i.e., $\beta = 1$ and $\alpha = 1$. The equilibrium for scenario O is summarized in Table 5.11. By conducting a comparative analysis of the manufacturer's profit across different scenarios, we offer valuable insights for the manufacturer on releasing product upgrades.

Table 5.11: Equilibrium outcomes of scenario O

	Period one	Period two
New-product price	$p_1^{O*} = \frac{\hat{v}^{O*}(\theta(5-\tau)+1)+\bar{v}(1-\theta)}{4}$	$p_2^{O*} = \frac{\hat{v}^{O*}(1+\theta(1-\tau))+\bar{v}(1-\theta)}{4}$
New-product demand	$d_1^{O*} = \frac{\bar{v}-\hat{v}^{O*}}{\bar{v}}$	$d_2^{O*} = \frac{\hat{v}^{O*}(1+\theta(1-\tau))+\bar{v}(1-\theta)}{2\bar{v}(1+\theta(1-\tau))}$
Total demand	$d^{O*} = \frac{\theta\left(\bar{v}(2\tau-1)+\hat{v}^{O*}(1-\tau)\right)-3\bar{v}+\hat{v}^{O*}}{2\bar{v}(1+\theta(1-\tau))}$	
Used-product price	$p_s^{O*} = \frac{\theta\left(\hat{v}^{O*}(1+\theta(1-\tau))-\bar{v}(1-\theta)\right)}{2(1+\theta(1-\tau))}$	
Used-product demand	$d_s^{O*} = \frac{\theta^2(\tau-1)\left(\bar{v}+\hat{v}^{O*}(\tau-1)\right)-\theta\bar{v}(\tau+2)+3\bar{v}-\hat{v}^{O*}}{4\bar{v}(\theta-1)(\theta(\tau-1)-1)}$	
Profit	$\pi_1^{O*} = \frac{\left(\bar{v}-\hat{v}^{O*}\right)\left(\hat{v}^{O*}(\theta(5-\tau)+1)+\bar{v}(1-\theta)\right)}{4\bar{v}}$	$\pi_2^{O*} = \frac{\left(\hat{v}^{O*}(1+\theta(1-\tau))+\bar{v}(1-\theta)\right)^2}{8\bar{v}(1+\theta(1-\tau))}$
Total Profit	$\pi^{O*} = \frac{\left(\bar{v}-\hat{v}^{O*}\right)\left(\hat{v}^{O*}(\theta(5-\tau)+1)+\bar{v}(1-\theta)\right)}{4\bar{v}} + \frac{\left(\hat{v}^{O*}(1+\theta(1-\tau))+\bar{v}(1-\theta)\right)^2}{8\bar{v}(1+\theta(1-\tau))}$	

Proposition 5.6 demonstrates the conditions of the investment cost parameter K for the manufacturer to benefit from releasing the upgraded version in the later period. Table 5.12 explains how to derive the thresholds in Proposition 5.6.

Proposition 5.6. *In the presence of CRP, when consumers are time-inconsistent, the manufacturer releases the upgraded version if the investment cost parameter is low,* *i.e., $K < K_T^*(\beta, \theta, \alpha, \tau)$; otherwise, the manufacturer continues selling the original version if $K \geq K_T^*(\beta, \theta, \alpha, \tau)$. In addition, when consumers are rational, the manufacturer releases the upgraded version if the investment cost parameter is low, i.e., $K < K_R^*(\theta, \alpha, \tau)$; otherwise, the manufacturer continues selling the original version if $K \geq K_R^*(\theta, \alpha, \tau)$.*



Notes. $\beta = 0.6$, $\theta = 0.6$, *and* $\tau = 0.1$.

Figure 5.12: Conditions of K for manufacturer to release the upgraded version

Table 5.12: Comparative matrix for K-threshold

	Time-inconsistent consumers	Rational consumers
Release the upgraded version	Main model	Scenario R
Do not release the upgraded version	Scenario N	Scenario O
K-threshold	$\pi = \pi^N \Rightarrow K_T^*$	$\pi^R = \pi^O \Rightarrow K_R^*$

By comparing the profit in the main model with that in scenario N, we can derive a threshold K_T^* for the investment cost parameter in the scenario where consumers exhibit time-inconsistent behavior. Similarly, the threshold K_R^* is obtained through a comparison of profits between scenarios R and O when consumers exhibit rational behavior. Figure 5.12 provides an illustrative example of K_T^* and K_R^*. When K falls below these thresholds, i.e., $\pi > \pi^N$ and $\pi^R > \pi^O$, the competitive advantage of the upgraded version benefits the manufacturer, thereby reducing competition from the used original products offered by the C2C resale market. The differentiation between versions leads to distinct products offerings in both the new and used markets, each catering to specific consumer segments. As a result, the manufacturer is inclined to release the upgraded version. Conversely, when K exceeds the thresholds, i.e., $\pi \leq \pi^N$ and $\pi^R \leq \pi^O$, the manufacturer opts to continue selling the original version across periods.

Moreover, we find that $\frac{\partial K_T^*}{\partial \alpha} < 0$ and $\frac{\partial K_R^*}{\partial \alpha} > 0$. This indicates that as the competitiveness of the upgraded version increases, the K-threshold exhibits different trends when consumers are either time-inconsistent or rational. Specifically, K_T^* slightly decreases with α, while K_R^* drastically increases with α. Corollary 5.1 compares the thresholds of K, demonstrating the conditions under which the manufacturer will release the upgraded version in the presence of time inconsistency.

Corollary 5.1. *The thresholds of K for time-inconsistent and rational consumers satisfies that:*

1. *when the differentiation level between product versions is low, i.e., $\alpha < \alpha_K$, the threshold of K for time-inconsistent consumers exceeds that of rational consumers, i.e., $K_T^*(\beta, \theta, \alpha, \tau) > K_R^*(\theta, \alpha, \tau)$;*

2. *when the differentiation level between product versions is high, i.e., $\alpha \geq \alpha_K$, the threshold of K for time-inconsistent consumers is less than that of rational consumers, i.e., $K_T^*(\beta, \theta, \alpha, \tau) \leq K_R^*(\theta, \alpha, \tau)$.*

When the upgraded version and the original version share more similar experiential features, i.e., $\alpha < \alpha_K$, we find that $K_T^* > K_R^*$. It shows that the threshold of the investment cost parameter K for the manufacturer to benefit from releasing the upgraded version is higher when consumers are time-inconsistent compared to when consumers are rational. As such, the manufacturer tends to release the upgraded version to get higher profit when dealing with time-inconsistent consumers compared to rational ones, referring to the spotted area in Figure 5.12. In this scenario, we demonstrate that time inconsistency introduces an *assistance effect*, facilitating the release of the upgraded version. The manufacturer leverages time inconsistency to differentiate product versions and mitigate competition from the CRP. By contrast, when the experiential features of the upgraded version and the original version become more distinct, i.e., $\alpha \geq \alpha_K$, $K_T^* \leq K_R^*$ exists, as the blank area shown in Figure 5.12. In this situation, the K-threshold for the manufacturer to benefit from releasing the upgraded version is lower when consumers are time-inconsistent compared to when consumers are rational. The manufacturer is more inclined to withhold the upgraded version to avoid profit reduction when time inconsistency exists, referred to as *deterrent effect*. In such instances, the manufacturer favors utilizing the original version to consolidate its established market and pursue a higher monopolistic position.

5.6 Theoretical Contribution and Managerial Implication

Chapter 5 combines the product perspective (product upgrades) with the consumer perspective (time-inconsistent behavior) to analyze the manufacturer's optimal dynamic pricing strategy and optimal product upgrade launch strategy for new products in the presence of CRP. Theoretical contribution and managerial implication of this chapter are as follows.

(1) Theoretical Contribution

This chapter incorporates consumers' time-inconsistent behavior into the theoretical framework of C2C resale markets and highlights the strategic significance of exploiting consumers' time-inconsistent behavior within the context of C2C Resale market, which is scarcely investigated in the literature. First, contradicting previous literature that suggests time inconsistency imposes limitations on firms' profit potential (Gilpatric 2009), our results identify the circumstances where the manufacturer can benefit from exploiting consumers' time-inconsistent behavior in the presence of the C2C resale market. We demonstrate that three demand effects - demand vanishing, demand expansion, and demand migration - emerge as the manufacturer employs tailored pricing and manages its product launches across periods. The manufacturer can profitably leverage the existence of CRP to mitigate the negative impact of consumers' time-inconsistent biases and create a more distinct market segmentation. Second, in contrast to Yin et al. (2010), which indicates that the C2C resale market always deters the release of the upgraded version, our results reveal different dynamics. We demonstrate that an assistant effect and a deterrent effect jointly shape the manufacturer's decision-making regarding product upgrade and are contingent on the differentiation level between product versions. Our findings offer theoretical support for manufacturers to strategically navigate their decisions in response to the challenges posed by consumers' time inconsistency.

(2) Managerial Implication

This chapter provides operational-level managerial guidance for manufacturers on adjusting prices and launching product upgrades in response to consumers' time inconsistency. The misestimation of intertemporal utilities leads to inconsistent consumer behavior, giving rise to three demand effects to the manufacturer: demand vanishing, demand migration, and demand expansion. Crucially, demand vanishing exerts a negative impact on the manufacturer's demand, while demand expansion and migration have positive effects. The heightened levels of time inconsistency exacerbate the discrepancies in consumers' misestimation of intertemporal utilities. Moreover, the increased differentiation level between product versions provides the manufacturer with a competitive advantage over the CRP. We alert manufacturers to pay attention to these two factors to effectively manage the magnitude of demand effects. Despite consumers' time-inconsistent behavior may intensify the competition brought by CRPs, manufacturers can still profit by leveraging C2C resale markets to alleviate the negative impact of consumers' misestimation of intertemporal utilities. Additionally, we advise manufacturers facing time-inconsistent consumers to carefully assess the differentiation level between product versions to determine whether to release the upgraded version. Specifically, when the upgraded version closely resembles the original version in experiential features, we encourage manufacturers to release the upgraded version to enhance profits. Conversely, when the experiential features of the upgraded version significantly diverge from those of the original version, we suggest continuing the release of the original version to avoid profit reduction.

5.7 Concluding Remarks

This chapter examines consumers' time-inconsistent behavior and analyzes the manufacturer's optimal dynamic pricing strategy and optimal product upgrade launch strategy in the presence of CRP. Our findings addressing the research questions proposed in Section 5.2 are outlined as follows. First, we identify three distinct demand effects - demand vanishing, demand expansion, and demand migration - regarding the impact of consumers' time-inconsistent behavior on market segmentation. Additionally, time inconsistency shrinks the available range where secondary transaction of used original products function. Second, in comparison to the scenario where consumers are rational, the manufacturer reduces prices at most cases due to consumers' time-inconsistent behavior, which intensifies the competition brought by C2C resale market. By contrast, compared to the scenario where the manufacturer does not release the upgraded version, the manufacturer can increases prices in the two periods while receiving higher total demand when it launches different product versions. In both cases, the manufacturer can profit and leverage time inconsistency to its advantage, particularly when the extent of time inconsistency is low. Third, an assistant effect and a deterrent effect jointly shape the manufacturer's decision-making regarding product upgrade and are contingent on the differentiation level between product versions. Chapter 5 highlights the strategic significance of exploiting consumers' time-inconsistent behavior for manufacturers from the operational level within the context of C2C Resale, which is scarcely investigated in the literature.

Chapter 6

Conclusion

6.1 Research Summary

Against the backdrop of circular economy and collaborative consumption, C2C resale markets have come into existence to connect individual consumers, by offering them a channel to participate in resale activities and facilitating the matching of supply and demand of used products. To cater to such a market trend, enterprises are adjusting their operational decisions. This thesis proposes a series of stylized models to analytically examine enterprises' optimal dynamic pricing strategy for new products in the presence of C2C resale markets. The objective is to offer decision-makers with operational-level managerial guidance. The major findings and managerial implications of this thesis are outlined below.

First, considering secondhand product characteristics, Chapter 3 investigates how retailers should dynamically adapt new product prices to the presence of CRP, along with the implications for consumers, society, and the environment. Our results shed novel light on managing new-product selling by the retailer in parallel to used-product transactions sustained on the CRP to improve the efficiency of product distribution. The main results include three parts:

1. We find that the retailer adopts a skimming policy to set prices over periods but adapts intertemporal price discrimination to align with the rise of CRP as a channel for used-product transactions. The extent of intertemporal price discrmination is related to consumers' perceived values of used products. When the market is dominated by the consumers perceiving the used product to be a peach, the retailer mitigates intertemporal price discrimination to deter consumers' strategic waiting. By contrast, with heterogeneity among consumers in perceiving used-product valuations, the presence of CRP entices the retailer to exacerbate intertemporal price discrimination. It results in an increase in new-product demand in both periods, generating a demand-expansion effect. The retailer benefits from the rise of CRP when consumers perceive a medium value from used-product consumption - that is, when consumers perceive certain discrepancies between the values of new and used products, and the demand-expansion effect is significant.

2. The presence of CRP benefits the retailer whenever it makes the consumers better off in most circumstances. Thus, the retailer and the consumers are likely to hold the same preference over the establishment of CRP, which competes with the retailer for demand but offers the consumers more opportunities to purchase or resell. In the situation where the retailer and the consumers benefit from CRP, the commission revenue reaped by the CRP through used-product transactions further contributes to an improvement in social welfare, leading to a win-win situation for all market participants. Nevertheless, against the intention for the CRP to support enterprises' and consumers' environmental-friendly ethos, the demand-expansion effect aggravates the negative impact on the environment. Thus, we suggest practitioners can positively impact the environment and cultivate a green image by proactively changing their operations and focusing on long-term benefits.

3. We have managed several extensions to unfold additional insights into the CRP.

Firstly, absent CRP, the existence of the option for consumers to dispose of used products to receive a positive salvage value benefits the retailer by yielding more demands for new products in both periods, while it harms the environment by increasing product volume. Furthermore, the disposal option to a large extent weakens the value of CRP in improving the retailer's revenue, since the salvage option is a substitute to CRP in dealing with used products. Secondly, as new consumers arrive in period two, despite all pre-owned consumers choose to resell rather than keep their products, the demand for new product in period two when CRP is present can still be lower than when CRP is absent. The patterns for prices and revenue are consistent with those in the main model. Thirdly, endogenizing the commission rate by a revenue-maximizing CRP can benefit the retailer. Fourthly, multiple symmetric CRPs can be viewed similarly as a holistic monopolistic CRP, which does not change the fundamental qualitative nature of the results.

Second, considering consumers' utility-dependent behavior due to repeat purchases, Chapter 4 delves into the retailer's optimal dynamic pricing strategy for new products and collaboration strategies between retailers and CRPs. By selling their used products in C2C resale markets, consumers can receive a resale value and then repurchase new products due to their utility dependence. Retailers adapt to the existence of utility dependence ushered in by the rise of CRPs to attract more demand. This study is framed in a two-period setting to explore the profits for the retailer and the CRP, consumer surplus, and social welfare. The goal is to generate insights into the value of CRPs on system performances, as consumers experience utility dependence. The primary results are summarized in three points:

1. Similar to Chapter 3, the retailer adheres to a skimming policy to set prices over periods. However, as consumers experience utility dependence, the rise of CRP always exacerbates the retailer's intertemporal price discrimination, en-

couraging consumers to strategically wait. The presence of utility dependence helps mitigate the direct competition between the retailer and the CRP, since it drives consumers to repurchase new products after ridding of used ones, which compensates for the demand that the platform takes away from the retailer. The retailer's intertemporal pricing strategy produces a cannibalization effect to harm the retailer's revenue in the early period but an enhancement effect to improve it in the later period. In most situations, the enhancement effect dominates, enabling the retailer to benefit from the rise of CRP. However, if consumers perceive a high value in consuming new products and the CRP's commission rate is high, the cannibalization effect is strong to cause a revenue loss to the retailer. We recommend that practitioners take advantage of consumers' heterogeneities regarding the quality levels of used products and their utility dependence from repeat purchases to enhance profit performance.

2. As consumers experience utility dependence, the rise of CRP benefits the retailer wherever it makes consumers better off, and it harms consumers whenever it worsens the retailer's revenue. Therefore, while the platform competes with the retailer for demand and provides consumers with additional purchase choices, channels, and rewards, the retailer and consumers can still be influenced in the same fashion by its emergence. Nevertheless, the CRP exerts opposing effects on the retailer and consumers in certain circumstances. Utility dependence grants the retailer enhanced power in demand management, making it more likely for the retailer to benefit from the presence of CRP than consumers. Even in the situation where either the retailer, or consumers, or both are harmed by the rise of CRP, the commission revenue reaped by the CRP through used-product transactions can result in an improved social welfare. We thus alert industry managers to market conditions to achieve a win-win situation, under which the CRP functions as a distribution channel to affect demand generation for new and used products and influences the allocation of revenue reaped from

new-product selling and used-product transactions.

3. We explore the collaboration strategies whereby retailers partner with the CRP to generate additional insights. The retailer benefits from self-managing a CRP when the marginal operating cost is low. Moreover, we show that offering a discount for repeat consumers is not an efficient revenue-enhancing instrument because it curbs the sales to waited consumers to harm the retailer's revenue. Furthermore, as a revenue-maximizing CRP sets the commission rate, the retailer can reap a higher revenue than in the absence of CRP when consumers perceive a low value from new-product consumption. Our findings provide valuable guidance for industrial practitioners on the collaboration with CRPs.

Third, considering consumers' time-inconsistent behavior, chapter 5 investigates the manufacturer's optimal dynamic pricing and optimal product upgrade strategies for new products. The prevalence of time inconsistency presents a unique challenge for manufacturers, particularly those with innovation agendas, in the situation where C2C resale markets have become a commonplace shopping channel for consumers. The aim is to offer valuable insights into how manufacturers can enhance their operational performance when consumers exhibit time-inconsistent behavior. The main results are as follows:

1. We clarify how time inconsistency affects consumers' current and future product consumption in the presence of CRP. Consumers tend to precisely estimate the resale revenue while often overestimating other payments and payoffs at the present time. This misestimation of intertemporal utilities leads to inconsistent consumer behavior, giving rise to three demand effects to the manufacturer: demand vanishing, demand migration, and demand expansion. Crucially, demand vanishing exerts a negative impact on the manufacturer's demand, while demand expansion and migration have positive effects. The heightened levels of time inconsistency exacerbate the discrepancies in consumers' misestimation

of intertemporal utilities. Moreover, the increased differentiation level between product versions provides the manufacturer with a competitive advantage over the CRP. These two factors interact dynamically, influencing the magnitude of the three demand effects accordingly.

2. The firm strategically utilizes consumers' time-inconsistent biases to shape market segmentation, employing tailored pricing strategies and managing its product launches across periods. Counter-intuitively, even with the introduction of an upgraded version in the later period, the firm follows a decreasing pricing trajectory in the two periods when consumers display time-inconsistency. Moreover, in comparison to the scenario where consumers are rational, the manufacturer reduces prices at most cases due to consumers' time-inconsistent behavior, which intensifies the competition brought by the C2C resale market. By contrast, compared to the scenario where the manufacturer does not release the upgraded version, the manufacturer can increases prices in the two periods while receiving higher total demand when it launches different product versions. In both cases, the manufacturer can profit and leverage time inconsistency to its advantage, particularly when the extent of time inconsistency is low. Furthermore, we highlight how time inconsistency influences the platform's position in setting the commission rate to sustain a balanced secondhand market. Our study constructs a comprehensive understanding of the dynamics surrounding time inconsistency and its implications for enterprises.

3. We add evidence to manufacturers regarding the optimal release strategy for sequentially launching different product versions. When the upgraded version closely resembles the original version in experiential features, the firm tends to release the upgraded version in the presence of time-inconsistent consumers, a phenomenon termed the assistance effect. Conversely, a deterrent effect is observed when the experiential features of the upgraded version significantly diverge from those of the original version. In such case, the firm is less likely to

release the upgraded version when time inconsistency exists. Thus, we advise manufacturers facing time-inconsistent consumers to carefully assess the differentiation level between product versions to determine whether to release the upgraded version.

6.2 Innovation and Contribution

Key innovative contributions of this thesis contain four parts.

First, in the presence of C2C resale markets, the intertemporal price discrimination adopted by monopolists for new products is influenced by the extent of heterogeneity in used products. When the heterogeneity of used products is high, the existence of C2C resale markets leads enterprises to exacerbate intertemporal price discrimination for new products to encourage consumers' strategic waiting. This contrasts with prior literature, which discourage discriminatory pricing over time by a monopolist when selling to strategic consumers (Coase 1972; Stokey 1979; Besanko & Winston 1990; Liu & Zhang 2013). The presence of C2C resale markets expands the purchase options for consumers, granting them the liberty of deciding when to purchase (period one versus period two), what to purchase (new products versus used products), and where to purchase (enterprises versus CRPs), forcing enterprises to dynamically adapt prices to suit the market change thus occurs. Consumers' heterogeneities play a vital role in shaping market dynamics. However, existing literature assume a homogeneous perceived value of used products among consumers (Yin et al. 2010; L. Jiang et al. 2017), which does not align with the nature of secondhand transactions based on the C2C mode. Our research incorporates consumers' heterogeneities in their valuations for both new and secondhand products. We emphasize the relationship between secondhand product heterogeneity and intertemporal price discrimination for new products. These findings enrich the literature on optimal dynamic pricing strategy by offering novel insights.

Second, this study systematically examines the effects of C2C resale on all market participants, including consumers, enterprises, platforms, as well as society and the environment. In the presence of C2C resale markets, consumers can strategically play the role of individual suppliers, postponed demanders, or repeat purchasers. These behaviors interactively influence the demand for both new and used products, thereby affecting the role of CRP in the marketplace. Existing literature suggest that CRPs expose enterprises to direct competition and cannibalize new-product demand (P. Desai et al. 2004; Yin et al. 2010). However, our research indicates that the existence of C2C resale transactions results in an increase in the total demand for new products, referred to as the demand-expansion effect. Enterprises can profit from managing new-product selling over periods in parallel to support used-product transactions on the platform, rather than competing with the platform for demand. Moreover, consumers and enterprises are likely to either benefit or get worse simultaneously from the rise of the C2C resale market, thus to have aligned preferences over the establishment of this new market entity. Whenever both consumers and enterprises are better off, the revenue reaped by the platforms strengthens the gain in social welfare, leading to a win-win situation for all market participants. In contrast to prior works (Xue et al. 2018; Vedantam et al. 2021), our result indicates that the demand-expansion effect aggravates the environmental impact brought by C2C resale markets, counteracting the original intention of creating an efficient and sustainable consumption mode to eliminate negative environmental impacts. This study clarifies the intricate impacts of C2C resale markets on market participants, society, and the environment. Our work identifies the conditions under which CRPs can create a win-win situation for all market participants and contributes to the literature on secondary markets by conducting a comprehensive investigation into the C2C mode.

Third, this research incorporates two behavioral factors, namely consumers' utility-dependent and time-inconsistent behaviors, into the research framework of C2C resale markets. Despite these behaviors significantly influence consumers' purchasing decisions (Moshkin & Shachar 2002; Meyer et al. 2008), there remain arguable issues regarding their effects in C2C resale transactions. Existing studies have not conclusively provided theoretical support in this regard. Our results demonstrate that, as a result of enhanced demand management, consumers' utility dependence mitigates the direct competition posed by CRPs to retailers. By leveraging the heterogeneities in consumers' utility dependence and perceived quality levels of used products, retailers can effectively exacerbate intertemporal price discrimination. This pricing strategy allows retailers to alternate and balance the demands for new and used products, producing an enhancement effect and a cannibalization effect on revenue. Furthermore, the presence of time inconsistency generates three distinct demand effects on market segmentation: demand vanishing, demand expansion, and demand migration. Despite consumers' time-inconsistent behavior may intensify the competition brought by CRPs, manufacturers can still profit by leveraging C2C resale markets to alleviate the negative impact of consumers' misestimation of intertemporal utilities. To the best of our knowledge, this work is the first analytical study to investigate the implications of utility dependence and time inconsistency on C2C resale dynamics. We propose the optimal dynamic pricing strategy considering consumers' utility dependence and time inconsistency in the presence of C2C resale markets. Moreover, we reveal how these two behaviors shape market segmentation and influence enterprises' operational decisions. Our findings fill the gap in the literature and offer valuable insights for enterprises to navigate their strategic decisions in response to the emergence of CRPs, particularly in consideration of consumers' utility-dependent and time-inconsistent behaviors.

Fourth, our research provides operational-level managerial implications to supply chain members dealing with C2C resale markets. We identify the conditions under which retailers can profit from C2C resale transactions. We also provide theoretical guidance for retailers on collaborating with CRPs and for manufacturers on the optimal strategy for releasing product upgrades. Specifically, retailers can benefit when consumers perceive certain discrepancies in the values of new and used products, whereas they may experience revenue loss if the CRP charges a high commission rate. It justifies the observations in the electronic, automotive, home furnishing, and branded apparel industries, where retailers have embraced CRPs that sets low commission rates to facilitate used-product transactions among consumers. Moreover, retailers can benefit from self-managing a CRP when the marginal operating cost is low. However, offering price discounts to consumers who participate in C2C resale transactions is not an efficient revenue-enhancement strategy, as it reduces new product sales and negatively affects retailers' revenue. Additionally, we advise manufacturers to carefully evaluate the differentiation between product versions to determine whether to release the upgraded version. In contrast to Yin et al. (2010), which indicates that the C2C resale market always deters the release of the upgraded version, our results reveal different dynamics. We demonstrate that if the upgraded version closely resembles the original version in experiential features, manufacturers tend to release the upgraded version, termed the assistance effect. Conversely, if the experiential features of the upgraded version significantly diverge from those of the original version, manufacturers tend to keep selling the original version, termed the deterrent effect. These findings bridge the theoretical aspects of our research with real-world practices and offer valuable guidance for supply chain members operating in the context of C2C resale markets.

6.3 Limitation and Future Research

Our work is not without limitations, which suggest promising future studies.

Firstly, this study does not account for the information asymmetry between supply-side and demand-side consumers, nor does it address the issue of adverse selection in the C2C resale market. In practice, individual supply-side consumers are aware of the true quality of their secondhand products but may withhold this information. This allows them to exploit their information advantage, placing demand-side consumers at a disadvantage in secondhand transactions. Future research could investigate the impact of information asymmetry in C2C secondhand transactions in detail. Recently, some enterprises have implemented blockchain technology to provide quality guarantees for their products. Additionally, some CRPs offer authentication services for secondhand products traded on their platforms. Exploring strategies to mitigate adverse selection could also be an intriguing avenue for future studies.

Secondly, this work does not explicitly consider the costs incurred by market incumbents when engaging in secondhand transactions. Specifically, we ignore the cost incurred by the retailer or the manufacturer in selling to consumers, such as operational cost and shipping cost, as well as the costs incurred by the CRP in handling used-product transactions. Besides, it has practical relevance and importance to include into consideration the efforts exerted by consumers to search for products, used and new, through multiple channels and create product lists on the CRP. Incorporating these factors is likely to yield more practical insights into the functioning of C2C markets.

Thirdly, our current analysis is conducted within a monopoly setting for both the incumbent enterprise and the entrant CRP. However, a market structure characterized by duopoly or oligopoly enterprises or platforms can be another direction worth exploration. Though in Chapters 4 and 5 we respectively explore the horizontal and vertical differentiation of new products offered by a monopolist, we did not consider the impact of horizontal and vertical differentiation of new products among competitive enterprises. Additionally, despite in Chapter 3, we discuss an extension involving multiple competitive CRPs, the results of this scenario are obtained assuming that consumers lack any intrinsic preference for the CRPs prior to engaging in secondhand transactions, i.e., CRPs are symmetric. However, in reality, consumers may have inherent preferences for CRPs influenced by factors such as platform image and network externality. Exploring competitive enterprises and asymmetric CRPs could be interesting research directions in the future.

Fourthly, in Chapter 4, to isolate the effects of heterogeneities among consumers in perceiving the quality levels of used products and reaping utility dependence, we ignore the heterogeneity among them in valuing new product. Similarly, in Chapter 5, to explicitly investigate the impacts of consumers' time-inconsistent behavior, our study assumes uniform hyperbolic discounting across the entire consumer population. It is of potential interest to incorporate the heterogeneity of new-product value and the extent of time-inconsistency among consumers, respectively, into consideration and better connect this research to reality. Introducing these heterogeneities could enhance the practical applicability of the model. Additionally, integrating different features examined in separate chapters into a single study represents a promising direction for future research.

References

36Kr. (2023). *Qi shuya from xianyu: young consumers of xianyu are embracing "green consumption" habit.* Retrieved from https://www.36kr.com/p/2540412511643398

Abhishek, V., Guajardo, J. A., & Zhang, Z. (2021). Business models in the sharing economy: Manufacturing durable goods in the presence of peer-to-peer rental markets. *Information Systems Research*, *32*(4), 1450–1469.

Agrawal, V. V., & Bellos, I. (2017). The potential of servicizing as a green business model. *Management Science*, *63*(5), 1545–1562.

Agrawal, V. V., Ferguson, M., Toktay, L. B., & Thomas, V. M. (2012). Is leasing greener than selling? *Management Science*, *58*(3), 523–533.

Altug, M. S., & Aydinliyim, T. (2016). Counteracting strategic purchase deferrals: The impact of misc retailers' return policy decisions. *Manufacturing & Service Operations Management*, *18*(3), 376–392.

Anderson, S. P., & Ginsburgh, V. A. (1994). Price discrimination via second-hand markets. *European Economic Review*, *38*(1), 23–44.

AutoTrader. (2016). *Is automotive brand loyalty a myth?* Retrieved from https://plc.autotrader.co.uk/press-centre/news-hub/is-automotive-brand-loyalty-a-myth/

Aviv, Y., & Pazgal, A. (2008). Optimal pricing of seasonal products in the presence of forward-looking consumers. *Manufacturing & Service Operations Management*, *10*(3), 339–359.

Aviv, Y., Wei, M. M., & Zhang, F. (2019). Responsive pricing of fashion products: The effects of demand learning and strategic consumer behavior. *Management Science*, *65*(7), 2982–3000.

Bass, F. M. (1969). A new product growth for model consumer durables. *Management science*, *15*(5), 215–227.

Bass, F. M., & Bultez, A. V. (1982). A note on optimal strategic pricing of technological innovations. *Marketing Science*, *1*(4), 371–378.

Bass, F. M., Krishnan, T. V., & Jain, D. C. (1994). Why the bass model fits without decision variables. *Marketing science*, *13*(3), 203–223.

Bayus, B. L. (1992). The dynamic pricing of next generation consumer durables. *Marketing Science*, *11*(3), 251–265.

Belk, R. (2014). You are what you can access: Sharing and collaborative consumption misc. *Journal of Business Research*, *67*(8), 1595–1600.

Bellos, I., Ferguson, M., & Toktay, L. B. (2017). The car sharing economy: Interaction of business model choice and product line design. *Manufacturing & Service Operations Management*, *19*(2), 185–201.

Benjaafar, S., Kong, G., Li, X., & Courcoubetis, C. (2019). Peer-to-peer product sharing: Implications for ownership, usage, and social welfare in the sharing economy. *Management Science*, *65*(2), 477–493.

Besanko, D., & Winston, W. L. (1990). Optimal price skimming by a monopolist facing rational consumers. *Management Science*, *36*(5), 555–567.

Binmore, K., Rubinstein, A., & Wolinsky, A. (1986). The nash bargaining solution in economic modelling. *The RAND Journal of Economics*, 176–188.

Brown, S. L., & Eisenhardt, K. M. (1995). Product development: Past research, present findings, and future directions. *Academy of management review*, *20*(2), 343–378.

Bulow, J. I. (1982). Durable-goods monopolists. *Journal of Political Economy*, *90*(2), 314–332.

Bulow, J. I. (1986). An economic theory of planned obsolescence. *The Quarterly Journal of Economics*, *101*(4), 729–749.

Chen, J., Zhang, C., & Xu, Y. (2009). The role of mutual trust in building members' loyalty to a C2C platform provider. *International Journal of Electronic Commerce*, *14*(1), 147–171.

Chen, X., Huang, Q., & Davison, R. M. (2017). Economic and social satisfaction of buyers on consumer-to-consumer platforms: The role of relational capital. *International Journal of Electronic Commerce*, *21*(2), 219–248.

Chen, Y., & Yang, C. (2020). Synchronizing pricing and replenishment to serve forward-looking customers. *Naval Research Logistics*, *67*(5), 321–333.

Coase, R. H. (1972). Durability and monopoly. *The Journal of Law and Economics*, *15*(1), 143–149.

Cortez, K. (2021). *8 retailers that reward you for recycling clothes.* Retrieved from https://reviewed.usatoday.com/style/features/retailers-reward-recycling-clothes-programs

COS. (2023). *About COS resell.* Retrieved from https://www.cosresell.com/about

Cosguner, K., & Seetharaman, P. (2022). Dynamic pricing for new products using a utility-based generalization of the bass diffusion model. *Management Science*, *68*(3), 1904–1922.

Cui, Y., Duenyas, I., & Sahin, O. (2018). Pricing of conditional upgrades in the presence of strategic consumers. *Management Science*, *64*(7), 3208–3226.

DellaVigna, S., & Malmendier, U. (2004). Contract design and self-control: Theory and evidence. *The Quarterly Journal of Economics*, *119*(2), 353–402.

Desai, P., Koenigsberg, O., & Purohit, D. (2004). Strategic decentralization and channel coordination. *Quantitative Marketing and Economics*, *2*, 5–22.

Desai, P. S. (1997). Advertising fee in business-format franchising. *Management Science*, *43*(10), 1401–1419.

Desai, P. S., & Purohit, D. (1998). Leasing and selling: Optimal marketing strategies for a durable goods firm. *Management Science*, *44*(11-part-2), S19–S34.

Desai, P. S., & Purohit, D. (1999). Competition in durable goods markets: The strategic consequences of leasing and selling. *Marketing Science*, *18*(1), 42–58.

Dockner, E., & Jørgensen, S. (1988). Optimal pricing strategies for new products in dynamic oligopolies. *Marketing Science*, *7*(4), 315–334.

Dolan, R. J., & Jeuland, A. P. (1981). Experience curves and dynamic demand models: Implications for optimal pricing strategies. *Journal of Marketing*, *45*(1), 52–62.

Dubé, J.-P., Hitsch, G. J., & Rossi, P. E. (2010). State dependence and alternative explanations for consumer inertia. *The RAND Journal of Economics*, *41*(3), 417–445.

Dubé, J.-P., Hitsch, G. J., Rossi, P. E., & Vitorino, M. A. (2008). Category pricing with state-dependent utility. *Marketing Science*, *27*(3), 417–429.

eBay. (2023). *Selling fees of eBay.* Retrieved from https://www.ebay.com/help/selling/fees-credits-invoices/selling-fees?id=4822#section3

Ebert, J. E., & Prelec, D. (2007). The fragility of time: Time-insensitivity and valuation of the near and far future. *Management Science*, *53*(9), 1423–1438.

ECRC. (2023). *China's secondhand e-commerce market data report.* Retrieved from https://www.100ec.cn/zt/2023Sesscbg/

eMarketer. (2023). *Us resale forecast 2023.* Retrieved from https://www.emarketer.com/content/us-resale-forecast-2023

Erdem, T. (1996). A dynamic analysis of market structure based on panel data. *Marketing Science*, *15*(4), 359–378.

Fraiberger, S. P., & Sundararajan, A. (2017). Peer-to-peer rental markets in the sharing economy. *NYU Stern School of Business Research Paper*.

Frenken, K. (2017). Political economies and environmental futures for the sharing economy. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *375*(2095), 20160367.

Galperti, S., & Strulovici, B. (2014). Forward-looking behavior revisited: A foundation of time inconsistency. *Report, Northwestern University, Center for Mathematical Studies in Economics and Management Science Oct*.

Gilbert, S. M., & Jonnalagedda, S. (2011). Durable products, time inconsistency, and lock-in. *Management Science*, *57*(9), 1655–1670.

Gilpatric, S. M. (2009). Slippage in rebate programs and present-biased preferences. *Marketing Science*, *28*(2), 229–238.

Gruber, J., & Köszegi, B. (2001). Is addiction "rational"? theory and evidence. *The Quarterly Journal of Economics*, *116*(4), 1261–1303.

Guadagni, P. M., & Little, J. D. (1983). A logit model of brand choice calibrated on scanner data. *Marketing Science*, *2*(3), 203–238.

Gümüş, M., Ray, S., & Yin, S. (2013). Returns policies between channel partners for durable products. *Marketing Science*, *32*(4), 622–643.

Guo, Q., Chen, Y., & Huang, W. (2022). Dynamic pricing of new experience products with dual-channel social learning and misc review manipulations. *Omega*, *109*, 102592.

Gupta, S. (1988). Impact of sales promotions on when, what, and how much to buy. *Journal of Marketing Research*, *25*(4), 342–355.

Guseo, R., & Mortarino, C. (2014). Within-brand and cross-brand word-of-mouth for sequential multi-innovation diffusions. *IMA Journal of Management Mathematics*, *25*(3), 287–311.

Hall, N. G., & Liu, Z. (2023). Scheduling with present bias. *Production and Operations Management*.

Haws, K. L., Bearden, W. O., & Nenkov, G. Y. (2012). Consumer spending self-control effectiveness and outcome elaboration prompts. *Journal of the Academy of Marketing Science*, *40*, 695–710.

Heidhues, P., & Köszegi, B. (2010). Exploiting naivete about self-control in the credit market. *American Economic Review*, *100*(5), 2279–2303.

Hendel, I., & Lizzeri, A. (1999). Interfering with secondary markets. *The Rand Journal of Economics*, 1–21.

H&M. (2020). *COS launches resell to prolong the lifespan of preloved clothes.* Retrieved from https://hmgroup.com/news/cos-launches-resell-to-prolong-the-lifespan-of-preloved-clothes/

Hoch, S. J., & Loewenstein, G. F. (1991). Time-inconsistent preferences and consumer self-control. *Journal of Consumer Research*, *17*(4), 492–507.

Horsky, D. (1990). A diffusion model incorporating product benefits, price, income and information. *Marketing Science*, *9*(4), 342–365.

Horsky, D., Misra, S., & Nelson, P. (2006). Observed and unobserved preference heterogeneity in brand-choice models. *Marketing Science*, *25*(4), 322–335.

Huang, C. Y. (2011). Excess loyalty in misc retailing. *International Journal of Electronic Commerce*, *16*(2), 115–134.

IKEA. (2024a). *Circular hub, a second chance for ikea furniture.* Retrieved from https://www.ikea.com/in/en/campaigns/circular-hub-pub0ff1ab70

IKEA. (2024b). *Re-shop and re-use, pre-loved items, good for your pocket and good for the planet.* Retrieved from https://www.ikea.com/gb/en/offers/circular-hub-pub2eab7840

iResearch. (2023). *Research on e-commerce market trends and growth strategies of China.* Retrieved from https://report.iresearch.cn/report_pdf.aspx?id=4263

Jain, D. C., & Rao, R. C. (1990). Effect of price on the demand for durables: Modeling, estimation, and findings. *Journal of Business & Economic Statistics*, *8*(2), 163–170.

Jain, S. (2012). Self-control and incentives: An analysis of multiperiod quota plans. *Marketing Science*, *31*(5), 855–869.

Jain, S. (2019). Time inconsistency and product design: A strategic analysis of feature creep. *Marketing Science*, *38*(5), 835–851.

J.D. Power. (2020). *Brand loyalty increasing among new-vehicle buyers, J.D. Power finds.* Retrieved from https://www.jdpower.com/business/press-releases/2020-us-automotive-brand-loyalty-study

Jiang, B., & Tian, L. (2018). Collaborative consumption: Strategic and economic implications of product sharing. *Management Science*, *64*(3), 1171–1188.

Jiang, L., Dimitrov, S., & Mantin, B. (2017). P2P marketplaces and retailing in the presence of consumers' valuation uncertainty. *Production and Operations Management*, *26*(3), 509–524.

Kalish, S. (1983). Monopolist pricing with dynamic demand and production cost. *Marketing Science*, *2*(2), 135–159.

Kalish, S., & Lilien, G. L. (1983). Optimal price subsidy policy for accelerating the diffusion of innovation. *Marketing Science*, *2*(4), 407–420.

Kavadias, S., & Loch, C. H. (2003). Optimal project sequencing with recourse at a scarce resource. *Production and Operations Management*, *12*(4), 433–444.

King, R. C., Schilhavy, R. A., Chowa, C., & Chin, W. W. (2016). Do customers identify with our website? the effects of website identification on repeat purchase intention. *International Journal of Electronic Commerce*, *20*(3), 319–354.

Kirshner, S. N., Levin, Y., & Nediak, M. (2017). Product upgrades with stochastic technology advancement, product failure, and brand commitment. *Production and Operations Management*, *26*(4), 742–756.

Kivetz, R., & Simonson, I. (2002). Self-control for the righteous: Toward a theory of precommitment to indulgence. *Journal of Consumer Research*, *29*(2), 199–217.

Kornish, L. J. (2001). Pricing for a durable-goods monopolist under rapid sequential innovation. *Management Science*, *47*(11), 1552–1561.

Krishnamurthi, L., & Raj, S. (1988). A model of brand choice and purchase quantity price sensitivities. *Marketing Science*, *7*(1), 1–20.

Krishnan, T. V., Bass, F. M., & Jain, D. C. (1999). Optimal pricing strategy for new products. *Management science*, *45*(12), 1650–1663.

Krishnan, T. V., Bass, F. M., & Kumar, V. (2000). Impact of a late entrant on the diffusion of a new product/service. *Journal of marketing research*, *37*(2), 269–278.

Krishnan, V., & Ramachandran, K. (2011). Integrated product architecture and pricing for managing sequential innovation. *Management Science*, *57*(11), 2040–2053.

Kuang, Y., & Jiang, L. (2023). Managing presales with two payments and return policy when consumers are time-inconsistent. *Production and Operations Management*.

Laibson, D. (1997). Golden eggs and hyperbolic discounting. *The Quarterly Journal of Economics*, *112*(2), 443–478.

Lee, H., & Whang, S. (2002). The impact of the secondary market on the supply chain. *Management Science*, *48*(6), 719–731.

Levinthal, D. A., & Purohit, D. (1989). Durable goods and product obsolescence. *Marketing Science*, *8*(1), 35–56.

Levi's. (2024). *Levi's secondhand.* Retrieved from https://www.levi.com/US/en_US/blog/article/levis-secondhand

Li, H. (2020). Optimal pricing under diffusion-choice models. *Operations Research*, *68*(1), 115–133.

Li, H., & Huh, W. T. (2012). Optimal pricing for a short life-cycle product when customer price-sensitivity varies over time. *Naval Research Logistics*, *59*(7), 552–576.

Li, K. J. (2021). Behavior-based quality discrimination. *Manufacturing & Service Operations Management*, *23*(2), 425–436.

Li, L., & Jiang, L. (2022). How should firms adapt pricing strategies when consumers are time-inconsistent? *Production and Operations Management*, *31*(9), 3457–3473.

Li, T., Xie, J., & Liu, X. (2020). Consumer return policies in presence of a P2P market. *Omega*, *97*, 102092.

Liang, C., Çakanyıldırım, M., & Sethi, S. P. (2014). Analysis of product rollover strategies in the presence of strategic customers. *Management Science*, *60*(4), 1033–1056.

Lim, W. S., & Tang, C. S. (2013). Advance selling in the presence of speculators and forward-looking consumers. *Production and Operations Management*, *22*(3), 571–587.

Liu, Q., & Zhang, D. (2013). Dynamic pricing competition with strategic customers under vertical product differentiation. *Management Science*, *59*(1), 84–101.

Lobel, I., Patel, J., Vulcano, G., & Zhang, J. (2016). Optimizing product launches in the presence of strategic consumers. *Management Science*, *62*(6), 1778–1799.

Loch, C. H., & Kavadias, S. (2002). Dynamic portfolio selection of npd programs using marginal returns. *Management Science*, *48*(10), 1227–1241.

MacInnes, I., Li, Y., & Yurcik, W. (2005). Reputation and dispute in ebay transactions. *International Journal of Electronic Commerce*, *10*(1), 27–54.

MacKenzie, I., Meyer, C., & Noble, S. (2013). *How retailers can keep up with consumers.* Retrieved from https://www.mckinsey.com/industries/retail/our-insights/how-retailers-can-keep-up-with-consumers

Mantin, B., Krishnan, H., & Dhar, T. (2014). The strategic role of third-party marketplaces in retailing. *Production and Operations Management*, *23*(11), 1937–1949.

Matzler, K., Veider, V., & Kathan, W. (2014). Adapting to the sharing economy. *MIT Sloan Management Review*.

Mazur, J. (1987). An adjusting procedure for studying delayed reinforcement. *Quantitative Analyses of Behavior: Vol.5, The Effect of Delay and of Intervening Events on Reinforcement Value*, 55–73.

Meyer, R. J., Zhao, S., & Han, J. K. (2008). Biases in valuation vs. usage of innovative product features. *Marketing Science*, *27*(6), 1083–1096.

Miao, Z., Fu, K., Xia, Z., & Wang, Y. (2017). Models for closed-loop supply chain with trade-ins. *Omega*, *66*, 308–326.

Moorthy, K. S., & Png, I. P. (1992). Market segmentation, cannibalization, and the timing of product introductions. *Management science*, *38*(3), 345–359.

Morgan, L. O., Morgan, R. M., & Moore, W. L. (2001). Quality and time-to-market trade-offs when there are multiple product generations. *Manufacturing & Service Operations Management*, *3*(2), 89–104.

Moshkin, N. V., & Shachar, R. (2002). The asymmetric information model of state dependence. *Marketing Science*, *21*(4), 435–454.

Muth, J. F. (1961). Rational expectations and the theory of price movements. *Econometrica: Journal of the Econometric Society*, 315–335.

Niu, B., Bao, J., & Cao, B. (2022). Retailer's make-or-buy decision for remanufactured products under in-house yield uncertainty. *Omega*, *110*, 102627.

Nocke, V., & Peitz, M. (2003). Hyperbolic discounting and secondary markets. *Games and Economic Behavior*, *44*(1), 77–97.

Norton, J. A., & Bass, F. M. (1987). A diffusion theory model of adoption and substitution for successive generations of high-technology products. *Management science*, *33*(9), 1069–1086.

O'Donoghue, T., & Rabin, M. (1999). Doing it now or later. *American Economic Review*, *89*(1), 103–124.

Ofek, E., & Sarvary, M. (2003). R&d, marketing, and the success of next-generation products. *Marketing Science*, *22*(3), 355–370.

Örsdemir, A., Deshpande, V., & Parlaktürk, A. K. (2019). Is servicization a win-win strategy? profitability and environmental implications of servicization. *Manufacturing & Service Operations Management*, *21*(3), 674–691.

Patagonia. (2024). *Used patagonia clothing and gear: worn wear.* Retrieved from https://wornwear.patagonia.com/

Paulson Gjerde, K. A., Slotnick, S. A., & Sobel, M. J. (2002). New product innovation with multiple features and technology constraints. *Management Science*, *48*(10), 1268–1284.

Rahmani, M., Roels, G., & Karmarkar, U. S. (2017). Collaborative work dynamics in projects with co-production. *Production and Operations Management*, *26*(4), 686–703.

Ramachandran, K., & Krishnan, V. (2008). Design architecture and introduction timing for rapidly improving industrial products. *Manufacturing & Service Operations Management*, *10*(1), 149–171.

Rao, R. S., Narasimhan, O., & John, G. (2009). Understanding the role of trade-ins in durable goods markets: Theory and evidence. *Marketing Science*, *28*(5), 950–967.

Risberg, E. (2014). *Clothing resale sites boom as more shoppers buy with reselling in mind.* Retrieved from https://www.nydailynews.com/life-style/fashion/resale-sites-boom-shoppers-buy-reselling-mind-article-1.1786409

Robertson, T. S. (2023). *The resale revolution.* Retrieved from https://hbr.org/2023/11/the-resale-revolution

Robinson, B., & Lakhani, C. (1975). Dynamic price models for new-product planning. *Management science*, *21* (10), 1113–1122.

Roy, R., Chintagunta, P. K., & Haldar, S. (1996). A framework for investigating habits,"the hand of the past," and heterogeneity in dynamic brand choice. *Marketing Science*, *15* (3), 280–299.

Rubinstein, A. (1982). Perfect equilibrium in a bargaining model. *Econometrica: Journal of the Econometric Society*, 97–109.

Rust, R. T., Thompson, D. V., & Hamilton, R. W. (2006). Defeating feature fatigue. *Harvard Business Review*, *84* (2), 37–47.

Santos, M. J., Jorge, D., Ramos, T., & Barbosa-Póvoa, A. (2023). Green reverse logistics: Exploring the vehicle routing problem with deliveries and pickups. *Omega*, *118*, 102864.

Savin, S., & Terwiesch, C. (2005). Optimal product launch times in a duopoly: Balancing life-cycle revenues with product cost. *Operations Research*, *53* (1), 26–47.

Seetharaman, P. (2004). Modeling multiple sources of state dependence in random utility models: A distributed lag approach. *Marketing Science*, *23* (2), 263–271.

SHEIN. (2022). *SHEIN builds new community destination through SHEIN Exchange resale platform.* Retrieved from https://www.sheingroup.com/corporate-news/

press-releases/shein-builds-new-community-destination-through-shein-exchange-resale-platform/

Shen, W., Duenyas, I., & Kapuscinski, R. (2014). Optimal pricing, production, and inventory for new product diffusion under supply constraints. *Manufacturing & Service Operations Management*, *16*(1), 28–45.

Shugan, S. M. (2002). Marketing science, models, monopoly models, and why we need them. *Marketing Science*, *21*(3), 223–228.

Statista. (2019). *When you change your phone, do you intend on staying with your current brand or switching to a different brand?* Retrieved from https://www.statista.com/statistics/1058847/mobile-phone-loyalty-in-the-us/

Stokey, N. L. (1979). Intertemporal price discrimination. *The Quarterly Journal of Economics*, *93*(3), 355–371.

Su, X. (2007). Intertemporal pricing with strategic customer behavior. *Management Science*, *53*(5), 726–741.

Su, X. (2010). Optimal pricing with speculators and strategic consumers. *Management Science*, *56*(1), 25–40.

Swappa. (2024). *Swappa fair fees.* Retrieved from https://swappa.com/fees

Thaler, R. H., & Shefrin, H. M. (1981). An economic theory of self-control. *Journal of political Economy*, *89*(2), 392–406.

Thompson, D. V., Hamilton, R. W., & Rust, R. T. (2005). Feature fatigue: When product capabilities become too much of a good thing. *Journal of Marketing Research*, *42*(4), 431–442.

Thompson, G. L., & Teng, J.-T. (1984). Optimal pricing and advertising policies for new product oligopoly models. *Marketing Science*, *3*(2), 148–168.

ThredUP. (2019). *ThredUP resale report 2019.* Retrieved from https://cf-assets-tup.thredup.com/resale_report/2019/thredUP-resaleReport2019.pdf

ThredUP. (2021). *ThredUP resale report 2021.* Retrieved from https://www.thredup.com/resale/2021/static/thredUP-Resale-and-Impact-Report-2021-980436a36adc4f84a26675c1fcf2c554.pdf

ThredUP. (2022). *ThredUP resale report 2022.* Retrieved from https://www.thredup.com/resale/2022/static/2022-resaleReport-full-92a77020598ceca50f43227326100cc2.pdf

ThredUP. (2023a). *Here's what happens after you clean out.* Retrieved from https://www.thredup.com/cleanout/consignment

ThredUP. (2023b). *ThredUP resale report 2023.* Retrieved from https://cf-assets-tup.thredup.com/resale_report/2023/thredUP_2023_Resale%20Report.pdf

ThredUP. (2024). *ThredUP resale report 2024.* Retrieved from https://cf-assets-tup.thredup.com/resale_report/2024/ThredUp_2024_Resale%20Report.pdf

Tian, L., & Jiang, B. (2018). Effects of consumer-to-consumer product sharing on distribution channel. *Production and Operations Management*, *27*(2), 350–367.

Ülkü, S., Dimofte, C. V., & Schmidt, G. M. (2012). Consumer valuation of modularly upgradeable products. *Management Science*, *58*(9), 1761–1776.

Vedantam, A., Demirezen, E. M., & Kumar, S. (2021). Trade-in or sell in my P2P marketplace: A game theoretic analysis of profit and environmental impact. *Production and Operations Management*, *30*(11), 3923–3942.

Vogue. (2022). *You can now get your Ganni fix via its new resale platform.* Retrieved from https://www.vogue.co.uk/fashion/article/ganni-resale-platform

Waldman, M. (1997). Eliminating the market for secondhand goods: An alternative explanation for leasing. *The Journal of Law and Economics*, *40*(1), 61–92.

Wang, L., Cai, G., Tsay, A. A., & Vakharia, A. J. (2017). Design of the reverse channel for remanufacturing: Must profit-maximization harm the environment? *Production and Operations Management*, *26*(8), 1585–1603.

Wang, W., Feng, L., Li, Y., Cai, G., & Zhang, W. (2023). Managing demand slowdown: The interplay between trade-ins and quality improvement. *Naval Research Logistics (NRL)*, *70*(8), 793–810.

Wertenbroch, K. (1998). Consumption self-control by rationing purchase quantities of virtue and vice. *Marketing Science*, *17*(4), 317–337.

Xiong, Y., Zhao, P., Xiong, Z., & Li, G. (2016). The impact of product upgrading on the decision of entrance to a secondary market. *European Journal of Operational Research*, *252*(2), 443–454.

Xue, Y., Caliskan-Demirag, O., Chen, Y., & Yu, Y. (2018). Supporting customers to sell used goods: Profitability and environmental implications. *International Journal of Production Economics*, *206*, 220–232.

Yang, J., Li, Y., & Fang, L. (2023). Financing capacity planning with environmental considerations: A non-parametric analysis. *Omega*, *118*, 102866.

Ye, T., & Sun, H. (2016). Price-setting newsvendor with strategic consumers. *Omega*, *63*, 103–110.

Yin, S., Ray, S., Gurnani, H., & Animesh, A. (2010). Durable products with multiple used goods markets: Product upgrade and retail pricing implications. *Marketing Science*, *29*(3), 540–560.

Yoon, H. (2020). Impatience and time inconsistency in discounting models. *Management Science*, *66*(12), 5850–5860.

Zhang, F., & Zhang, R. (2018). Trade-in remanufacturing, customer purchasing behavior, and government policy. *Manufacturing & Service Operations Management*, *20*(4), 601–616.

Zhang, M., Ahn, H.-S., & Uichanco, J. (2022). Data-driven pricing for a new product. *Operations Research*, *70*(2), 847–866.

Zhang, S., Chan, T. Y., Luo, X., & Wang, X. (2022). Time-inconsistent preferences and strategic self-control in digital content consumption. *Marketing Science*, *41*(3), 616–636.

Zhao, H., & Jagpal, S. (2006). The effect of secondhand markets on the firm's dynamic pricing and new product introduction strategies. *International Journal of Research in Marketing*, *23*(3), 295–307.

Zhao, X., Fang, F., & Whinston, A. B. (2006). Designing misc mediation services for C2C markets. *International Journal of Electronic Commerce*, *10*(3), 71–93.

Zhou, Y., Xiong, Y., & Jin, M. (2021). Less is more: Consumer education in a closed-loop supply chain with remanufacturing. *Omega*, *101*, 102259.

Appendix A

Supplementary Material for Chapter 3

A.1 Thresholds

The expressions for the thresholds are summarized in Table A.1.

Table A.1: List of thresholds

Threshold	Mathematical expressions
$\hat{v}^*$	$$\frac{\left(\begin{array}{l} 2\theta^3(\tau-1)^2(\eta-1)\left(\eta^3-\eta^2+3\eta-2\right)+ \\ \theta^2\left(3(\tau-1)\eta^3-\eta^2\left(3\tau(\tau-2)+4\right)+\eta\left(\tau(6\tau-7)+2\right)-4\tau(\tau-1)\right)- \\ \theta\left(2\eta^4+\left(\eta^2-1\right)\left(\eta(\tau-2)-4(\tau-1)\right)\right)+\eta\left(\eta^2-2\right) \end{array}\right)}{\left(\begin{array}{l} 2\theta^3(\tau-1)^2(\eta-1)\left(\eta^3-\eta^2+2\eta-1\right)+ \\ \theta^2\left((6\tau-5)\eta^3-2\eta^2\left(\tau(\tau+2)-2\right)+\eta\left(\tau(5\tau-4)\right)-4\tau(\tau-1)\right)- \\ \theta\left(4\eta^4+2(\tau-2)\eta^3-4(\tau-1)\left(2\eta^2-(\eta+1)\right)\right)+\eta\left(3\eta^2-4\right) \end{array}\right)}$$

to be continued

Table A.1 Continued

Threshold	Mathematical expressions
$\underline{\theta}(\tau,\eta)$	Given τ and η, the value of θ that satisfies $\dfrac{2\eta\left(\begin{array}{l} \theta^4\left(\begin{array}{l} \theta\left(\eta^3+2\eta-1\right)(\eta-1)^2(\tau-1)^3- \\ \left(\eta^4(\tau-1)-\frac{5\eta^3}{2}+\eta^2\left(\frac{5\tau}{2}-4\right)-\eta\left(\frac{7\tau}{2}+1\right)+\frac{3\tau}{2}+1\right) \\ (\eta-1)(\tau-1)^2 \end{array}\right)- \\ \frac{3\theta^3}{2}\left(\begin{array}{l} \eta^4\left(\frac{2\eta}{3}+\left(\frac{2\tau-1}{3}\right)\right)-\eta^3\left(\tau^2-5\tau+5\right)+\eta^2\tau\left(\frac{7\tau-13}{3}\right)- \\ \eta\left(2\tau^2+\frac{4\tau-4}{3}\right)+\tau\left(\frac{\tau-7}{3}\right)-\frac{4}{3} \end{array}\right)(\tau-1)+ \\ \theta^2\left(\begin{array}{l} \eta^5(\tau-1)-\eta^4\left(\frac{\tau^2}{2}-3\tau+\frac{7}{2}\right)- \\ \frac{3\eta^3}{2}\left(\tau^2+\tau+1\right)+2\eta^2\left(\tau^2-5\tau+3\right)- \\ 2\eta\left(3\tau^2-5\tau+2\right)+2\tau\left(\tau+\frac{1}{4}\right)-2 \end{array}\right)+ \\ \theta\left(\frac{\eta^4}{2}(1-\tau)+\eta^3\left(\frac{5}{2}-\tau\right)+\eta^2\left(\frac{3\tau}{2}+1\right)+\eta(3\tau-4)-\frac{5\tau}{2}+1\right)-\eta^2+1 \end{array}\right)}{\left(\begin{array}{l} 4\theta^3(\eta-1)(\tau-1)^2\left(\eta^3-\eta^2+2\eta-1\right)+ \\ \theta^2\left(\eta^3(6\tau-5)-2\eta^2\left(\tau^2-2\tau+2\right)+\eta\tau(5\tau-4)-4\tau(\tau-1)\right)- \\ 2\theta\left(2\eta^4-\eta^3(\tau-3)-4\eta^2(1-\tau)-2\eta(\tau-2)-2(\tau-1)\right)+\eta\left(3\eta^2-4\right) \end{array}\right)}=0$
Λ_1	$1+\theta(9-\tau)$
Λ_2	$1+\theta(1-\tau)$
$\tau_{p_1}(\theta)$	$\frac{28\theta^2+13\theta+1-\sqrt{912\theta^4+632\theta^3+193\theta^2+26\theta+1}}{2\theta(1+4\theta)}$
$\tau_{p_2}(\theta)$	$\frac{20\theta^2+13\theta+1-\sqrt{656\theta^4+328\theta^3+145\theta^2+26\theta+1}}{2\theta(1+4\theta)}$
$\Lambda_{p_1^*}$	$\left(\begin{array}{l} \theta^3(\tau-1)^2\left(\hat{v}^*\eta^2(\eta-1)+\eta\left(2\hat{v}^*-1\right)-\hat{v}^*+1\right)(\eta-1)+ \\ \theta^2(\tau-1)\left(3\hat{v}^*\eta^3-\eta^2\left(\tau\left(\hat{v}^*-2\right)-\hat{v}^*+3\right)-\eta\left(\tau\left(4-3\hat{v}^*\right)-3\right)-2\tau\left(\hat{v}^*-1\right)\right)- \\ \theta\left(2\eta^4\hat{v}^*-\hat{v}^*\eta^3(\tau-2)-\eta^2\left(2\hat{v}^*+\tau\left(1-3\hat{v}^*\right)\right)-2(\eta+1)(\tau-1)\left(\hat{v}^*+1\right)\right)+ \\ \eta\left(\hat{v}^*\left(\eta^2-2\right)-\eta\right) \end{array}\right)$
$\theta_{d_2}(\tau)$	Given τ, the value of θ that satisfies $\theta^3\left(2\tau^2-34\right)-\theta^2(3\tau-23)+\theta(10-\tau)+1=0$
$\theta_{r_1}(\tau)$	Given τ, the value of θ that satisfies $4\theta^4\left(3\tau^2-18\tau-17\right)+4\theta^3\left(\tau^2-10\tau+5\right)+7\theta^2(5-\tau)+\theta(12-\tau)+1=0$
$\theta_{r_2}(\tau)$	Given τ, the value of θ that satisfies $\left(\begin{array}{l} 16\theta^4\left(\begin{array}{l} \theta^2\left(\tau^2-5\tau-4\right)+ \\ 8\theta\left(\tau^4-21\tau^3+114\tau^2-93\tau-289\right) \end{array}\right)+ \\ \theta^4\left(\tau^4-50\tau^3+513\tau^2-1456\tau+560\right)-2\theta^3\left(2\tau^3-50\tau^2+307\tau-559\right)+ \\ \theta^2\left(7\tau^2-100\tau+334\right)+6\theta(7-\tau)+2 \end{array}\right)=0$
$\theta_r(\tau)$	Given τ, the value of θ that satisfies $4\theta^4\left(\tau^3-7\tau^2-4\tau+2\right)+\theta^3\left(\tau^3-21\tau^2+64\tau+72\right)-\theta^2\left(3\tau^2-32\tau+54\right)-4\theta(6-\tau)-2=0$
$\bar{\theta}_{r_1}$	The real root to $16\theta^3(8\theta-1)-\theta(28\theta+11)-1=0$, with $\bar{\theta}_{r_1}\approx 0.5684$
$\bar{\theta}_{r_2}$	The real root to $256\theta^3\left(\theta^2(4\theta-9)-24(18\theta-25)\right)+\theta(241\theta+36)+2=0$, with $\bar{\theta}_{r_2}\approx 0.6805$
$\bar{\theta}_r$	The real root to $4\theta^3(8\theta-29)+5\theta(5\theta+4)+2=0$, with $\bar{\theta}_r\approx 0.6400$

to be continued

Table A.1 Continued

Threshold	Mathematical expressions
$\theta_c(\tau)$	Given τ, the value of θ that satisfies $\left(\begin{array}{l} 16\theta^4\left(\begin{array}{l}\theta^4(\tau-1)\left(\tau^4(\tau-13)+57\tau^3-57\tau^2-298\tau+182\right)+\\ 4\theta^3\left(2\tau^4\left(\tau^2-36\tau+248\right)-956\tau^3+2062\tau^2-160\tau-136\right)+\\ \theta^2\left(\tau^4\left(\tau^2-30\tau+132\right)-314\tau^3+4403\tau^2-11096\tau+2808\right)-\\ 2\theta\left(\tau^4(\tau+19)-427\tau^3+1337\tau^2+390\tau-200\right)-\\ 2\left(3\tau^4-141\tau^3+1020\tau^2-1576\tau-82\right)\end{array}\right)+\\ 2\theta^3\left(13\tau^3-223\tau^2+700\tau+92\right)-\theta^2\left(35\tau^2-264\tau+56\right)+20\theta(\tau-2)-4\end{array}\right)=0$
$s^{B,D}$	$\frac{\sqrt{(\theta\eta^2+1)(\theta\eta+1)^2}-1-\theta\eta^2}{2-\eta(1-\theta)}$
v_p^{D*}	$\frac{1-\theta(1-2s(1-\eta))-s(2-\eta)}{2(1-\theta)(1-\theta(1-\eta))}$
v_l^{D*}	$\frac{1-\theta+s\eta}{2(1-\theta(1-\eta))}$
s_T	$\frac{\theta(1-\tau)\left(\begin{array}{l}\theta^2\left(\hat{v}^*(\eta-1)+1\right)(\eta-1)(\tau-1)+\\ \theta\left(-\hat{v}^*(\tau-1)\eta^2+\eta\left(1+\tau\left(\hat{v}^*-1\right)\right)-\tau\left(\hat{v}^*-1\right)\right)+\hat{v}^*-1\end{array}\right)}{\eta\Lambda_2(\theta(\eta-1)(\tau-1)+\eta+1)}$
$\theta_w(\tau)$	Given τ, the value of θ that satisfies $\left(\begin{array}{l}16\theta^4\left(\begin{array}{l}\theta^3(\tau-1)\left(\tau^4(\tau-13)+65\tau^3-145\tau^2+110\tau-146\right)+\\ 8\theta^2\left(\tau^4\left(\tau^2-18\tau+82\right)-70\tau^3-197\tau^2+1320\tau-606\right)-\\ \theta\left(\tau^4\left(\tau^2-30\tau+228\right)-250\tau^3-77\tau^2-7832\tau-232\right)-\\ 2\left(\tau^4(\tau-31)+233\tau^3-359\tau^2+1170\tau-3990\right)\end{array}\right)+\\ 2\theta^3\left(3\tau^4-75\tau^3+172\tau^2+1320\tau-644\right)-2\theta^2\left(7\tau^3-49\tau^2-500\tau+1536\right)+\\ \theta\left(13\tau^2+72\tau-816\right)-4(\tau+15)\end{array}\right)=0$
$\eta(\theta,\tau)$	Given θ and τ, the value of η that satisfies $\left(\begin{array}{l}2\theta^3(\tau-1)^2\left(\hat{v}^*\eta^2(\eta-1)+\eta\left(2\hat{v}^*-1\right)-\hat{v}^*+1\right)(\eta-1)+\\ \theta^2(\tau-1)\left(3\hat{v}^*\eta^3-\eta^2\left(\tau\left(\hat{v}^*-2\right)-\hat{v}^*+3\right)-\eta\left(\tau\left(4-3\hat{v}^*\right)-3\right)-2\tau\left(\hat{v}^*-1\right)\right)-\\ \theta\left(\begin{array}{l}2\eta^4\hat{v}^*-\hat{v}^*\eta^3(\tau-2)-\eta^2\left(2\hat{v}^*+\tau\left(1-4\hat{v}^*\right)\right)-\\ \eta\left(\tau\left(\hat{v}^*+1\right)-2\right)-2\left(\hat{v}^*-1\right)(\tau-1)\end{array}\right)+\\ \eta(\eta-1)\left(\hat{v}^*(\eta+2)-1\right)\end{array}\right)=0$
$\bar{v}_I$	Given θ,τ,and η, the value of $\hat{v}$ that satisfies $\left(\begin{array}{l}\left(\theta\left(\hat{v}(1-\tau)-1\right)+1\right)^2\left(\theta(\eta-1)(\tau-1)+\eta+1\right)\left(\theta(\tau-1)-1\right)+\\ \left(\theta\left(\hat{v}\eta+1-\hat{v}(\tau-2)\right)-\hat{v}\eta-1\right)^2\left(1+\theta\tau(\eta-1)\right)(1-\theta\tau)\end{array}\right)=0$
$\bar{v}_{II}$	Given θ,τ,and η,the value of $\hat{v}$ that satisfies $\left(\theta\left(\hat{v}(1-\tau)-1\right)+1\right)^2(\theta-1)+(\theta\hat{v}-1)^2\left(1+\theta\tau(\eta-1)\right)(1-\theta\tau)=0$
$\bar{v}_{III}$	Given θ,τ,and η,the value of $\hat{v}$ that satisfies $\left(\theta\left(\hat{v}\eta+1-\hat{v}(\tau-2)\right)-\hat{v}\eta-1\right)^2(\theta-1)+(\theta\hat{v}-1)^2\left(\theta(\eta-1)(\tau-1)+\eta+1\right)\left(1-\theta(\tau-1)\right)=0$
$\ddot{\theta}(\tau,\eta)$	Given τ and η,the value of θ that satisfies $2\theta^3(1-\eta)(1-\tau)+\theta^2\left(\eta(3-2\tau)+6(\tau-1)\right)+4\left(\theta(\eta-\tau+1)-\eta\right)=0$
Λ_c	$\left(\begin{array}{l}\theta^4\left(\begin{array}{l}\theta^2\left(-\tau^4\left(\tau^2-14\tau+68\right)+74\tau^3+477\tau^2-840\tau+344\right)+\\ 2\theta\left(\tau^4(\tau-13)+77\tau^3-199\tau^2-186\tau+192\right)+\\ 2\left(3\tau^4-5\tau^3-164\tau^2+440\tau-18\right)\end{array}\right)-\\ 2\theta^3\left(13\tau^3-35\tau^2-196\tau+188\right)+\theta^2\left(35\tau^2-40\tau-312\right)-4\theta(5\tau+2)+4\end{array}\right)$

to be continued

Table A.1 Continued

Threshold	Mathematical expressions
$\Lambda_{\Delta c}$	$\left(\begin{array}{l} 16\theta^4 \left(\begin{array}{l} \theta^4(\tau-1)\left(\tau^4(\tau-13)+57\tau^3-57\tau^2-298\tau+182\right)+ \\ 4\theta^3\left(2\tau^4\left(\tau^2-36\tau+248\right)-956\tau^3+2062\tau^2-160\tau-136\right)+ \\ \theta^2\left(\tau^4\left(\tau^2-30\tau+132\right)-314\tau^3+4403\tau^2-11096\tau+2808\right)- \\ 2\theta\left(\tau^4(\tau+19)-427\tau^3+1337\tau^2+390\tau-200\right)- \\ 2\left(3\tau^4-141\tau^3+1020\tau^2-1576\tau-82\right) \end{array}\right)+ \\ 2\theta^3\left(13\tau^3-223\tau^2+700\tau+92\right)-\theta^2\left(35\tau^2-264\tau+56\right)+20\theta(\tau-2)-4 \end{array}\right)$
Λ_w	$\left(\begin{array}{l} \theta^4 \left(\begin{array}{l} \theta^2(\tau-1)\left(\tau^4(\tau-13)+71\tau^3-259\tau^2+704\tau-632\right)- \\ 2\theta\left(\tau^4(\tau-1)-23\tau^3-67\tau^2+314\tau-352\right)+ \\ 2\left(\tau^4+45\tau^3-312\tau^2-40\tau+178\right) \end{array}\right)+ \\ 2\theta^3\left(\tau^3-159\tau^2+820\tau-276\right)-\theta^2\left(11\tau^2-392\tau+984\right)+4\theta(3\tau-38)-4 \end{array}\right)$
$\Lambda_{\Delta w}$	$\left(\begin{array}{l} 16\theta^4 \left(\begin{array}{l} \theta^3(\tau-1)\left(\tau^4(\tau-13)+65\tau^3-145\tau^2+110\tau-146\right)+ \\ 8\theta^2\left(\tau^4\left(\tau^2-18\tau+82\right)-70\tau^3-197\tau^2+1320\tau-606\right)- \\ \theta\left(\tau^4\left(\tau^2-30\tau+228\right)-250\tau^3-77\tau^2-7832\tau-232\right)- \\ 2\left(\tau^4(\tau-31)+233\tau^3-359\tau^2+1170\tau-3990\right) \end{array}\right)+ \\ 2\theta^3\left(3\tau^4-75\tau^3+172\tau^2+1320\tau-644\right)-2\theta^2\left(7\tau^3-49\tau^2-500\tau+1536\right)+ \\ \theta\left(13\tau^2+72\tau-816\right)-4(\tau+15) \end{array}\right)$
Λ_d	$\left(\begin{array}{l} 2\theta^3(\tau-1)^2\left(\hat{v}^*\eta^2(\eta-1)+\eta\left(2\hat{v}^*-1\right)-\hat{v}^*+1\right)(\eta-1)+ \\ \theta^2(\tau-1)\left(\begin{array}{l} 3\hat{v}^*\eta^3-\eta^2\left(\tau\left(\hat{v}^*-2\right)-\hat{v}^*+3\right)- \\ \eta\left(\tau\left(4-3\hat{v}^*\right)-3\right)-2\tau\left(\hat{v}^*-1\right) \end{array}\right)- \\ \theta\left(\begin{array}{l} 2\eta^4\hat{v}^*-\hat{v}^*\eta^3(\tau-2)-\eta^2\left(2\hat{v}^*+\tau\left(1-4\hat{v}^*\right)\right)- \\ \eta\left(\tau\left(\hat{v}^*+1\right)-2\right)-2\left(\hat{v}^*-1\right)(\tau-1) \end{array}\right)\eta(\eta-1)\left(\hat{v}^*(\eta+2)-1\right) \end{array}\right)$
$\bar{v}_I^{B,D}$	$\frac{(\theta-1-s\eta)\left(\theta(1-\eta)-1+\sqrt{(1+\theta(\eta-1))(1-\theta+\eta)}\right)}{\eta(\theta-1)(1+\theta(\eta-1))}$
$\bar{v}_{II}^{B,D}$	$\frac{s\eta-\theta+1+\sqrt{(\theta-1)(\theta-\eta-1)}}{\eta(\theta-1)}$
$\bar{s}(\theta,\eta)$	$\frac{\theta-1+\sqrt{(1-\theta)(1+\theta(\eta-1))}}{\eta}$

A.2 Equilibrium

We first provide a sketch of proof. Our model contains utility-based demand formation in the two periods. We apply the concept of Rational Equilibrium (RE) and conjecture the existence of a marginal consumer in period one. A consumer with a new-product valuation above that held by the marginal consumer purchases a new product (to be a pre-owned consumer), while a consumer with a new-product valuation below that held by the marginal consumer postpones purchase to period two (to be a waited consumer). In period two, pre-owned and waited consumers make their respective utility-driven purchase decisions. A general-equilibrium price is formed to match the supply with the demand on the CRP. The retailer sets the new-product price to maximize period-two revenue. In period one, the retailer sets the new-product price to maximize total revenue, anticipating the revenue to receive in period two. The conjectured structure holds in equilibrium.

A.2.1 Benchmark: In the Absence of CRP

In the benchmark, given new-product prices, we conjecture that the marginal consumer with $\hat{v}^B \in (0,1)$ is indifferent between purchasing a new product in period one or postponing the purchase to period two. As to be demonstrated, this conjecture holds in equilibrium. Consumers with new-product valuations in $\left[\hat{v}^B, 1\right]$ purchase new products in period one and those with new-product valuations in $\left[0, \hat{v}^B\right)$ postpone to period two. Using backward induction, in period two, pre-owned consumers keep the used products; while waited consumers prefer to purchase new products over leaving when $v - p_2^B \geq 0 \Rightarrow v \geq v_{n,l}^B = p_2^B$. Note that $1 \geq \hat{v}^B \geq v_{n,l}^B \geq 0$. The market segmentation is shown in Figure A.1.

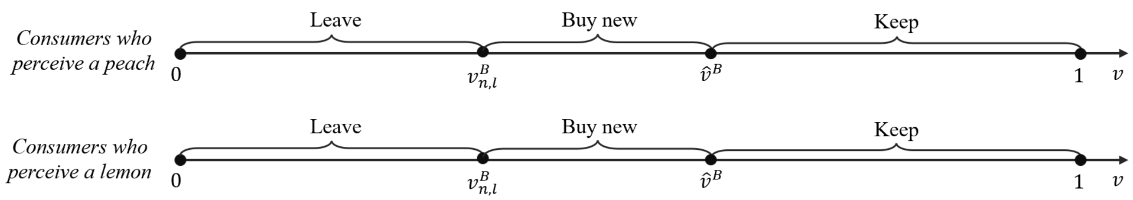


Figure A.1: Market segmentation in the absence of CRP

The demands from various segments are $d_{p,k}^B = 1 - \hat{v}^B$, $d_{w,n}^B = \hat{v}^B - v_{n,l}^B$, and $d_{w,l}^B = v_{n,l}^B$. The new-product demand in period two is $d_2^B = d_{p,dn}^B + d_{w,n}^B = \hat{v}^B - v_{n,l}^B$. The retailer maximizes period-two revenue $\max_{p_2^B} r_2^B = p_2^B d_2^B$. $\frac{d^2 r_2^B}{dp_2^{B^2}} = -2 < 0$ and $\frac{dr_2^B}{dp_2^B} = 0 \Rightarrow p_2^{B*}$. The subgame equilibrium outcomes are $p_2^{B*} = \frac{\hat{v}^B}{2}$, $d_2^{B*} = \frac{\hat{v}^B}{2}$, $r_2^{B*} = \frac{\hat{v}^{B^2}}{4}$. To decide the optimal p_1^{B*}, we push back to period one.

In period one, observing new-product price p_1^B and anticipating retailer's selling behavior in period two, a consumer purchases a new product if $v > \hat{v}^B$, but postpones purchase to period two if $v < \hat{v}^B$, where $\hat{v}^B$ is the marginal consumer who is indifferent between purchasing a new product in period one and postponing the purchase to period two in the absence of CRP. To derive period-one consumer choice, it suffices to identify the marginal consumer $\hat{v}^B$, who makes a period-one choice to maximize expected total surplus over two periods.

Recall that the marginal consumer is indifferent between purchasing in period one to keep used products in period two and postponing to purchase new products in period two for consumers who perceive either a peach or a lemon (See Figure A.1). The expected utility of purchasing for consumers who perceive either a peach or a lemon is $\eta\left(\hat{v}^B - p_1^B + E\left(\theta\right)\hat{v}^B\right) + \left(1-\eta\right)\left(\hat{v}^B - p_1^B + 0\right)$. The expected utility of postponing for consumers who perceive either a peach or a lemon is $\eta\left(0 + \hat{v}^B - p_2^B\right) + \left(1-\eta\right)\left(0 + \hat{v}^B - p_2^B\right)$. Recall that $E\left(\theta\right) = \eta\theta$. As such, the marginal consumer type holds the utility:

$$\eta\left(\hat{v}^B - p_1^B + \eta\theta\hat{v}^B\right) + \left(1-\eta\right)\left(\hat{v}^B - p_1^B\right) = \hat{v}^B - p_2^B. \tag{A.1}$$

Thus, we have $\hat{v}^B = \frac{p_1^B - p_2^B}{\theta\eta^2}$. The retailer maximizes the total revenue:

$$\max {r^B}_{\hat{v}^B} = p_1^B\left(\hat{v}^B\right) d_1^B\left(\hat{v}^B\right) + r_2^{B*}\left(\hat{v}^B\right)$$

where $d_1^B\left(\hat{v}^B\right) = 1 - \hat{v}^B$. $\frac{\partial^2 r^B}{\partial \hat{v}^{B2}} = -2\theta\eta^2 - \frac{1}{2} < 0$ and $\frac{\partial r^B}{\partial \hat{v}^B} = 0 \Rightarrow \hat{v}^{B*} = \frac{1+2\theta\eta^2}{1+4\theta\eta^2}$. Substituting $\hat{v}^{B*}$, we derive the optimal outcomes in the benchmark setting, as shown in Table 3.3. As shown in Figure 3.6, $d_{p,k}^B = d_1^B = \frac{2\theta\eta^2}{1+4\theta\eta^2}$, $d_{w,n}^B = d_2^B = \frac{1+2\theta\eta^2}{2(1+4\theta\eta^2)}$, and $d_{w,l}^B = \frac{1+2\theta\eta^2}{2(1+4\theta\eta^2)}$.

By the equilibrium outcomes, $p_1^{B*} - p_2^{B*} = \frac{\theta\eta^2\left(1+2\theta\eta^2\right)}{1+4\theta\eta^2}$. It can be verified that $\frac{\partial(p_1^{B*} - p_2^{B*})}{\partial\theta} > 0$, $\frac{\partial d_1^{B*}}{\partial\theta} > 0$, $\frac{\partial d_2^{B*}}{\partial\theta} < 0$, and $\frac{\partial(d_1^{B*} + d_2^{B*})}{\partial\theta} > 0$, while $\frac{\partial d_1^{B*}}{\partial\eta} > 0$, $\frac{\partial p_1^{B*}}{\partial\eta} > 0$, $\frac{\partial d_2^{B*}}{\partial\eta} < 0$, $\frac{\partial p_2^{B*}}{\partial\eta} < 0$ and $\frac{\partial d_{w,l}^{B}}{\partial\eta} < 0$.

A.2.2 Main Model: In the Presence of CRP

In the CRP model, given new-product prices, we conjecture that the marginal consumer with $\hat{v} \in (0, 1)$ is indifferent between purchasing a new product in period one or postponing the purchase to period two. As to be demonstrated, this conjecture holds in the equilibrium. Consumers with new-product valuations in $[\hat{v}, 1]$ purchase new products in period one and those with new-product valuations in $[0, \hat{v})$ postpone to period two.

Using backward induction, pre-owned consumers who perceive a peach prefer 'resell and repurchase' than 'keep' if $(1-\tau)\, p_s + v - p_2 \geq \theta v \Rightarrow v \geq v_{sn,k} = \frac{p_2 - (1-\tau) p_s}{1-\theta}$; prefer 'keep' than 'resell and leave' if $\theta v \geq (1-\tau)\, p_s \Rightarrow v \geq v_{k,sl} = \frac{(1-\tau) p_s}{\theta}$; and prefer 'resell and repurchase' than 'resell and leave' if $(1-\tau)\, p_s + v - p_2 \geq (1-\tau)\, p_s \Rightarrow v \geq v_{sn,sl} = p_2$. Waited consumers who perceive a peach prefer 'buy new' over 'buy used' if $v - p_2 \geq \theta v - p_s \Rightarrow v_{n,s} = \frac{p_2 - p_s}{1-\theta}$; prefer 'buy new' over 'leave' if $v - p_2 \geq 0 \Rightarrow v_{n,l} = p_2$; and prefer 'buy used' over 'leave' if $\theta v - p_s \geq 0 \Rightarrow v_{s,l} = \frac{p_s}{\theta}$. Among consumers who perceive a lemon, pre-owned ones choose between 'resell and repurchase' and 'resell and leave' options by $v_{sn,sl} = p_2$; waited ones choose between 'buy new' and 'leave' options by $v_{n,l} = p_2$.

Note that (i) $v_{sn,sl} = v_{n,l}$; (ii) $v_{sn,k} \geq v_{n,s}$ and $v_{s,l} \geq v_{k,sl}$, indicating that 'resell and leave' option for pre-owned consumers and 'leave' option for waited consumers cannot coexist. If $p_2 \geq \frac{(1-\tau)p_s}{\theta}$, $v_{sn,k} \geq v_{sn,sl} \geq v_{k,sl}$; if $p_2 < \frac{(1-\tau)p_s}{\theta}$, $v_{k,sl} > v_{sn,sl} > v_{sn,k}$. If $p_2 \geq \frac{p_s}{\theta}$, $v_{n,s} \geq v_{n,l} \geq v_{s,l}$; if $p_2 < \frac{p_s}{\theta}$, $v_{s,l} > v_{n,l} > v_{n,s}$. As such, the constraint can be rewritten as $\begin{cases} v_{k,sl} > v_{sn,sl} > v_{sn,k}, \;\; v_{s,l} > v_{n,l} > v_{n,s} \;\; if \;\; p_2 < \frac{(1-\tau)p_s}{\theta} \\ v_{sn,k} \geq v_{sn,sl} \geq v_{k,sl}, \;\; v_{s,l} > v_{n,l} > v_{n,s} \;\; if \;\; \frac{(1-\tau)p_s}{\theta} \leq p_2 < \frac{p_s}{\theta} \\ v_{sn,k} \geq v_{sn,sl} \geq v_{k,sl}, \;\; v_{n,s} \geq v_{n,l} \geq v_{s,l} \;\; if \;\; p_2 \geq \frac{p_s}{\theta} \end{cases}$.

When $v_{s,l} > v_{n,l} > v_{n,s}$, for waited consumers, the 'buy used' option is always dominated. It implies that used-product demand on the CRP diminishes, i.e., $d_{w,s} = 0$, and no transactions would occur. Thus, the cases satisfying constraint $p_2 < \frac{p_s}{\theta}$ are infeasible. We enumerate four patterns for market segmentation in Table A.2.

Table A.2: Cases in the presence of CRP

Case	Constraint
1	$1 \geq v_{sn,k} \geq v_{n,s} \geq v_{sn,sl} = v_{n,l} \geq \hat{v} \geq v_{s,l} \geq v_{k,sl} \geq 0$
2	$1 \geq v_{sn,k} \geq v_{n,s} \geq \hat{v} \geq v_{sn,sl} = v_{n,l} \geq v_{s,l} \geq v_{k,sl} \geq 0$
3	$1 \geq v_{sn,k} \geq \hat{v} \geq v_{n,s} \geq v_{sn,sl} = v_{n,l} \geq v_{s,l} \geq v_{k,sl} \geq 0$
4	$1 \geq \hat{v} \geq v_{sn,k} \geq v_{n,s} \geq v_{sn,sl} = v_{n,l} \geq v_{s,l} \geq v_{k,sl} \geq 0$

Case 1: $p_2 \geq \frac{p_s}{\theta}$, $1 \geq v_{sn,k} \geq v_{n,s} \geq v_{sn,sl} = v_{n,l} \geq \hat{v} \geq v_{s,l} \geq v_{k,sl} \geq 0$

Among consumers who perceive a peach, pre-owned ones choose between 'keep' and 'resell and repurchase', while waited ones choose between 'buy used' and 'leave'. Among consumers who perceive a lemon, pre-owned ones choose between 'resell and repurchase' and 'resell and leave', while waited ones leave the market. The market segmentation is shown in Figure A.2.

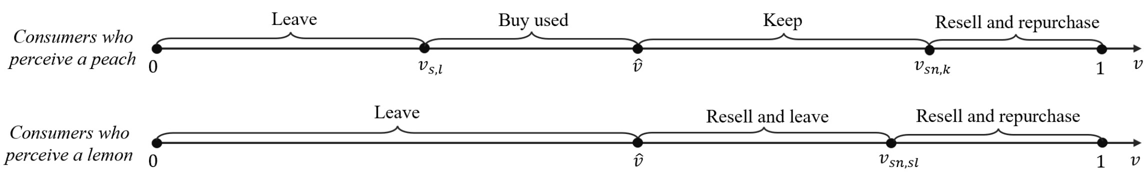


Figure A.2: Market segmentation in the presence of CRP, Case 1

The demands from various segments are $d_{p,sn} = \eta\left(1 - v_{sn,k}\right) + \left(1 - \eta\right)\left(1 - v_{sn,sl}\right)$, $d_{p,sl} = \left(1 - \eta\right)\left(v_{sn,sl} - \hat{v}\right)$, $d_{p,k} = \eta\left(v_{sn,k} - \hat{v}\right), d_{w,n} = 0$, $d_{w,s} = \eta(\hat{v} - v_{s,l})$ and $d_{w,l} = \eta v_{s,l} + (1-\eta)\hat{v}$. The new-product demand is $d_2 = d_{p,sn} + d_{w,n} = \eta\left(1 - v_{sn,k}\right) + \left(1 - \eta\right)\left(1 - v_{sn,sl}\right)$. Matching used-product supply and demand on CRP, $d_{p,sn} + d_{p,sl} = d_{w,s} \Rightarrow p_s\left(p_2, \hat{v}\right) = \frac{\theta(\theta(\hat{v}-1) - \eta p_2 - \hat{v} + 1)}{\eta(\theta\tau - 1)}$. Substituting $p_s\left(p_2, \hat{v}\right)$ into d_2, $d_2\left(p_2, \hat{v}\right) = \frac{\theta((\tau(p_2(\eta-1)+\hat{v})+1)-\hat{v}+1)+p_2-1}{\theta\tau-1}$.

The retailer maximizes period-two revenue:

$$\max r_{2_{p_2}} = p_2 d_2, \text{ s.t. } p_2 \geq \frac{p_s}{\theta} \Leftrightarrow p_2 \leq \frac{\left(1 - \hat{v}\right)\left(1 - \theta\right)}{\theta\tau\eta}.$$

Adding Lagrange multiplier λ, $L(p_2,\lambda) = p_2 d_2 + \lambda\left(\frac{(1-\hat{v})(1-\theta)}{\theta\tau\eta} - p_2\right)$, $\lambda \geq 0$, and $\lambda\left(\frac{(1-\hat{v})(1-\theta)}{\theta\tau\eta} - p_2\right) = 0$. $\frac{\partial^2 L(p_2,\lambda)}{\partial {p_2}^2} = \frac{2(\theta\tau(\eta-1)+1)}{\theta\tau-1} < 0$ and $\frac{\partial L(p_2,\lambda)}{\partial p_2} = 0 \Rightarrow p_2^*(\hat{v},\lambda) = \frac{\theta(\hat{v}(1-\tau)-1)+1}{2(1+\theta\tau(\eta-1))} - \lambda$.

If $\lambda = 0$, $p_2^*(\hat{v}) = \frac{\theta(\hat{v}(1-\tau)-1)+1}{2(1+\theta\tau(\eta-1))}$, $r_2^*(\hat{v}) = \frac{(\theta(1-\hat{v}(1-\tau))-1)^2}{4(1+\theta\tau(\eta-1))(1-\theta\tau)}$.

If $\lambda > 0$, $p_2^*(\hat{v}) = \frac{(1-\hat{v})(1-\theta)}{\theta\tau\eta}$, $r_2^*(\hat{v}) = \frac{(\theta-1)(\hat{v}-1)((\hat{v}(\tau\eta-1)+1)\theta+\hat{v}-1)}{\eta^2\theta^2\tau^2}$.

The $r_2^*(\hat{v})$ derived under $\lambda > 0$ is always less than that under $\lambda = 0$. Thus, the subgame equilibrium outcomes in Case 1 are: $p_2^*(\hat{v}) = \frac{\theta(\hat{v}(1-\tau)-1)+1}{2(1+\theta\tau(\eta-1))}$, $d_2^*(\hat{v}) = \frac{\theta(\hat{v}(\tau-1)+1)-1}{2(\theta\tau-1)}$, $p_s^*(\hat{v}) = \frac{\theta\left(\tau\theta^2(\hat{v}-1)(\eta-1)+\theta\left(\tau\left(\eta\left(1-\frac{\hat{v}}{2}\right)+\hat{v}-1\right)\frac{(\hat{v}-1)(\eta-2)}{2}\right)-\frac{\eta}{2}-\hat{v}+1\right)}{\eta(1+\theta\tau(\eta-1))(\theta\tau-1)}$, and $r_2^*(\hat{v}) = \frac{(\theta(\hat{v}(1-\tau)-1)+1)^2}{4(1+\theta\tau(\eta-1))(1-\theta\tau)}$.

Case 2: $p_2 \geq \frac{p_s}{\theta}$, $1 \geq v_{sn,k} \geq v_{n,s} \geq \hat{v} \geq v_{sn,sl} = v_{n,l} \geq v_{s,l} \geq v_{k,sl} \geq 0$

Among consumers who perceive a peach, pre-owned ones choose between 'keep' and 'resell and repurchase', while waited ones choose between 'buy used' and 'leave'. Among consumers who perceive a lemon, per-owned ones choose "resell and repurchase', while waited ones choose between 'buy new' and 'leave'. The market segmentation is shown in Figure A.3.

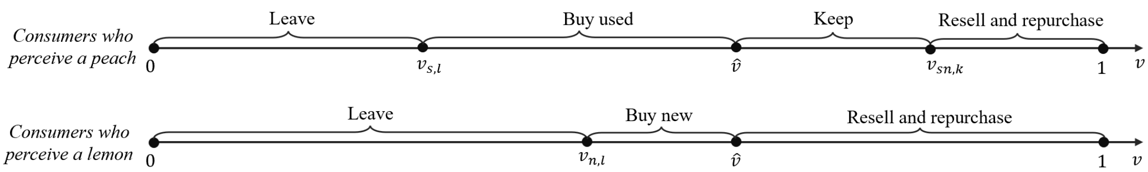


Figure A.3: Market segmentation in the presence of CRP, Case 2

The demands from various segments are $d_{p,sn} = \eta(1-v_{sn,k}) + (1-\eta)(1-\hat{v})$, $d_{p,sl} = 0, d_{p,k} = \eta(v_{sn,k}-\hat{v})$, $d_{w,n} = (1-\eta)(\hat{v}-v_{n,l})$, $d_{w,s} = \eta(\hat{v}-v_{s,l})$ and $d_{w,l} = \eta v_{s,l} + (1-\eta)v_{n,l}$. The new-product demand is $d_2 = d_{p,sn} + d_{w,n} = \eta(1-v_{sn,k}) + (1-\eta)(1-\hat{v}) + (1-\eta)(\hat{v}-v_{n,l})$. Matching the used-product supply and demand on the CRP, $d_{p,sn} + d_{p,sl} = d_{w,s} \Rightarrow p_s(p_2,\hat{v}) = \frac{\theta(\theta(\hat{v}-1)-\eta p_2-\hat{v}+1)}{\eta(\theta\tau-1)}$. Substituting $p_s(p_2,\hat{v})$ into d_2, we have $d_2(p_2,\hat{v}) = \frac{\theta((\tau(p_2(\eta-1)+\hat{v})+1)-\hat{v}+1)+p_2-1}{\theta\tau-1}$. Note that $p_s(p_2,\hat{v})$ and $d_2(p_2,\hat{v})$ in this case are the same as those in Case 1, so do the subgame equilibrium outcomes.

Case 3: $p_2 \geq \frac{p_s}{\theta}$, $1 \geq v_{sn,k} \geq \hat{v} \geq v_{n,s} \geq v_{sn,sl} = v_{n,l} \geq v_{s,l} \geq v_{k,sl} \geq 0$

Among consumers who perceive a peach, pre-owned ones choose between 'keep' and 'resell and repurchase', while waited ones choose among 'buy new', 'buy used', and 'leave'. Among consumers who perceive a lemon, pre-owned ones choose 'resell and repurchase', while waited ones choose between 'buy new' and 'leave'. The market segmentation is shown in Figure A.4.

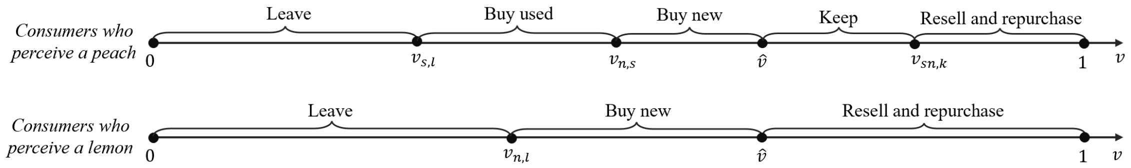


Figure A.4: Market segmentation in the presence of CRP, Case 3

The demands from various segments are $d_{p,sn} = \eta\left(1 - v_{sn,k}\right) + (1-\eta)\left(1-\hat{v}\right)$, $d_{p,sl} = 0$, $d_{p,k} = \eta\left(v_{sn,k} - \hat{v}\right)$, $d_{w,n} = \eta\left(\hat{v} - v_{n,s}\right) + (1-\eta)\left(\hat{v} - v_{n,l}\right)$, $d_{w,s} = \eta(v_{n,s} - v_{s,l})$ and $d_{w,l} = \eta v_{s,l} + (1-\eta)v_{n,l}$, where $v_{sn,k} \geq \hat{v} \geq v_{n,s}$. The new-product demand is $d_2 = d_{p,sn} + d_{w,n} = \eta\left(1 - v_{sn,k}\right) + (1-\eta)\left(1-\hat{v}\right) + \eta\left(\hat{v} - v_{n,s}\right) + (1-\eta)\left(\hat{v} - v_{n,l}\right)$. Matching the used-product supply and demand on the CRP, we have:

$$d_{p,sn} + d_{p,sl} = d_{w,s} \Rightarrow p_s\left(p_2, \hat{v}\right) = \frac{\theta\left(\theta(\hat{v}\left(\eta-1\right)+1) + \hat{v}\left(1-\eta\right) + 2\eta p_2 - 1\right)}{\eta\left(1 - \theta\left(\tau-1\right)\right)}.$$

Substituting $p_s\left(p_2, \hat{v}\right)$ into d_2, $d_2\left(p_2, \hat{v}\right) = \frac{\theta(p_2(\eta-1)(\tau-1)+\hat{v}(\tau-2+\eta)+1)+p_2(1+\eta)-\eta\hat{v}-1}{\theta(\tau-1)-1}$. The retailer maximizes period-two revenue:

$$\max r_{2p_2} = p_2 d_2, \text{ s.t. } \; p_2 \geq \frac{p_s}{\theta} \Leftrightarrow \begin{cases} p_2 \geq \frac{(1+\hat{v}(\eta-1))(1-\theta)}{\eta(1+\theta(\tau-1))} & if\ \theta \geq \frac{1}{1-\tau} \\ p_2 < \frac{(1+\hat{v}(\eta-1))(1-\theta)}{\eta(1+\theta(\tau-1))} & if\ \theta < \frac{1}{1-\tau} \end{cases}.$$

Note that $\frac{1}{1-\tau} \geq 1$ if $\tau \in [0,1]$ and the feasibility constraint is $p_2 < \frac{(1+\hat{v}(\eta-1))(1-\theta)}{\eta(1+\theta(\tau-1))}$. Adding Lagrange multiplier λ, we have $L\left(p_2, \lambda\right) = p_2 d_2 + \lambda\left(\frac{(1+\hat{v}(\eta-1))(1-\theta)}{\eta(1+\theta(\tau-1))} - p_2\right)$, $\lambda \geq 0$, and $\lambda\left(\frac{(1+\hat{v}(\eta-1))(1-\theta)}{\eta(1+\theta(\tau-1))} - p_2\right) = 0$. $\frac{\partial^2 L(p_2,\lambda)}{\partial p_2{}^2} = \frac{2(\theta(\eta-1)(\tau-1)+1+\eta)}{\theta(\tau-1)-1} < 0$ and $\frac{\partial L(p_2,\lambda)}{\partial p_2} = 0 \Rightarrow p_2^*\left(\hat{v}, \lambda\right) = \frac{\theta(\hat{v}(2-\tau)-\hat{v}\eta-1)+\hat{v}\eta+1}{2\theta(\eta-1)+2(\eta+1)(\tau-1)} - \lambda$.

If $\lambda = 0$, $p_2^*(\hat{v}) = \frac{\theta(\hat{v}(2-\tau)-\hat{v}\eta-1)+\hat{v}\eta+1}{2\theta(\eta-1)+2(\eta+1)(\tau-1)}$, $r_2^*(\hat{v}) = \frac{(\theta(\hat{v}\eta+1-\hat{v}(\tau-2))-\hat{v}\eta-1)^2}{4(\theta(\eta-1)(\tau-1)+\eta+1)(1-\theta(\tau-1))}$.

If $\lambda > 0$, $p_2^*(\hat{v}) = \frac{(1+\hat{v}(\eta-1))(1-\theta)}{\eta(1+\theta(\tau-1))}$, $r_2^*(\hat{v}) = \frac{(1-\theta)(\hat{v}(\eta-1)+1)((\hat{v}(\tau\eta-1)+1)\theta+\hat{v}-1)}{\eta^2(1+\theta(\tau-1))^2}$.

The $r_2^*(\hat{v})$ derived under $\lambda > 0$ is always less than that under $\lambda = 0$. Thus, the subgame equilibrium outcomes in Case 3 are: $p_s^*(\hat{v}) = \frac{\theta^3(\hat{v}(\eta-1)+1)(\eta-1)(\tau-1)}{\eta(1-\theta(\tau-1))(\theta(\eta-1)(\tau-1)+\eta+1)} + \frac{\theta^2\left(-\hat{v}(\tau-1)\eta^2+\eta(1+\tau(\hat{v}-1))-\tau(\hat{v}-1)\right)+\theta\hat{v}-\theta}{\eta(1-\theta(\tau-1))(\theta(\eta-1)(\tau-1)+\eta+1)}$, $p_2^*(\hat{v}) = \frac{\theta(\hat{v}(2-\tau)-\hat{v}\eta-1)+\hat{v}\eta+1}{2\theta(\eta-1)+2(\eta+1)(\tau-1)}$, $d_2^*(\hat{v}) = \frac{\theta(\hat{v}(\tau+\eta-2)+1)}{2(\theta(\tau-1)-1)} - \frac{\hat{v}\eta-1}{2(\theta(\tau-1)-1)}$, and $r_2^*(\hat{v}) = \frac{(\theta(\hat{v}\eta+1-\hat{v}(\tau-2))-\hat{v}\eta-1)^2}{4(\theta(\eta-1)(\tau-1)+\eta+1)(1-\theta(\tau-1))}$.

Case 4: $p_2 \geq \frac{p_s}{\theta}$, $1 \geq \hat{v} \geq v_{sn,k} \geq v_{n,s} \geq v_{sn,sl} = v_{n,l} \geq v_{s,l} \geq v_{k,sl} \geq 0$

Among consumers who perceive a peach, pre-owned ones choose 'resell and repurchase', but waited ones choose among 'buy new', 'buy used', and 'leave'. Among consumers who perceive a lemon, pre-owned ones choose 'resell and repurchase', while waited ones choose between 'buy new' and 'leave'. The market segmentation is shown in Figure A.5.

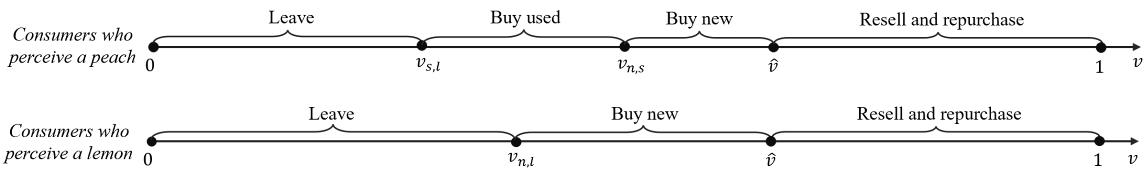


Figure A.5: Market segmentation in the presence of CRP, Case 4

The demands from various segments are $d_{p,sn} = 1 - \hat{v}$, $d_{p,sl} = 0, d_{p,k} = 0, d_{w,n} = \eta\left(\hat{v} - v_{n,s}\right) + (1-\eta)\left(\hat{v} - v_{n,l}\right), d_{w,s} = \eta(v_{n,s} - v_{s,l})$ and $d_{w,l} = \eta v_{s,l} + (1-\eta)v_{n,l}$. The new-product demand $d_2 = d_{p,sn} + d_{w,n} = 1 - \hat{v} + \eta\left(\hat{v} - v_{n,s}\right) + (1-\eta)\left(\hat{v} - v_{n,l}\right)$. Matching used-product supply and demand on the CRP, $d_{p,sn} + d_{p,sl} = d_{w,s} \Rightarrow p_s\left(p_2, \hat{v}\right) = \frac{\theta((\eta-1)p_2-\hat{v}+1)}{\eta}$. Substituting $p_s\left(p_2, \hat{v}\right)$ into d_2, we have $d_2\left(p_2, \hat{v}\right) = \frac{\theta\hat{v}+p_2-1}{\theta-1}$.

The retailer maximizes period-two revenue:

$$\max r_{2_{p_2}} = p_2 d_2, \text{ s.t. } \ p_2 \geq \frac{p_s}{\theta} \Leftrightarrow p_2 \geq 1 - \hat{v}\ .$$

Adding Lagrange multiplier λ, $L\left(p_2, \lambda\right) = p_2 d_2 + \lambda\left(p_2 - 1 + \hat{v}\right), \lambda\left(p_2 - 1 + \hat{v}\right) = 0$, and $\lambda \geq 0$. $\frac{\partial^2 L(p_2,\lambda)}{\partial {p_2}^2} = \frac{2}{\theta-1} < 0$ and $\frac{\partial L(p_2,\lambda)}{\partial p_2} = 0 \Rightarrow p_2^*\left(\hat{v}, \lambda\right) = \frac{1-\theta\hat{v}}{2} + \lambda$.

If $\lambda = 0$, $p_2^*(\hat{v}) = \frac{1-\theta\hat{v}}{2}$, $r_2^*(\hat{v}) = \frac{(\theta\hat{v}-1)^2}{4(1-\theta)}$.

If $\lambda > 0$, $p_2^*(\hat{v}) = 1 - \hat{v}, r_2^*(\hat{v}) = \hat{v}(1-\hat{v})$.

The $r_2^*(\hat{v})$ derived under $\lambda > 0$ is always less than that derived under $\lambda = 0$. Thus, the subgame equilibrium outcomes in Case 4 are $p_2^*(\hat{v}) = \frac{1-\theta\hat{v}}{2}$, $p_s^*(\hat{v}) = \frac{\theta(1+\eta-\hat{v}(\theta(\eta-1)+2))}{2\eta}$, $d_2^*(\hat{v}) = \frac{1-\theta\hat{v}}{2(1-\theta)}$, and $r_2^*(\hat{v}) = \frac{(\theta\hat{v}-1)^2}{4(1-\theta)}$.

Given the marginal consumer type $\hat{v}$, by comparing the period-two revenue r_2, we find that (i) Case 2 dominates Case 1: the two cases achieve the same period-two revenue $r_2^*(\hat{v}) = \frac{(\theta(\hat{v}(1-\tau)-1)+1)^2}{4(1+\theta\tau(\eta-1))(1-\theta\tau)}$, where $r_2^*(\hat{v})$ increases with $\hat{v}$. The feasible boundary of $\hat{v}$ in Case 2 is larger than that in Case 1; (ii) Case 3 dominates Case 2 when $\hat{v} \geq \bar{v}_I$; (iii) Case 4 dominates Case 2 when $\hat{v} < \bar{v}_{II}$; (iv) Case 3 dominates Case 4 when $\hat{v} \geq \bar{v}_{III}$. As such, given θ, τ, and η, $1 > \bar{v}_{II} > \bar{v}_{III} > \bar{v}_I > 0$, so that Case 2 is dominated and $p_2^*(\hat{v}) = \begin{cases} \frac{1-\theta\hat{v}}{2} \; when \; \hat{v} < \bar{v}_{III} \\ \frac{\theta(\hat{v}(2-\tau)-\hat{v}\eta-1)+\hat{v}\eta+1}{2\theta(\eta-1)+2(\eta+1)(\tau-1)} \; when \; \hat{v} \geq \bar{v}_{III} \end{cases}$. Note that $\bar{v}_I$, $\bar{v}_{II}$, and $\bar{v}_{III}$ are shown in Table A.1. To decide the optimal $\hat{v}^*$, we push Case 3 and Case 4 back to period one.

In period one, observing new-product price p_1 and anticipating the new-product price in period two, the consumer's objective is to maximize expected total utility over two periods. The marginal consumer with $\hat{v}$ is indifferent between purchasing a new product in period one and postponing the purchase to period two in the presence of CRP. A consumer purchases a new product if $v \geq \hat{v}$ but postpones purchase to period two if $v < \hat{v}$. To derive the consumer's choice in period one, it suffices to identify the marginal consumer $\hat{v}$. Based on the discussions above, we discuss Case 3 and Case 4 in the following.

Case 3. The marginal consumer is indifferent between 'purchase in period one and keep in period two' and 'wait in period one and buy new in period two' for consumers who perceive a peach; and between 'purchase in period one and resell it then repurchase in period two' and 'wait in period one and buy new in period two' for consumers who perceive a lemon (See Figure A.4). The expected utility of purchasing for consumers who perceive either a peach or a lemon is $\eta\left(\hat{v}-p_1+E\left(\theta\right)\hat{v}\right)+\left(1-\eta\right)\left(\hat{v}-p_1+\left(1-\tau\right)p_s+\hat{v}-p_2\right)$. The expected utility of postponing for consumers who perceive either a peach or a lemon is $\eta\left(0+\hat{v}-p_2\right)+\left(1-\eta\right)\left(0+\hat{v}-p_2\right)$. Recall that $E\left(\theta\right)=\eta\theta$. We have:

$$\eta\left(\hat{v}-p_1+\eta\theta\hat{v}\right)+\left(1-\eta\right)\left(\hat{v}-p_1+\left(1-\tau\right)p_s+\hat{v}-p_2\right)=\hat{v}-p_2 \tag{A.2}$$

which implies that

$$\hat{v}(p_1)=\frac{\begin{pmatrix}2\theta^3(\tau-1)^2(\eta-1)^2+\\ \theta^2(\tau-1)\left(\eta^2\left(\tau^2\left(\tau\left(p_1-1\right)-p_1+\frac{3}{2}\right)+\eta\left(\tau\left(2-p_1\right)+p_1-1\right)-\tau\right)\right)+\\ \theta\left(-\tau\eta^2+2\left(\eta\left(2p_1-1\right)+1\right)\left(\tau-1\right)\right)+\left(1-2p_1\right)\eta^2-2p_1\eta\end{pmatrix}}{\begin{pmatrix}2\theta^3(\tau-1)^2(\eta-1)\left(\eta^3-\eta^2+2\eta-1\right)-\\ \theta^2(\tau-1)\left(-3\eta^3+\tau\eta^2-2\left(\eta\left(1+\tau\right)+\tau\right)\right)+\\ \theta\left(-2\eta^4+\eta^3\left(\tau-2\right)+\eta^2\left(2-3\tau\right)+2\left(\eta+1\right)\left(\tau-1\right)\right)+\eta^3-2\eta\end{pmatrix}}.$$

The retailer maximizes total revenue:

$$\max r_{\hat{v}}=p_1(\hat{v})d_1(\hat{v})+r_2^*(\hat{v})$$

where $d_1(\hat{v})=1-\hat{v}$. When $\frac{\partial^2 r}{\partial\hat{v}^2}<0$ and $\frac{\partial r}{\partial\hat{v}}=0$, we can derive:

$$\hat{v}^*=\frac{\begin{pmatrix}2\theta^3(\tau-1)^2(\eta-1)\left(\eta^3-\eta^2+3\eta-2\right)+\\ \theta^2\left(3(\tau-1)\eta^3-\eta^2\left(3\tau(\tau-2)+4\right)+\eta\left(\tau(6\tau-7)+2\right)-4\tau(\tau-1)\right)-\\ \theta\left(2\eta^4+\left(\eta^2-1\right)\left(\eta(\tau-2)-4(\tau-1)\right)\right)+\eta\left(\eta^2-2\right)\end{pmatrix}}{\begin{pmatrix}2\theta^3(\tau-1)^2(\eta-1)\left(\eta^3-\eta^2+2\eta-1\right)+\\ \theta^2\left((6\tau-5)\eta^3-2\eta^2\left(\tau(\tau+2)-2\right)+\eta\left(\tau(5\tau-4)\right)-4\tau(\tau-1)\right)-\\ \theta\left(4\eta^4+2(\tau-2)\eta^3-4(\tau-1)\left(2\eta^2-(\eta+1)\right)\right)+\eta\left(3\eta^2-4\right)\end{pmatrix}}.$$

Substituting $\hat{v}^*$, the optimal outcomes of Case 3 in the CRP model can be derived.

Case 4. The marginal consumer is indifferent between ‘purchase in period one and resell it then repurchase in period two’ and ‘wait in period one and buy new in period two' for consumers who perceive either a peach or a lemon (See Figure A.5. The expected utility of purchasing for consumers who perceive either a peach or a lemon is $\eta\left(\hat{v}-p_1+(1-\tau)\,p_s+\hat{v}-p_2\right)+(1-\eta)\left(\hat{v}-p_1+(1-\tau)\,p_s+\hat{v}-p_2\right)$. The expected utility of postponing for consumers who perceive either a peach or a lemon is $\eta\left(0+\hat{v}-p_2\right)+(1-\eta)\left(0+\hat{v}-p_2\right)$. We have:

$$\hat{v}-p_1+(1-\tau)\,p_s+\hat{v}-p_2=\hat{v}-p_2 \tag{A.3}$$

which implies that $\hat{v}(p_1)=\frac{\theta(\tau-1)(\eta+1)+2p_1\eta}{\theta^2(\tau-1)(\eta-1)+2\theta(\tau-1)+2\eta}$. The retailer maximizes total revenue:

$$\max r_{\hat{v}}=p_1(\hat{v})d_1(\hat{v})+r_2^*(\hat{v})$$

where $d_1(\hat{v})=1-\hat{v}$. From $\frac{\partial^2 r}{\partial \hat{v}^2}<0$ if $\theta<\ddot{\theta}(\tau,\eta)$ and $\frac{\partial r}{\partial \hat{v}}=0$, we can derive that $\hat{v}^*=\frac{\theta^3(\eta-1)(\tau-1)+4\theta^2(\tau-1)+\theta(\eta(4-\tau)-3(\tau-1))-2\eta}{2\theta^3(\eta-1)(\tau-1)+\theta^2(\eta(3-2\tau)+6(\tau-1))+4\theta(\eta-\tau+1)-4\eta}$. Substituting $\hat{v}^*$, we find that Case 4 is ruled out since CRP does not exist ($p_s^*<0$) when $\theta<\ddot{\theta}(\tau,\eta)$ and $\ddot{\theta}(\tau,\eta)$ is shown in Table A.1. As such, the optimal outcomes of the CRP model occur in Case 3 and is summarized in Table 3.5.

A.3 Proofs of Lemmas and Propositions

Proof of Lemma 3.1. The market-clearing price of used products is:

$$p_s^*=\frac{\theta\begin{pmatrix}\theta^2\left(\hat{v}^*\left(\eta-1\right)+1\right)\left(\eta-1\right)\left(\tau-1\right)+\\ \theta\left(-\hat{v}^*\left(\tau-1\right)\eta^2+\eta\left(1+\tau\left(\hat{v}^*-1\right)\right)-\tau\left(\hat{v}^*-1\right)\right)+\hat{v}^*-1\end{pmatrix}}{\eta\left(1-\theta\left(\tau-1\right)\right)\left(\theta\left(\eta-1\right)\left(\tau-1\right)+\eta+1\right)}$$

$p_s^*=0$ when $\theta=\underline{\theta}(\tau,\eta)$. $\frac{\partial p_s^*}{\partial\theta}=0$ when $\theta=\bar{\theta}_{p_s^*}(\tau,\eta)$; $\bar{\theta}_{p_s^*}(\tau,\eta)<\underline{\theta}(\tau,\eta)$. For $\theta\in\left[0,\bar{\theta}_{p_s^*}\right)$, $\frac{\partial p_s^*}{\partial\theta}<0$, $p_s^*<0$; for $\theta\in\left[\bar{\theta}_{p_s^*},\underline{\theta}\right)$, $\frac{\partial p_s^*}{\partial\theta}\geq 0$, $p_s^*<0$; and for $\theta\in[\underline{\theta},1]$, $\frac{\partial p_s^*}{\partial\theta}>0$, $p_s^*\geq 0$. When $p_s^*>0$, transactions on CRP can sustain. Moreover, it can be verified that $\frac{\partial\underline{\theta}(\tau,\eta)}{\partial\tau}>0$ and $\frac{\partial\underline{\theta}(\tau,\eta)}{\partial\eta}<0$. When $\eta=1$, $\underline{\theta}_{\eta=1}(\tau)=\frac{\tau+2}{\tau^2-7\tau+14}$. In the following proofs with $\eta=1$, for simplicity, we denote $\underline{\theta}=\underline{\theta}_{\eta=1}(\tau)=\frac{\tau+2}{\tau^2-7\tau+14}$. □

Proof of Lemma 3.2. By the equilibrium outcomes, $p_1^* - p_2^* = \frac{\theta(1+\theta(5-\tau))}{\Lambda_1} > 0$. The quantity of pre-owned consumers is $d_p^* = 1 - \hat{v}_{\eta=1}^* = \frac{4\theta}{\Lambda_1}$, and the quantity of waited consumers is $d_w^* = \hat{v}_{\eta=1}^* = \frac{1+\theta(5-\tau)}{\Lambda_1}$. Since $\frac{\partial \hat{v}_{\eta=1}^*}{\partial \theta} = -\frac{4}{{\Lambda_1}^2} < 0$, $\frac{\partial d_p^*}{\partial \theta} > 0$ and $\frac{\partial d_w^*}{\partial \theta} < 0$. Moreover, it can be verified that $\frac{\partial p_1^*}{\partial \theta} > 0$, $\frac{\partial p_2^*}{\partial \theta} < 0$, $\frac{\partial (p_1^* - p_2^*)}{\partial \theta} > 0$, $\frac{\partial p_s^*}{\partial \theta} > 0$ when $\theta \geq \underline{\theta}$; and $\frac{\partial d_1^*}{\partial \theta} > 0$, $\frac{\partial d_2^*}{\partial \theta} < 0$, $\frac{\partial d_s^*}{\partial \theta} < 0$, $\frac{\partial d_{w,l}^*}{\partial \theta} < 0$ when $\theta \geq \underline{\theta}$. □

Proof of Proposition 3.1. Denote $\Delta p_1 = p_1^* - p_1^{B*} = \frac{\theta\left(\theta^2\left(\tau^2-7\tau-2\right)+\frac{\theta}{4}\left(\tau^2-13\tau+8\right)-\frac{\tau}{4}\right)}{\Lambda_1(1+4\theta)}$. $\Delta p_1 = 0$ when $\tau = \tau_{p_1}(\theta) = \frac{28\theta^2+13\theta+1-\sqrt{912\theta^4+632\theta^3+193\theta^2+26\theta+1}}{2\theta(1+4\theta)}$. $\frac{\partial \Delta p_1}{\partial \tau} < 0$, i.e., Δp_1 monotonically decreases in τ, with $\Delta p_1|_{\tau=0} = \frac{2\theta^2(1-\theta)}{36\theta^2+13\theta+1} > 0$ and $\Delta p_1|_{\tau=1} = -\frac{4\theta^2(8-\theta)-\theta}{4(32\theta^2+12\theta+1)} < 0$. As such, if $\tau \geq \tau_{p_1}(\theta)$, $\Delta p_1 \leq 0$; if $\tau < \tau_{p_1}(\theta)$, $\Delta p_1 > 0$. Denote $\Delta p_2 = p_2^* - p_2^{B*} = \frac{\theta\left(\theta^2\left(\tau^2-5\tau-4\right)+\frac{\theta}{4}\left(\tau^2-13\tau+16\right)-\frac{\tau}{4}\right)}{\Lambda_1(1+4\theta)} = 0$. $\frac{\partial \Delta p_2}{\partial \tau} < 0$, i.e., Δp_2 monotonically decreases in τ, with $\Delta p_2|_{\tau=0} = \frac{4\theta^2(1-\theta)}{36\theta^2+13\theta+1} > 0$ and $\Delta p_2|_{\tau=1} = -\frac{4\theta^2(\theta-8)-\theta}{4(32\theta^2+12\theta+1)} < 0$. $\Delta p_2 = 0$ when $\tau = \tau_{p_2}(\theta) = \frac{20\theta^2+13\theta+1-\sqrt{656\theta^4+328\theta^3+145\theta^2+26\theta+1}}{2\theta(1+4\theta)}$. $\Delta p_2 \leq 0$ if $\tau \geq \tau_{p_2}(\theta)$, but $\Delta p_2 > 0$ if $\tau < \tau_{p_2}(\theta)$. Denote $\Delta p_d = p_1^* - p_2^* - \left(p_1^{B*} - p_2^{B*}\right) = \frac{2\theta^2(\theta(1-\tau)-1)}{\Lambda_1(1+4\theta)} < 0$. $\frac{\partial \Delta p_d}{\partial \tau} < 0$, i.e., Δp_d monotonically decreases in τ. Denote $\Delta d_1 = d_1^* - d_1^{B*} = \frac{2\theta(1-\theta(1-\tau))}{\Lambda_1(1+4\theta)} \geq 0$, and $\Delta d_2 = d_2^* - d_2^{B*} = \frac{\theta^3\left(2\tau^2-34\right)-\theta^2(3\tau-23)+\theta(10-\tau)+1}{2\Lambda_1\Lambda_2(1+4\theta)}$. $\frac{\partial \Delta d_2}{\partial \theta} < 0$, i.e., Δd_2 monotonically decreases in θ, with $\Delta d_2|_{\theta=\underline{\theta}} = \frac{\tau^2(5-\tau)+20(3-\tau)}{8(\tau^2-3\tau+22)} > 0$ and $\Delta d_2|_{\theta=1} = \frac{\tau}{5(\tau-10)} < 0$. $\Delta d_2 = 0$ when $\theta = \theta_{d_2}(\tau)$, which satisfies $\theta^3\left(2\tau^2-34\right) - \theta^2\left(3\tau-23\right) + \theta\left(10-\tau\right) + 1 = 0$. Thus, $\Delta d_2 > 0$ when $\theta < \theta_{d_2}(\tau)$ while $\Delta d_2 \leq 0$ when $\theta \geq \theta_{d_2}(\tau)$. □

Proof of Proposition 3.2. Denote

$$\Delta r = r^* - r^{B*} = \frac{\begin{pmatrix} -4\theta^4\left(\tau^3-7\tau^2-4\tau+2\right)-\theta^3\left(\tau^3-21\tau^2+64\tau+72\right)+ \\ \theta^2\left(3\tau^2-32\tau+54\right)+4\theta\left(6-\tau\right)+2 \end{pmatrix}}{8\Lambda_1\Lambda_2\left(1+4\theta\right)}.$$

$\Delta r = 0$ when $\theta = \theta_r(\tau)$, which satisfies $4\theta^4\left(\tau^3-7\tau^2-4\tau+2\right) + \theta^3(\tau^3-21\tau^2+64\tau+72) - \theta^2\left(3\tau^2-32\tau+54\right) - 4\theta\left(6-\tau\right) - 2 = 0$. $\frac{\partial \Delta r}{\partial \theta} < 0$, i.e., Δr monotonically decreases in θ, with $\Delta r|_{\theta=\underline{\theta}} = -\frac{\tau^4(\tau-21)+8\tau^2(25\tau-111)+16(221\tau-237)}{64(\tau^2-7\tau+14)(\tau^2-3\tau+22)} > 0$ and $\Delta r|_{\theta=1} =$

$\frac{5\tau-42}{40(10-\tau)} < 0$. Thus, $\Delta r > 0$ when $\theta < \theta_r(\tau)$, while $\Delta r \leq 0$ when $\theta \geq \theta_r(\tau)$. Denote

$$\Delta r_1 = r_1^* - r_1^{B*} = \frac{\theta \begin{pmatrix} 4\theta^4\left(3\tau^2 - 18\tau - 17\right) + 4\theta^3\left(\tau^2 - 10\tau + 5\right) + \\ 7\theta^2\left(5-\tau\right) + \theta\left(12-\tau\right) + 1 \end{pmatrix}}{{\Lambda_1}^2\left(1+4\theta\right)^2}.$$

$\frac{\partial \Delta r_1}{\partial \theta} < 0$, i.e., Δr_1 monotonically decreases in θ, with $\Delta r_1|_{\theta=1} = \frac{8\tau(2\tau-15)}{25(\tau-10)^2} < 0$ and $\Delta r_1|_{\theta=\underline{\theta}} = \frac{(\tau+2)\left(\tau^5(3\tau-46)+\tau^3(323\tau-1600)+8\tau(553\tau-1244)+8304\right)}{64(\tau^2-7\tau+14)(\tau^2-3\tau+22)^2} > 0$. $\Delta r_1 = 0$ when $\theta = \theta_{r_1}(\tau)$, which is shown in Table A.1. Thus, $\Delta r_1 > 0$ when $\theta < \theta_{r_1}(\tau)$ while $\Delta r_1 \leq 0$ when $\theta \geq \theta_{r_1}(\tau)$. Denote

$$\Delta r_2 = r_2^* - r_2^{B*} = \frac{\begin{pmatrix} 16\theta^6\left(\tau^2 - 5\tau - 4\right) + 8\theta^5\left(\tau^4 - 21\tau^3 + 114\tau^2 - 93\tau - 289\right) + \\ \theta^4\left(\tau^4 - 50\tau^3 + 513\tau^2 - 1456\tau + 560\right) - \\ 2\theta^3\left(2\tau^3 - 50\tau^2 + 307\tau - 559\right) + \\ \theta^2\left(7\tau^2 - 100\tau + 334\right) + 6\theta\left(7-\tau\right) + 2 \end{pmatrix}}{8{\Lambda_1}^2\Lambda_2\left(1+4\theta\right)^2}.$$

$\frac{\partial \Delta r_2}{\partial \theta} < 0$, i.e., Δr_2 monotonically decreases in θ, with $\Delta r_2|_{\theta=1} = -\frac{\tau\left(25\tau^2-332\tau+1140\right)}{200(\tau-10)^2} < 0$ and $\Delta r_2|_{\theta=\underline{\theta}} = -\frac{\tau^6(\tau-16)+\tau^4(43\tau-242)+4\tau^2(729\tau-2190)+192(101\tau-87)}{64(\tau^2-7\tau+14)(\tau^2-3\tau+22)^2} > 0$. $\Delta r_2 = 0$ when $\theta = \theta_{r_2}(\tau)$, which is shown in Table A.1. Thus, $\Delta r_2 > 0$ when $\theta < \theta_{r_2}(\tau)$ while $\Delta r_2 \leq 0$ when $\theta \geq \theta_{r_2}(\tau)$. $\square$

Proof of Proposition 3.3. Denote $\Delta cs = cs - cs^B = \frac{\Lambda_{\Delta c}}{16{\Lambda_1}^2{\Lambda_2}^2(1-\theta)(1+4\theta)^2}$. $\frac{\partial \Delta cs}{\partial \theta} > 0$, i.e., Δcs monotonically increases in θ, with

$$\Delta cs|_{\theta=\underline{\theta}} = -\frac{\begin{pmatrix} \tau^7\left(\tau-27\right) + 5\tau^5\left(57\tau - 401\right) + \\ 2\tau^3\left(4637\tau - 15996\right) - 16(7377\tau - 2394) \end{pmatrix}}{128\left(\tau^2 - 7\tau + 14\right)\left(\tau^2 - 3\tau + 22\right)^2} < 0$$

when τ is low and $\lim_{\theta \to 1} \Delta cs = \infty$. $\Delta cs = 0$ when $\theta = \theta_c(\tau)$, which satisfies $\Lambda_{\Delta c} = 0$. Note that Λ_c, $\theta_c(\tau)$, and $\Lambda_{\Delta c}$ can be found in Table A.1. Thus, $\Delta cs < 0$ when $\theta < \theta_c(\tau)$ while $\Delta cs \geq 0$ when $\theta \geq \theta_c(\tau)$. $\square$

Proof of Proposition 3.4. Let $\Delta sw = sw - sw^B = \frac{\theta\Lambda_{\Delta w}}{16{\Lambda_1}^2{\Lambda_2}^2(\theta-1)(1+4\theta)^2}$. $\frac{\partial \Delta sw}{\partial \theta} < 0$ when $\theta > \underline{\theta}$, i.e., Δsw monotonically decreases in θ, with

$$\Delta sw|_{\theta=\underline{\theta}} = -\frac{(\tau+2)\begin{pmatrix}\tau^6(\tau-27)+\tau^4(291\tau-2017)+\\ 8\tau^2(1176\tau-3701)+16(3893\tau-4017)\end{pmatrix}}{128\left(\tau^2-7\tau+14\right)\left(\tau^2-3\tau+22\right)^2} > 0$$

and $\lim\limits_{\theta\to 1}\Delta sw = -\infty$. $\Delta sw = 0$ when $\theta = \theta_w(\tau)$, which satisfies $\Lambda_{\Delta w} = 0$. Note that Λ_w, $\theta_w(\tau)$, and $\Lambda_{\Delta w}$ can be found in Table A.1. Thus, $\Delta sw > 0$ when $\theta < \theta_w(\tau)$ while $\Delta sw \leq 0$ when $\theta \geq \theta_w(\tau)$. □

Proof of Proposition 3.5. Denote

$$\Delta d = d^* - d^{B*} = \frac{2\theta^3\left(-\tau^2+4\tau-19\right)+\theta^2\left(23-3\tau\right)+\theta\left(14-\tau\right)+1}{2\Lambda_1\Lambda_2\left(1+4\theta\right)}.$$

$\frac{\partial \Delta d}{\partial \theta} < 0$, i.e., Δd monotonically decreases in θ, with the minimum $\Delta d|_{\theta=1} = \frac{\tau}{5(10-\tau)} \geq 0 \Rightarrow \Delta d \geq 0$. Denote $\Delta E = E - E^B$, where E^B can be simplified into $(e_p + e_{un} + e_d)d^{B*} + e_{us}d_1^{B*}$ and E can be simplified into $(e_p + e_{un} + e_d)\, d^* + e_{us}\left(d_1^* + d_s^*\right)$. From Proof of Proposition 3.1, $\Delta d \geq 0 \Rightarrow d^*\left(e_p + e_{un} + e_d\right) \geq d^{B*}\left(e_p + e_{un} + e_d\right)$ and $\Delta d_1 \geq 0 \Rightarrow e_{us}\left(d_1^* + d_s^*\right) > e_{us}d_1^{B*}$. As such, $E > E^B$. □

Proof of Proposition 3.6. Denote

$$\Delta p_d = p_1^* - p_2^* - \left(p_1^{B*} - p_2^{B*}\right) = \frac{\Lambda_d}{2\eta\Lambda_2\left(1-\eta\right)\left(1+\eta-\theta(1-\tau)\right)}.$$

$\frac{\partial \Delta p_d}{\partial \eta} < 0$ when CRP exists, i.e., $\theta > \underline{\theta}(\tau,\eta)$, i.e., Δp_d monotonically decreases in η, with $\Delta p_d|_{\eta=0} = \frac{\theta((2\theta+1)(1-\tau)-1)}{4\Lambda_2} > 0$ and $\Delta p_d|_{\eta=1} = \frac{2\theta^2(\theta(1-\tau)-1)}{\Lambda_1(1+4\theta)} < 0$. $\Delta p_d = 0$ when $\eta = \eta(\theta,\tau)$, which satisfies $\Lambda_d = 0$ and Λ_d is shown in Table A.1. Thus, $\Delta p_d \leq 0$ when $\eta \geq \eta(\theta,\tau)$ while $\Delta p_d > 0$ when $\eta < \eta(\theta,\tau)$. □

Proof of Lemma 3.3. By the equilibrium outcomes in Table 3, it can be verified that $\frac{\partial d_p}{\partial \eta} = \frac{\partial(1-\hat{v}^*)}{\partial \eta} > 0$, $\frac{\partial d_w}{\partial \eta} = \frac{\partial \hat{v}^*}{\partial \eta} < 0$; $\frac{\partial d_2^*}{\partial \eta} < 0$; $\frac{\partial d_s^*}{\partial \eta} < 0$, and $\frac{\partial d_{w,l}^*}{\partial \eta} < 0$. □

A.4 Disposal with a Positive Salvage Value

In the benchmark, if disposal is possible, the retailer maximizes the total revenue:

$$\max r^{B,D} = p_1^{B,D} d_1^{B,D} + p_2^{B,D} d_2^{B,D}$$

where $(p_1^{B,D}, p_2^{B,D})$ are the prices and $(d_1^{B,D}, d_2^{B,D})$ are the demands for new product in the two periods. Given new-product prices, we conjecture marginal consumer with $\hat{v}^{B,D}$ in the benchmark, where $\hat{v}^{B,D} \in (0,1)$, is indifferent between purchasing a new product in period one or postponing the purchase to period two. As to be demonstrated, this conjecture holds in the equilibrium. Consumers with new-product valuations in $\left[\hat{v}^{B,D}, 1\right]$ purchase new products in period one and those with new-product valuations in $\left[0, \hat{v}^{B,D}\right)$ postpone to period two. To ease expressions, we assume $s_1 = s$ and $s_2 = 0$.

Using backward induction, in period two, among consumers who perceive a peach, pre-owned ones prefer 'dispose and repurchase' over 'keep' if $s + v - p_2^{B,D} \geq \theta v \Rightarrow v \geq v_{dn,k}^{B,D} = \frac{p_2^{B,D} - s}{1-\theta}$; prefer 'dispose and repurchase' over 'dispose and leave' if $s + v - p_2^{B,D} \geq s \Rightarrow v \geq v_{dn,dl}^{B,D} = p_2^{B,D}$; but prefer 'keep' over 'dispose and leave' if $\theta v \geq s \Rightarrow v \geq v_{k,dl}^{B,D} = \frac{s}{\theta}$. Among consumers who perceive a lemon, pre-owned ones no longer choose 'keep' since it brings zero utility, and they choose between 'dispose and repurchase' and 'dispose and leave' with threshold $v_{dn,dl}^{B,D}$ to delimit new-product valuations. Waited consumers, no matter perceiving a peach or a lemon, prefer 'buy new' over 'leave' when $v - p_2^{B,D} \geq 0 \Rightarrow v \geq v_{n,l}^{B,D} = v_{dn,dl}^{B,D} = p_2^{B,D}$. As $v_{dn,dl}^{B,D} = v_{n,l}^{B,D}$, the 'dispose and leave' option for pre-owned consumer and the 'leave' option for waited consumer cannot coexist. When $p_2^{B,D} \geq \frac{s}{\theta}$, $v_{dn,k}^{B,D} \geq v_{dn,dl}^{B,D} = v_{n,l}^{B,D} \geq v_{k,dl}^{B,D}$; while if $p_2^{B,D} < \frac{s}{\theta}$, $v_{k,dl}^{B,D} > v_{dn,dl}^{B,D} = v_{n,l}^{B,D} > v_{dn,k}^{B,D}$. Table A.3 enumerates five patterns for market segmentation.

Case 1: $p_2^{B,D} \geq \frac{s}{\theta}$, $1 \geq v_{dn,k}^{B,D} \geq v_{dn,dl}^{B,D} = v_{n,l}^{B,D} \geq v_{k,dl}^{B,D} \geq \hat{v}^{B,D} \geq 0$

Among consumers who perceive a peach, pre-owned ones choose among three

Table A.3: Cases in the absence of CRP with disposal

Constraint	Case	Constraint
$p_2^{B,D} \geq \frac{s}{\theta}$	1	$1 \geq v_{dn,k}^{B,D} \geq v_{dn,dl}^{B,D} = v_{n,l}^{B,D} \geq v_{k,dl}^{B,D} \geq \hat{v}^{B,D} \geq 0$
	2	$1 \geq v_{dn,k}^{B,D} \geq v_{dn,dl}^{B,D} = v_{n,l}^{B,D} \geq \hat{v}^{B,D} \geq v_{k,dl}^{B,D} \geq 0$
	3	$1 \geq v_{dn,k}^{B,D} \geq \hat{v}^{B,D} \geq v_{dn,dl}^{B,D} = v_{n,l}^{B,D} \geq v_{k,dl}^{B,D} \geq 0$
	4	$1 \geq \hat{v}^{B,D} \geq v_{dn,k}^{B,D} \geq v_{dn,dl}^{B,D} = v_{n,l}^{B,D} \geq v_{k,dl}^{B,D} \geq 0$
$p_2^{B,D} < \frac{s}{\theta}$	5	$1 \geq v_{k,dl}^{B,D} > v_{dn,dl}^{B,D} = v_{n,l}^{B,D} > v_{dn,k}^{B,D} \geq \hat{v}^{B,D} \geq 0$
	6	$1 \geq v_{k,dl}^{B,D} > v_{dn,dl}^{B,D} = v_{n,l}^{B,D} \geq \hat{v}^{B,D} > v_{dn,k}^{B,D} \geq 0$
	7	$1 \geq v_{k,dl}^{B,D} \geq \hat{v}^{B,D} > v_{dn,dl}^{B,D} = v_{n,l}^{B,D} > v_{dn,k}^{B,D} \geq 0$
	8	$1 \geq \hat{v}^{B,D} \geq v_{k,dl}^{B,D} > v_{dn,dl}^{B,D} = v_{n,l}^{B,D} > v_{dn,k}^{B,D} \geq 0$

options, while waited ones leave the market without purchasing. Among consumers who perceive a lemon, pre-owned ones choose between 'dispose and repurchase' and 'dispose and leave', while waited ones leave the market. The market segmentation is shown in Figure A.6.

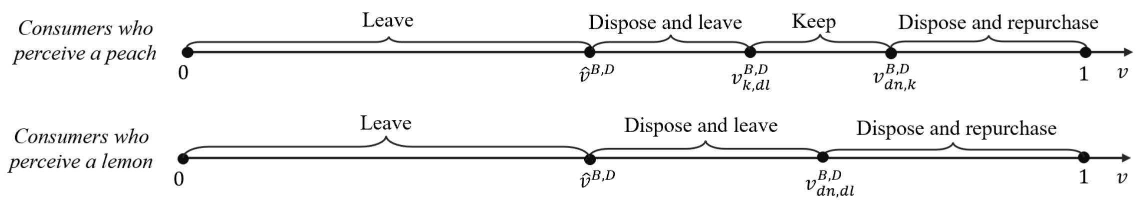


Figure A.6: Market segmentation in the absence of CRP with disposal, Case 1

The demands from various segments are $d_{p,dn}^{B,D} = \eta \left(1 - v_{dn,k}^{B,D}\right) + (1-\eta)(1-v_{dn,dl}^{B,D})$, $d_{p,k}^{B,D} = \eta \left(v_{dn,k}^{B,D} - v_{k,dl}^{B,D}\right)$, $d_{p,dl}^{B,D} = \eta \left(v_{k,dl}^{B,D} - \hat{v}^{B,D}\right) + (1-\eta)(v_{dn,dl}^{B,D} - \hat{v}^{B,D})$, $d_{w,n}^{B,D} = 0$, and $d_{w,l}^{B,D} = \hat{v}^{B,D}$. The new-product demand in period two is $d_2^{B,D} = d_{p,dn}^{B,D} + d_{w,n}^{B,D} = \eta \left(1 - v_{dn,k}^{B,D}\right) + (1-\eta)(1 - v_{dn,dl}^{B,D})$. The retailer maximizes the second-period revenue:

$$\max_{p_2^{B,D}} r_2^{B,D} = p_2^{B,D} d_2^{B,D}, \text{ s.t. } p_2^{B,D} \geq \frac{s}{\theta}.$$

Adding Lagrange multiplier λ, $L\left(p_2^{B,D}, \lambda\right) = d_2^{B,D} p_2^{B,D} + \lambda \left(p_2^{B,D} - \frac{s}{\theta}\right)$, $\lambda \geq 0$, and $\lambda\left(p_2^{B,D}-\frac{s}{\theta}\right)=0$. $\frac{\partial^2 L\left(p_2^{B,D},\lambda\right)}{\partial {p_2^{B,D}}^2}=\frac{2-2\theta(1-\eta)}{\theta-1}<0$ and $\frac{\partial L\left(p_2^{B,D},\lambda\right)}{\partial p_2^{B,D}}=0 \Rightarrow p_2^{B,D*}(\lambda)=\frac{s\eta-\theta+1}{2-2\theta(1-\eta)}+\lambda$.

If $\lambda=0$, $p_2^{B,D*}=\frac{s\eta-\theta+1}{2-2\theta(1-\eta)}$, $r_2^{B,D*}=\frac{(\theta-s\eta-1)^2}{4(1+\theta(\eta-1))(1-\theta)}$.

If $\lambda>0$, $p_2^{B,D*}=\frac{s}{\theta}$, $r_2^{B,D*}=\frac{(\theta-s)s}{\theta^2}$.

The $r_2^{B,D*}$ derived under $\lambda>0$ is always less than that derived under $\lambda=0$.

The subgame equilibrium outcomes in Case 1 are: $p_2^{B,D*}=\frac{s\eta-\theta+1}{2-2\theta(1-\eta)}$, $d_2^{B,D*}=\frac{\theta-s\eta-1}{2(\theta-1)}$, $r_2^{B,D*}=\frac{(\theta-s\eta-1)^2}{4(1+\theta(\eta-1))(1-\theta)}$.

Case 2: $p_2^{B,D}\geq\frac{s}{\theta}$, $1\geq v_{dn,k}^{B,D}\geq v_{dn,dl}^{B,D}=v_{n,l}^{B,D}\geq\hat{v}^{B,D}\geq v_{k,dl}^{B,D}\geq 0$

Among consumers who perceive a peach, pre-owned ones choose between 'keep' and 'dispose and repurchase', while waited ones leave the market. Among consumers who perceive a lemon, pre-owned ones choose between 'dispose and repurchase' and 'dispose and leave', while waited ones leave the market. The market segmentation is shown in Figure A.7.

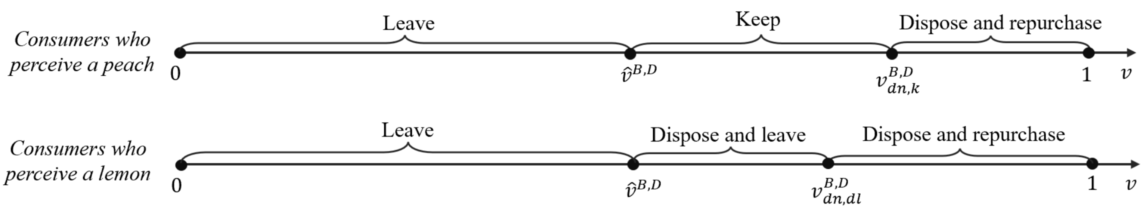


Figure A.7: Market segmentation in the absence of CRP with disposal, Case 2

The demands from various segments are $d_{p,dn}^{B,D}=\eta\left(1-v_{dn,k}^{B,D}\right)+(1-\eta)(1-v_{dn,dl}^{B,D})$, $d_{p,k}^{B,D}=\eta\left(v_{dn,k}^{B,D}-\hat{v}^{B,D}\right)$, $d_{p,dl}^{B,D}=(1-\eta)(v_{dn,dl}^{B,D}-\hat{v}^{B,D})$, $d_{w,n}^{B,D}=0$, and $d_{w,l}^{B,D}=\hat{v}^{B,D}$. The new-product demand in period two is $d_2^{B,D}=d_{p,dn}^{B,D}+d_{w,n}^{B,D}=\eta\left(1-v_{dn,k}^{B,D}\right)+(1-\eta)(1-v_{dn,dl}^{B,D})$. The retailer maximizes the period-two revenue:

$$\max_{p_2^{B,D}} r_2^{B,D}=p_2^{B,D}d_2^{B,D}, \text{ s.t. } p_2^{B,D}\geq\frac{s}{\theta}.$$

The subgame equilibrium in Case 2 is the same as Case 1, despite different constraints for $\hat{v}^{B,D}$.

Case 3: $p_2^{B,D} \geq \frac{s}{\theta}$, $1 \geq v_{dn,k}^{B,D} \geq \hat{v}^{B,D} \geq v_{dn,dl}^{B,D} = v_{n,l}^{B,D} \geq v_{k,dl}^{B,D} \geq 0$

Among consumers who perceive a peach, pre-owned ones choose between 'keep' and 'dispose and repurchase', while waited ones choose between 'buy new' and 'leave'. Among consumers who perceive a lemon, pre-owned ones choose 'dispose and repurchase', while waited ones choose between 'buy new' and 'leave'. The market segmentation is shown in Figure A.8.

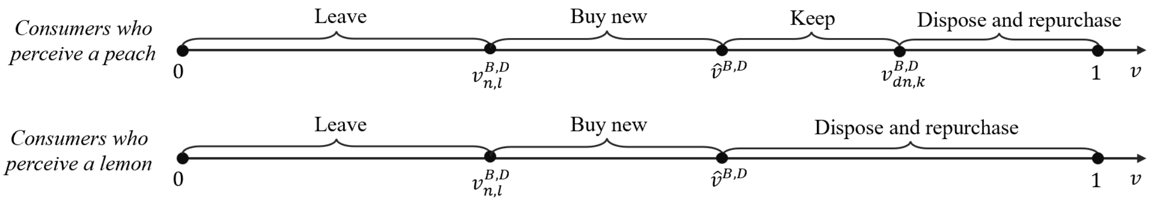


Figure A.8: Market segmentation in the absence of CRP with disposal, Case 3

The demands from various segments are $d_{p,dn}^{B,D} = \eta\left(1 - v_{dn,k}^{B,D}\right) + (1-\eta)(1-\hat{v}^{B,D})$, $d_{p,k}^{B,D} = \eta\left(v_{dn,k}^{B,D} - \hat{v}^{B,D}\right)$, $d_{p,dl}^{B,D} = 0$, and $d_{w,n}^{B,D} = \hat{v}^{B,D} - v_{n,l}^{B,D}$, and $d_{w,l}^{B,D} = v_{n,l}^{B,D}$. The new-product demand in period two is $d_2^{B,D} = d_{p,dn}^{B,D} + d_{w,n}^{B,D} = \eta\left(1 - v_{dn,k}^{B,D}\right) + (1-\eta)\left(1 - \hat{v}^{B,D}\right) + \hat{v}^{B,D} - v_{n,l}^{B,D}$.

The retailer maximizes period-two revenue:

$$\max_{p_2^{B,D}} r_2^{B,D} = p_2^{B,D} d_2^{B,D}, \text{ s.t. } p_2^{B,D} \geq \frac{s}{\theta}.$$

Adding Lagrange multiplier λ, $L\left(p_2^{B,D}, \lambda\right) = d_2^{B,D} p_2^{B,D} + \lambda\left(p_2^{B,D} - \frac{s}{\theta}\right)$, $\lambda \geq 0$, and $\lambda\left(p_2^{B,D} - \frac{s}{\theta}\right) = 0$. $\frac{\partial^2 L\left(p_2^{B,D},\lambda\right)}{\partial {p_2^{B,D}}^2} = \frac{2\eta}{\theta-1} - 2 < 0$ and $\frac{\partial L\left(p_2^{B,D},\lambda\right)}{\partial p_2^{B,D}} = 0 \Rightarrow p_2^{B,D*}(\hat{v}^{B,D}, \lambda) = \frac{\theta + \eta\left(\hat{v}^{B,D}(\theta-1) - s\right) - 1}{2(\theta-\eta-1)} + \lambda$.

If $\lambda = 0$, $p_2^{B,D*}\left(\hat{v}^{B,D}\right) = \frac{\theta + \eta\left(\hat{v}^{B,D}(\theta-1) - s\right) - 1}{2(\theta-\eta-1)}$, $r_2^{B,D*}\left(\hat{v}^{B,D}\right) = \frac{\left(\theta + \eta\left(\hat{v}^{B,D}(\theta-1) - s\right) - 1\right)^2}{4(\theta-\eta-1)(\theta-1)}$.

If $\lambda > 0$,$p_2^{B,D*} = \frac{s}{\theta}$, $r_2^{B,D*} = \frac{(\theta-s)s}{\theta^2}$.

The $r_2^{B,D*}$ derived under $\lambda > 0$ is always less than that under $\lambda = 0$ with $\hat{v}^{B,D} \geq v_{k,dl}^{B,D}$.

The subgame equilibrium in Case 3 are: $p_2^{B,D*}\left(\hat{v}^{B,D}\right) = \frac{\theta+\eta\left(\hat{v}^{B,D}(\theta-1)-s\right)-1}{2(\theta-\eta-1)}$, $d_2^{B,D*}\left(\hat{v}^{B,D}\right) = \frac{\theta+\eta\left(\hat{v}^{B,D}(\theta-1)-s\right)-1}{2(\theta-1)}$, $r_2^{B,D*}\left(\hat{v}^{B,D}\right) = \frac{\left(\theta+\eta\left(\hat{v}^{B,D}(\theta-1)-s\right)-1\right)^2}{4(\theta-\eta-1)(\theta-1)}$.

Case 4: $p_2^{B,D} \geq \frac{s}{\theta}$, $1 \geq \hat{v}^{B,D} \geq v_{dn,k}^{B,D} \geq v_{dn,dl}^{B,D} = v_{n,l}^{B,D} \geq v_{k,dl}^{B,D} \geq 0$

Pre-owned consumers choose 'dispose and repurchase', while waited consumers choose between 'buy new' and 'leave'. The market segmentation is shown in Figure A.9.

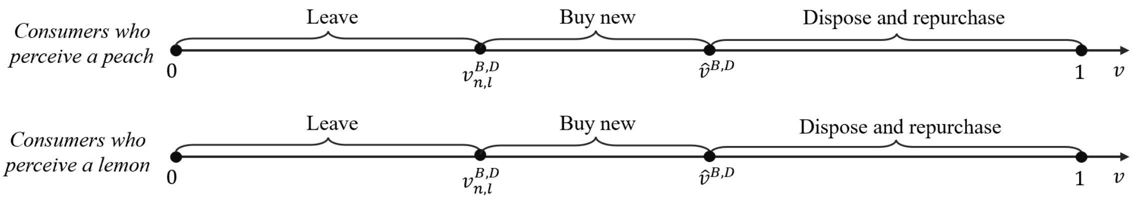


Figure A.9: Market segmentation in the absence of CRP with disposal, Case 4

The demands from various segments are $d_{p,dn}^{B,D} = 1 - \hat{v}^{B,D}$, $d_{p,k}^{B,D} = 0$, $d_{p,dl}^{B,D} = 0$, $d_{w,n}^{B,D} = \hat{v}^{B,D} - v_{n,l}^{B,D}$, and $d_{w,l}^{B,D} = v_{n,l}^{B,D}$. The new-product demand in period two is $d_2^{B,D} = d_{p,dn}^{B,D} + d_{w,n}^{B,D} = 1 - \hat{v}^{B,D} + \hat{v}^{B,D} - v_{n,l}^{B,D}$. The retailer maximizes period-two revenue:

$$\max_{p_2^{B,D}} r_2^{B,D} = p_2^{B,D} d_2^{B,D}, \text{ s.t. } p_2^{B,D} \geq \frac{s}{\theta}.$$

Adding Lagrange multiplier λ, $L\left(p_2^{B,D}, \lambda\right) = d_2^{B,D} p_2^{B,D} + \lambda\left(p_2^{B,D} - \frac{s}{\theta}\right)$, $\lambda \geq 0$, and $\lambda\left(p_2^{B,D} - \frac{s}{\theta}\right) = 0$. $\frac{\partial^2 L\left(p_2^{B,D},\lambda\right)}{\partial {p_2^{B,D}}^2} = -2 < 0$ and $\frac{\partial L\left(p_2^{B,D},\lambda\right)}{\partial p_2^{B,D}} = 0 \Rightarrow p_2^{B,D*}(\lambda) = \frac{1}{2} + \lambda$.

If $\lambda = 0$, $p_2^{B,D*} = \frac{1}{2}$, $r_2^{B,D*} = \frac{1}{4}$. If $\lambda > 0$, $p_2^{B,D*} = \frac{s}{\theta}$, $r_2^{B,D*} = \frac{(\theta-s)s}{\theta^2}$.

The $r_2^{B,D*}$ derived under $\lambda > 0$ is always less than that under $\lambda = 0$.

The subgame equilibrium outcomes in Case 4 are: $p_2^{B,D*} = \frac{1}{2}$, $d_2^{B,D*} = \frac{1}{2}$, $r_2^{B,D*} = \frac{1}{4}$.

Case 5: $p_2^{B,D} < \frac{s}{\theta}$, $1 \geq v_{k,dl}^{B,D} > v_{dn,dl}^{B,D} = v_{n,l}^{B,D} > v_{dn,k}^{B,D} \geq \hat{v}^{B,D} \geq 0$, $1 \geq v_{k,dl}^{B,D} > v_{dn,dl}^{B,D} = v_{n,l}^{B,D} \geq \hat{v}^{B,D} > v_{dn,k}^{B,D} \geq 0$, $1 \geq v_{k,dl}^{B,D} \geq \hat{v}^{B,D} > v_{dn,dl}^{B,D} = v_{n,l}^{B,D} > v_{dn,k}^{B,D} \geq 0$, $1 \geq \hat{v}^{B,D} \geq v_{k,dl}^{B,D} > v_{dn,dl}^{B,D} = v_{n,l}^{B,D} > v_{dn,k}^{B,D} \geq 0$

Pre-owned consumers choose between 'dispose and repurchase' and 'dispose and leave', while waited consumers leave the market. The market segmentation is shown in Figure A.10.

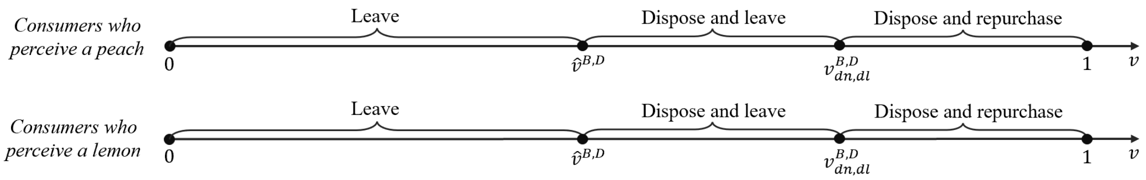


Figure A.10: Market segmentation in the absence of CRP with disposal, Case 5

The demands from various segments are $d^{B,D}_{p,dn} = 1 - v^{B,D}_{dn,dl}$, $d^{B,D}_{p,k} = 0$, $d^{B,D}_{p,dl} = v^{B,D}_{dn,dl} - \hat{v}^{B,D}$, $d^{B,D}_{w,n} = 0$, and $d^{B,D}_{w,l} = \hat{v}^{B,D}$. The new-product demand in period two is $d^{B,D}_2 = d^{B,D}_{p,dn} + d^{B,D}_{w,n} = 1 - v^{B,D}_{dn,dl}$. The retailer maximizes period-two revenue:

$$\max_{p_2^{B,D}} r_2^{B,D} = p_2^{B,D} d_2^{B,D}, \text{ s.t. } p_2^{B,D} < \frac{s}{\theta}.$$

Adding Lagrange multiplier λ, $L\left(p_2^{B,D}, \lambda\right) = d_2^{B,D} p_2^{B,D} + \lambda\left(\frac{s}{\theta} - p_2^{B,D}\right)$, $\lambda \geq 0$, and $\lambda\left(\frac{s}{\theta} - p_2^{B,D}\right) = 0$. $\frac{\partial^2 L\left(p_2^{B,D}, \lambda\right)}{\partial {p_2^{B,D}}^2} = -2 < 0$ and $\frac{\partial L\left(p_2^{B,D}, \lambda\right)}{\partial p_2^{B,D}} = 0 \Rightarrow p_2^{B,D*}(\lambda) = \frac{1}{2} - \lambda$.

If $\lambda = 0$, $p_2^{B,D*} = \frac{1}{2}$, $r_2^{B,D*} = \frac{1}{4}$. If $\lambda > 0$, $p_2^{B,D*} = \frac{s}{\theta}$, $r_2^{B,D*} = \frac{(\theta - s)s}{\theta^2}$.

$p_2^{B,D*} = \frac{s}{\theta}$ does not satisfy the constraint $p_2^{B,D} < \frac{s}{\theta}$. Besides, the $r_2^{B,D*}$ derived under $\lambda > 0$ is always less than that under $\lambda = 0$. Thus, the subgame equilibrium outcomes in Case 5 are $p_2^{B,D*} = \frac{1}{2}$, $d_2^{B,D*} = \frac{1}{2}$, $r_2^{B,D*} = \frac{1}{4}$.

Given marginal consumer type $\hat{v}^{B,D}$, comparing period-two revenue $r_2^{B,D}$, we find that (i) Benchmark Cases 1 and 2 achieve the same period-two revenue $r_2^{B,D*} = \frac{(\theta - s\eta - 1)^2}{4(1+\theta(\eta-1))(1-\theta)}$, where $r_2^{B,D*}$ is not influenced by $\hat{v}^{B,D}$; (ii) Benchmark Cases 4 and 5 achieve the same period-two revenue $r_2^{B,D*} = \frac{1}{4}$, where $r_2^{B,D*}$ is not influenced by $\hat{v}^{B,D}$; (iii) Benchmark Cases 1 and 2 dominate Case 3 when $\hat{v}^{B,D} < \bar{v}_I^{B,D}(\theta, \eta, s)$; (iv) Benchmark Case 3 dominates Cases 4 and 5 when $\hat{v}^{B,D} \geq \bar{v}_{II}^{B,D}(\theta, \eta, s)$; (v) Benchmark Cases 1 and 2 dominate Cases 4 and 5 when $s \geq \bar{s}(\theta, \eta)$. Since $1 > \bar{v}_I^{B,D} > \bar{v}_{II}^{B,D} > 0$

exists, $p_2^{B,D*} = \begin{cases} \frac{s\eta-\theta+1}{2-2\theta(1-\eta)} & if\ s \geq \bar{s}(\theta,\eta)\ and\ \hat{v}^{B,D} < \bar{v}_{II}^{B,D} \\ \frac{1}{2} & if\ s < \bar{s}(\theta,\eta)\ and\ \hat{v}^{B,D} < \bar{v}_{II}^{B,D} \\ \frac{s\eta-\theta+1}{2-2\theta(1-\eta)} & if\ \bar{v}_{II}^{B,D} \leq \hat{v}^{B,D} < \bar{v}_{I}^{B,D} \\ \frac{\theta+\eta\left(\hat{v}^{B,D}(\theta-1)-s\right)-1}{2(\theta-\eta-1)} & if\ \bar{v}_{I}^{B,D} \leq \hat{v}^{B,D} \end{cases}$. Note that $\bar{v}_I^{B,D}$, $\bar{v}_{II}^{B,D}$, and $\bar{s}(\theta,\eta)$ are shown in Table A.1.

To decide the optimal $\hat{v}^{B,D*}$, we push back to period one.

In period one, observing the new-product price $p_1^{B,D}$ and anticipating the retailer's selling behavior in period two, a consumer purchases a new product if $v \geq \hat{v}^{B,D}$, but postpones purchase to period two if $v < \hat{v}^{B,D}$. From the discussions above, we consider the following cases:

Case 1, 5. The marginal consumer is indifferent between 'purchase in period one and dispose of it to leave in period two' and 'wait in period one and leave in period two' for consumers who perceive either a peach or a lemon (See Figure A.6 and Figure A.10). The expected utility of purchasing for consumers who perceive either a peach or a lemon is $\eta\left(\hat{v}^{B,D} - p_1^{B,D} + s\right) + (1-\eta)\left(\hat{v}^{B,D} - p_1^{B,D} + s\right)$. The expected utility of postponing for consumers who perceive either a peach or a lemon is 0. We have:

$$\hat{v}^{B,D} - p_1^{B,D} + s = 0 \tag{A.4}$$

which implies that $\hat{v}^{B,D}\left(p_1^{B,D}\right) = p_1^{B,D} - s$.

The retailer maximizes total revenue:

$$\max r^{B,D}{}_{\hat{v}^{B,D}} = p_1^{B,D}\left(\hat{v}^{B,D}\right) d_1^{B,D}\left(\hat{v}^{B,D}\right) + r_2^{B,D*}\left(\hat{v}^{B,D}\right)$$

where $d_1^{B,D}\left(\hat{v}^{B,D}\right) = 1 - \hat{v}^{B,D}$. $\frac{\partial^2 r^{B,D}}{\partial \hat{v}^{B,D^2}} = -2 < 0$ and $\frac{\partial r^{B,D}}{\partial \hat{v}^{B,D}} = 0 \Rightarrow \hat{v}^{B,D*} = \frac{1-s}{2}$.

Case 2. The marginal consumer is indifferent between 'purchase in period one and keep it in period two' and 'wait in period one and leave in period two' for consumers who perceive a peach; and between 'purchase in period one and dispose of it to leave in period two' and 'wait in period one and leave in period two' for consumers who perceive a lemon (See Figure A.7. The expected utility of purchasing for consumers who perceive either a peach or a lemon is

$$\eta\left(\hat{v}^{B,D} - p_1^{B,D} + E(\theta)\hat{v}^{B,D}\right) + (1-\eta)\left(\hat{v}^{B,D} - p_1^{B,D} + s\right).$$

The expected utility of postponing for consumers who perceive either a peach or a lemon is 0. Recall that $E(\theta) = \eta\theta$. We have:

$$\eta\left(\hat{v}^{B,D} - p_1^{B,D} + \eta\theta\hat{v}^{B,D}\right) + (1-\eta)\left(\hat{v}^{B,D} - p_1^{B,D} + s\right) = 0 \tag{A.5}$$

which implies that $\hat{v}^{B,D}\left(p_1^{B,D}\right) = \frac{p_1^{B,D}+s(\eta-1)}{\theta\eta^2+1}$.

The retailer maximizes total revenue:

$$\max r^{B,D}{}_{\hat{v}^{B,D}} = p_1^{B,D}\left(\hat{v}^{B,D}\right) d_1^{B,D}\left(\hat{v}^{B,D}\right) + r_2^{B,D*}\left(\hat{v}^{B,D}\right)$$

where $d_1^{B,D}\left(\hat{v}^{B,D}\right) = 1 - \hat{v}^{B,D}$. $\frac{\partial^2 r^{B,D}}{\partial \hat{v}^{B,D^2}} = -2(\theta\eta^2+1) < 0$ and $\frac{\partial r^{B,D}}{\partial \hat{v}^{B,D}} = 0 \Rightarrow \hat{v}^{B,D*} = \frac{\theta\eta^2+s(\eta-1)+1}{2(\theta\eta^2+1)}$.

Case 3. The marginal consumer is indifferent between 'purchase in period one and keep in period two' and 'wait in period one and buy new in period two' for consumers who perceive a peach; and between 'purchase in period one and dispose of it to repurchase in period two' and 'wait in period one and buy new in period two' for consumers who perceive a lemon (See Figure A.8). The expected utility of purchasing for consumers who perceive either a peach or a lemon is $\eta\left(\hat{v}^{B,D} - p_1^{B,D} + E(\theta)\hat{v}^{B,D}\right) + (1-\eta)\left(\hat{v}^{B,D} - p_1^{B,D} + s + \hat{v}^{B,D} - p_2^{B,D}\right)$. The expected utility of postponed consumers who perceive peach or lemon is $\eta\left(\hat{v}^{B,D} - p_2^{B,D}\right) + (1-\eta)\left(\hat{v}^{B,D} - p_2^{B,D}\right)$. Recall that $E(\theta) = \eta\theta$. We have:

$$\eta\left(\hat{v}^{B,D} - p_1^{B,D} + \eta\theta\hat{v}^{B,D}\right) + (1-\eta)\left(\hat{v}^{B,D} - p_1^{B,D} + s + \hat{v}^{B,D} - p_2^{B,D}\right) = \hat{v}^{B,D} - p_2^{B,D} \tag{A.6}$$

which implies that $\hat{v}^{B,D}\left(p_1^{B,D}\right) = \frac{-s\eta^2+\eta\left(\theta(2s-1)-2p_1^{B,D}+1\right)-2\left(s-p_1^{B,D}\right)(\theta-1)}{-2\theta\eta^3+\eta^2(2\theta^2-\theta+1)-2\theta(\eta-1)-2}$.

The retailer maximizes total revenue:

$$\max r^{B,D}{}_{\hat{v}^{B,D}} = p_1^{B,D}\left(\hat{v}^{B,D}\right) d_1^{B,D}\left(\hat{v}^{B,D}\right) + r_2^{B,D*}\left(\hat{v}^{B,D}\right)$$

where $d_1^{B,D}\left(\hat{v}^{B,D}\right)=1-\hat{v}^{B,D}$. $\frac{\partial^2 r^{B,D}}{\partial \hat{v}^{B,D^2}}=\frac{-4\theta^2\eta^2+\theta\left(4\eta^3+3\eta^2+4(\eta-1)\right)-3\eta^2+4}{2(\theta-\eta-1)}<0$ and $\frac{\partial r^{B,D}}{\partial \hat{v}^{B,D}}=0 \Rightarrow \hat{v}^{B,D*}=\frac{2\theta^2\eta^2-\theta\left(2\eta^3+\eta^2+2(\eta-1)(s-1)\right)+\eta^2(1-2s)+2(s-1)}{4\theta^2\eta^2-\theta(4\eta^3+3\eta^2+4(\eta-1))+3\eta^2-4}$.

Case 4. The marginal consumer is indifferent between 'purchase in period one and dispose of it to repurchase in period two' and 'wait in period one and buy new in period two' for consumers who perceive either a peach or a lemon (See Figure A.9). The expected utility of purchasing for consumers who perceive peach or lemon is $\eta\left(\hat{v}^{B,D}-p_1^{B,D}+s+\hat{v}^{B,D}-p_2^{B,D}\right)+(1-\eta)\left(\hat{v}^{B,D}-p_1^{B,D}+s+\hat{v}^{B,D}-p_2^{B,D}\right)$. The expected utility of postponing for consumers who perceive either a peach or a lemon is $\eta\left(\hat{v}^{B,D}-p_2^{B,D}\right)+(1-\eta)\left(\hat{v}^{B,D}-p_2^{B,D}\right)$. We have:

$$\hat{v}^{B,D}-p_1^{B,D}+s+\hat{v}^{B,D}-p_2^{B,D}=\hat{v}^{B,D}-p_2^{B,D} \tag{A.7}$$

implying that $\hat{v}^{B,D}\left(p_1^{B,D}\right)=p_1^{B,D}-s$.

The retailer maximizes total revenue:

$$\max r^{B,D}{}_{\hat{v}^{B,D}}=p_1^{B,D}\left(\hat{v}^{B,D}\right)d_1^{B,D}\left(\hat{v}^{B,D}\right)+r_2^{B,D*}\left(\hat{v}^{B,D}\right)$$

where $d_1^{B,D}\left(\hat{v}^{B,D}\right)=1-\hat{v}^{B,D}$. $\frac{\partial^2 r^{B,D}}{\partial \hat{v}^{B,D^2}}=-2<0$ and $\frac{\partial r^{B,D}}{\partial \hat{v}^{B,D}}=0 \Rightarrow \hat{v}^{B,D*}=\frac{1-s}{2}$.

Comparing total revenue $r^{B,D*}$ in the cases with constraints, we find the optimal outcomes are from Cases 1 and 2, which are summarized in Table 3.7 and Figure 3.16. Specifically, when $s\geq s^{B,D}$, Case 1 dominates Case 2; otherwise, when $s<s^{B,D}$, Case 2 dominates Case 1. By the equilibrium outcomes, $p_1^{B,D*}>p_2^{B,D*}$ and $d_1^{B,D*}>d_2^{B,D*}$ exist. It can be verified that $\frac{\partial p_1^{B,D*}}{\partial s}>0$, $\frac{\partial p_2^{B,D*}}{\partial s}<0$, and $\frac{\partial v_p^{D*}}{\partial s}<0$, while $\frac{\partial v_l^{D*}}{\partial s}>0$.

Proof of Proposition 3.7. Denote

$$\Delta p_1^{B,D}=p_1^{B,D*}-p_1^{B*}=\begin{cases}\frac{\theta\eta^2+s(1-\eta)+1}{2}-\frac{\left(1+2\theta\eta^2\right)^2}{2(1+4\theta\eta^2)} & if\ s<s^{B,D}\\ \frac{1+s}{2}-\frac{\left(1+2\theta\eta^2\right)^2}{2(1+4\theta\eta^2)} & if\ s\geq s^{B,D}\end{cases}.$$

$\frac{\partial \Delta p_1^{B,D}}{\partial s}>0$, i.e., $\Delta p_1^{B,D}$ monotonically increases in s. If $s<s^{B,D}$, $p_1^{B,D*}>p_1^{B*}$ always exists. If $s\geq s^{B,D}$, $p_1^{B,D*}>p_1^{B*}$ when $s\geq\max\left\{\frac{4\theta^2\eta^4}{4\theta\eta^2+1},s^{B,D}\right\}$. Denote

$\Delta p_2^{B,D} = p_2^{B,D*} - p_2^{B*} = \frac{1-\theta+s\eta}{2(1-\theta(1-\eta))} - \frac{1+2\theta\eta^2}{2(1+4\theta\eta^2)}$. $\frac{\partial \Delta p_2^{B,D}}{\partial s} > 0$, i.e., $\Delta p_2^{B,D}$ monotonically increases in s. If $s < s^{B,D}$, $p_2^{B,D*} < p_2^{B*}$ always exists. If $s \geq s^{B,D}$, $p_2^{B,D*} > p_2^{B*}$ when $s \geq \max\left\{\frac{2\theta^2\eta^2-2\theta\eta(1-\theta)+\theta}{4\theta\eta^2+1}, s^{B,D}\right\}$. Denote $\Delta d_1^{B,D} = d_1^{B,D*} - d_1^{B*} = \begin{cases} \frac{\theta\eta^2+s(1-\eta)+1}{2(\theta\eta^2+1)} - \frac{2\theta\eta^2}{1+4\theta\eta^2} & if\ s < s^{B,D} \\ \frac{1+s}{2} - \frac{2\theta\eta^2}{1+4\theta\eta^2} & if\ s \geq s^{B,D} \end{cases}$. $\frac{\partial \Delta d_1^{B,D}}{\partial s} > 0$, i.e., $\Delta d_1^{B,D}$ monotonically increases in s, with $\Delta d_1^{B,D}\Big|_{s=0} = \frac{1}{2(1+4\theta\eta^2)} > 0$. Thus, $d_1^{B,D*} > d_1^{B*}$. Denote $\Delta d^{B,D} = d^{B,D*} - d^{B*} = \begin{cases} 1 + \frac{s\left(1+\theta\left(\eta^3+\eta-1\right)\right)}{2(\theta\eta^2+1)(1-\theta)} - \frac{1+6\theta\eta^2}{2(1+4\theta\eta^2)} & if\ s < s^{B,D} \\ 1 + \frac{s(1+\eta-\theta)}{2(1-\theta)} - \frac{1+6\theta\eta^2}{2(1+4\theta\eta^2)} & if\ s \geq s^{B,D} \end{cases}$. $\frac{\partial \Delta d^{B,D}}{\partial s} > 0$, i.e., $\Delta d^{B,D}$ monotonically increases in s, with $\Delta d^{B,D}\big|_{s=0} = \frac{1+2\theta\eta^2}{2(1+4\theta\eta^2)} > 0$. Thus, $d^{B,D*} > d^{B*}$. Denote $\Delta r^{B,D} = r^{B,D*} - r^{B*} = \begin{cases} \frac{\left(\theta\eta^2+s(1-\eta)+1\right)^2}{4(\theta\eta^2+1)} + \frac{(1-\theta+s\eta)^2}{4(1-\theta)(1-\theta(1-\eta))} - \frac{\left(1+2\theta\eta^2\right)^2}{4(1+4\theta\eta^2)} & if\ s < s^{B,D} \\ \frac{(1+s)^2}{4} + \frac{(1-\theta+s\eta)^2}{4(1-\theta)(1-\theta(1-\eta))} - \frac{\left(1+2\theta\eta^2\right)^2}{4(1+4\theta\eta^2)} & if\ s \geq s^{B,D} \end{cases}$. $\frac{\partial \Delta r^{B,D}}{\partial s} > 0$, i.e., $\Delta r^{B,D}$ monotonically increases in s, with $\Delta r^{B,D}|_{s=s^{B,D}} = \frac{\left(1+s^{B,D}\right)^2}{4} + \frac{\left(1-\theta+s^{B,D}\eta\right)^2}{4(1-\theta)(1-\theta(1-\eta))} - \frac{\left(1+2\theta\eta^2\right)^2}{4(1+4\theta\eta^2)} > 0$ if $s \geq s^{B,D}$ and $\Delta r^{B,D}|_{s=0} = \frac{1-\theta^2\eta^2(5-\eta)-\theta\left(1-5\eta^2\right)}{4(\theta\eta^2+1)(1-\theta(1-\eta))} > 0$ if $s < s^{B,D}$. Thus, $r^{B,D*} > r^{B*}$. Denote $\Delta E^{B,D} = E^{B,D} - E^B$. E^B can be rewritten as $(e_p + e_{un} + e_d)\, d^{B*} + e_{us} d_1^{B*}$ and $E^{B,D}$ can be rewritten as $(e_p + e_{un} + e_d)\, d^{B,D*} + e_{us} d_1^{B,D*}$. $d^{B,D*} > d^{B*} \Rightarrow (e_p + e_{un} + e_d)\, d^{B,D*} > (e_p + e_{un} + e_d)\, d^{B*}$ and $d_1^{B,D*} > d_1^{B*} \Rightarrow e_{us} d_1^{B,D*} > e_{us} d_1^{B*}$. As such, $E^{B,D} > E^B$. □

When the salvage value exceeds the net income of selling a used product on the CRP, i.e., $s_1 \geq (1-\tau)\, p_s^D$, disposal dominates reselling, reducing the system to be the one without CRP. Otherwise, i.e., $s_1 < (1-\tau)\, p_s^D$, the CRP is the channel for pre-owned consumers to sell used products. With $s_1 = s$ and $s_2 = 0$, the condition for sustaining used-product transactions on the CRP is $s < (1-\tau)\, p_s^D \Rightarrow s < s_T$. It can be verified that $\frac{\partial s_T}{\partial \eta} < 0$ and $\frac{\partial s_T}{\partial \tau} > 0$.

A.5 Extensions

A.5.1 New Entrants in Period Two

Proof. Denote

$$\Delta d_2^A = d_2^{A*} - d_2^{B,A*} = \frac{\begin{pmatrix} (1-\theta)\left(\theta^3\left(2\tau^2-34\right)-\theta^2\left(3\tau-23\right)+\theta\left(10-\tau\right)+1\right)+ \\ \theta\alpha\begin{pmatrix} \theta^3\left(\tau^3-5\tau^2-3\tau+23\right)+\frac{(\tau-2)\theta^2\left(\tau^2-16\tau+23\right)}{4}- \\ \theta\left(\frac{\tau^2}{2}-4\tau+11\right)+\frac{\tau}{4}-\frac{1}{2} \end{pmatrix}\end{pmatrix}}{2\Lambda_1\Lambda_2\left(1+4\theta\right)\left(1-\theta\right)}.$$

$\frac{\partial \Delta d_2^A}{\partial\theta} < 0$, i.e., Δd_2^A monotonically decreases in θ, with $\Delta d_2^A\big|_{\theta=0} = \frac{1}{2} > 0$ and $\lim_{\theta\to 1}\Delta d_2^A = -\infty$. $\Delta d_2^A = 0$ when $\theta = \theta_{d_2^A}(\tau)$. Thus, $\Delta d_2^A > 0$ when $\theta < \theta_{d_2^A}(\tau)$ while $\Delta d_2^A < 0$ when $\theta > \theta_{d_2^A}(\tau)$. □

A.5.2 CRP's Endogenized Commission Pricing

Proof of Proposition 3.8. The platform first sets a commission rate, responding to which the retailer sets new-product prices in the two periods. Based on the equilibrium outcomes, the platform's revenue is:

$$r_p = \tau p_s^* d_s^* = \frac{\begin{pmatrix} \theta^2\tau\left(\theta\left(\tau^2-7\tau+14\right)-\tau-2\right) \\ \left(\theta^3\left(\tau^3-6\tau^2+\tau+4\right)-2\theta^2\left(\tau^2-4\tau-9\right)+\theta\left(3\tau-20\right)-2\right)\end{pmatrix}}{8(\theta-1){\Lambda_1}^2{\Lambda_2}^2}.$$

$\frac{\partial r_p}{\partial\tau} = 0$ when $\tau = \tau(\theta)$. Differentiating $\tau(\theta)$ with θ, we find that $\frac{\partial\tau(\theta)}{\partial\theta} > 0$ when $\theta \in \left[\underline{\theta}, \bar{\theta}_1\right)$, $\frac{\partial\tau(\theta)}{\partial\theta} = 0$ when $\theta \in \left[\bar{\theta}_1, \bar{\theta}_2\right]$, and $\frac{\partial\tau(\theta)}{\partial\theta} < 0$ when $\theta \in \left(\bar{\theta}_2, 1\right]$. Note that $\bar{\theta}_1$ and $\bar{\theta}_2$ are the real roots to $\tau(\theta) = 1$, i.e., $320\theta^4\left(8\theta-5\right)-3\theta^2\left(408\theta-175\right)+141\theta+8 = 0$, with $\bar{\theta}_1 \approx 0.6349$ and $\bar{\theta}_2 \approx 0.7713$. To summarize, $\tau^* = 1$ if $\theta \in \left[\bar{\theta}_1, \bar{\theta}_2\right]$, while $\tau^* = \tau(\theta) < 1$ if $\theta \in \left[\underline{\theta}, \bar{\theta}_1\right)$ and $\theta \in \left(\bar{\theta}_2, 1\right]$. Moreover, we find that, when $\theta \geq \bar{\theta}_r$, $\tau^* \geq {\theta_r}^{-1}(\tau)$, where ${\theta_r}^{-1}(\cdot)$ is the inverse function of $\theta_r(\cdot)$; otherwise, when $\underline{\theta} \leq \theta < \bar{\theta}_r$, $\tau^* < {\theta_r}^{-1}(\tau)$. Specifically, $\bar{\theta}_1 < \bar{\theta}_r$, i.e., $0.6349 < 0.6400$. □

Appendix B

Supplementary Material for Chapter 4

B.1 Thresholds

The thresholds used in this chapter and the appendices are summarized in Table B.1.

B.2 Equilibrium

B.2.1 Fully Covered Market

Given new-product price in period one p_1 and marginal consumer type $\hat{\varepsilon}$, using backward induction, we first derive market segmentation in period two. For the active consumers, "resell and buy new" option always dominates the "resell and leave" option since $v + \varepsilon - p_2 + (1-\tau)\,p_s \geq (1-\tau)\,p_s \Leftrightarrow p_2 \leq v + \varepsilon$. We compare options "keep" with utility θv and "resell and buy new" with utility $v + \varepsilon - p_2 + (1-\tau)\,p_s$.

Table B.1: List of thresholds

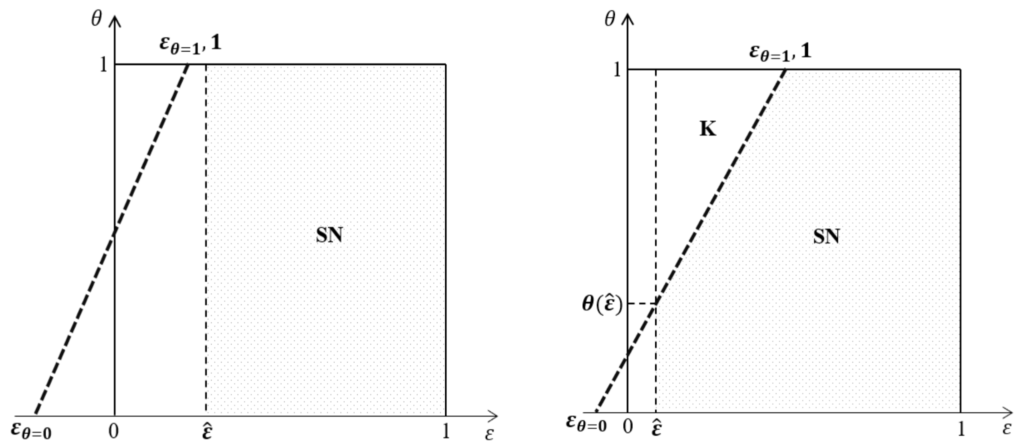
Thresholds	Mathematical expressions
$\tilde{v}^r(\tau)$	$\dfrac{\begin{pmatrix} (21\sqrt{3}-36)4\tau^5-(147\sqrt{3}+252)2\tau^4+(108\sqrt{3}+189)4\tau^3- \\ (41\sqrt{3}+71)8\tau^2+(31\sqrt{3}+53)4\tau-(18\sqrt{3}+32) \end{pmatrix}}{\begin{pmatrix} (36\sqrt{3}+63)2\tau^6-\left(70\sqrt{3}+123\right)3\tau^5+\left(77\sqrt{3}+132\right)3\tau^4- \\ \left(34\sqrt{3}+57\right)2\tau^3-\left(29\sqrt{3}+49\right)\tau^2+\left(46\sqrt{3}+79\right)\tau-(9\sqrt{3}+16) \end{pmatrix}}$
$\tilde{\tau}^{r*}$	$\frac{C_1^2+C_1(2-v)+7v^2-10v+1}{3C_1v}$
$\tilde{v}_1^{r*}$	$\frac{8\sqrt{2}\left(C_2{}^2-13C_2+35\right)-2C_2{}^2\left(C_2{}^2-17\right)-2(72C_2-175)}{4\sqrt{2}\left(-5C_2{}^2-4C_2+46\right)+C_2{}^2\left(3C_2{}^2-29\right)-20C_2+223} \approx 0.596$
$\tilde{v}_2^{r*}$	$\frac{3\sqrt{2}(3C_3+65)-C_3{}^2\left(4C_3{}^2+51\right)+41C_3+270}{3\sqrt{2}\left(3C_3{}^2-3C_3-38\right)+2C_3{}^2\left(2C_3{}^2-21\right)-4(5C_3+39)} \approx 0.880$
$\tilde{v}^c(\tau)$	Given τ, v satisfies $v=\frac{4\bar{\varepsilon}^2\left(\bar{\varepsilon}^2\tau-2\bar{\varepsilon}(\tau+1)+\tau\right)}{(8-19\tau)\bar{\varepsilon}^2+8\bar{\varepsilon}(1-2\tau)-4\tau}$
$\tilde{v}^s(\tau)$	Given τ, v satisfies $v=\frac{4\bar{\varepsilon}\left(1-\bar{\varepsilon}^2\right)}{12\bar{\varepsilon}^2-13\bar{\varepsilon}+4}$
C_1	$\sqrt[3]{\left(3\sqrt{2}-19\right)v^3+\left(18\sqrt{2}+33\right)v^2-\left(27\sqrt{2}+39\right)v+17+12\sqrt{2}}$
C_2	$\sqrt[3]{16\sqrt{2}+13}$
C_3	$\sqrt[3]{17+12\sqrt{2}}$
C_4	$\begin{pmatrix} 595v^6+2574v^5+1185v^4+ \\ 36v^2\sqrt{\frac{3\left(-9v^9+51v^8-323v^7-2438v^6-2523v^5+3858v^4-1581v^3+258v^2-10v-1\right)}{v}}- \\ 828v^3+165v^2-18v-1 \end{pmatrix}^{\frac{1}{3}}$
C_5	$\frac{C_4\left(C_4+v^2-6v+1\right)+73v^4+204v^3-146v^2+12v+1}{18vC_4}$
C_6	$2\sqrt{v\left(v\left(\tau-\frac{1}{2}\right)^2-\tau+1\right)}$
C_7	$\sqrt{4\tau^2-8\tau+5}$
$\bar{v}^r$	$\frac{2}{\sqrt{3}+1}$
$\bar{\tau}^r$	$\frac{\sqrt{3}}{3}$
$\bar{v}^c$	The real root to $4v^4-5v^3-4v^2+4v=0$, which approximates to 0.7242
$\bar{\tau}^c$	$\frac{27+\sqrt{5}-\sqrt{118\sqrt{5}-98}}{32} \approx 0.5112$
$\bar{v}^s$	$\frac{13}{16}$
$\bar{\tau}^s$	The real root to $\dfrac{\begin{pmatrix} 16\left(\tau^2(\tau+1)+C_7\right)+\tau\left(4C_7^2+4C_7-82\right)- \\ 2C_7^2-21C_7+55 \end{pmatrix}}{48\tau^2+\tau(24C_7-98)-25C_7+57}=0$, which approximates to 0.7073
$\bar{v}_p$	$\frac{2}{\sqrt{13}-1}$
$\bar{\tau}_p$	$\frac{5\sqrt[3]{6912^2}+120\sqrt[3]{6912}+1440}{6\sqrt[3]{6912^2}+168\sqrt[3]{6912}+2304} \approx 0.7212$
$\underline{\varepsilon}$	$\frac{v(\tau-1)+\sqrt{v(\tau-1)(v(\tau-1)-4)}}{2}$
$\bar{\varepsilon}$	$\frac{v(2\tau-1)+C_6}{2}$

The perceived quality level of used product at which consumer is indifferent between the two options is $\theta=\frac{\varepsilon}{v}+\frac{v-p_2+(1-\tau)p_s}{v}$. The active consumer keeps the used product at a perceived high-quality level, i.e., $\theta>\frac{\varepsilon}{v}+\frac{v-p_2+(1-\tau)p_s}{v}$, but sells the used product and buys a new one at a perceived low-quality level, i.e., $\theta<\frac{\varepsilon}{v}+\frac{v-p_2+(1-\tau)p_s}{v}$. In Figure B.1, the curve $\theta=\frac{\varepsilon}{v}+\frac{v-p_2+(1-\tau)p_s}{v}$ is the dashed line with positive slope $\frac{1}{v}$.

An intuitive situation is $p_2 > p_s$, when the price for new product exceeds that of used product. Under the assumption $p_2 \leq v$, when $p_2 > p_s$, the line $\theta = \frac{\varepsilon}{v} + \frac{v - p_2 + (1-\tau)p_s}{v}$ intercepts the horizontal axis at $\varepsilon_{\theta=0} = p_2 - (1-\tau)\,p_s - v < 0$; and horizontal line $\theta = 1$ at $\varepsilon_{\theta=1} = p_2 - (1-\tau)\,p_s > 0$, with $\varepsilon_{\theta=1} > \varepsilon_{\theta=0}$ since $\varepsilon_{\theta=1} - \varepsilon_{\theta=0} = v$. The line intercepts $\varepsilon = 1$ at $\theta = \frac{\varepsilon}{v} + \frac{v - p_2 + (1-\tau)p_s}{v} > 1$ because $p_2 > p_s$. $[\hat{\varepsilon}, 1]$ is the range for the types of the active consumers. To compare $\hat{\varepsilon}$ and $\varepsilon_{\theta=1}$, we consider two possible segments of the active consumers as Table B.2 and Figure B.1 explicated. Here a, b denote the two constraints that lead to different market situations.

Table B.2: Constraints in the presence of CRP

Constraint	Condition
(a)	$\hat{\varepsilon} \geq \varepsilon_{\theta=1}$, i.e., $p_2 \leq (1-\tau)p_s + \hat{\varepsilon}$
(b)	$\hat{\varepsilon} < \varepsilon_{\theta=1}$, i.e., $p_2 > (1-\tau)p_s + \hat{\varepsilon}$



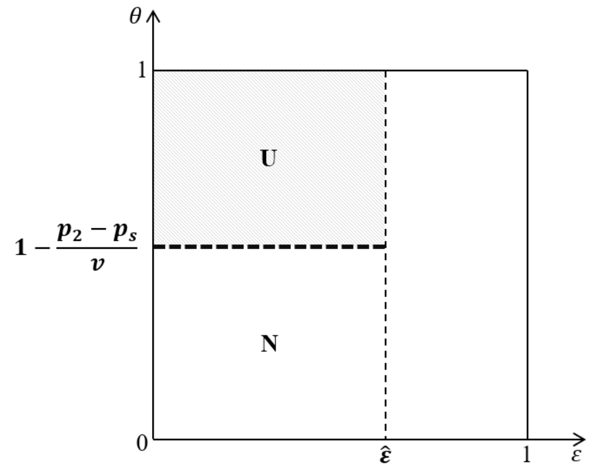
(a) (b)

Notes. "SN" denotes the choice "resell and buy new" and "K" denotes the choice "keep".

Figure B.1: Segmentation of active consumers

Under constraint (a), as shown in Figure B.1(a), all the active consumers choose the option "resell and buy new" and no one keeps the product. The number of active consumers who choose the "resell and buy new" option is $d_{a,sn} = 1 - \hat{\varepsilon}$. Under constraint (b), as shown in Figure B.1(b), most active consumers choose the "resell and buy new" option and the remaining active consumers choose the "keep the used" option. Note that $\theta(\hat{\varepsilon}) = \frac{\hat{\varepsilon}}{v} + \frac{v-p_2+(1-\tau)p_s}{v}$. The number of "resell and buy new" segment of the active consumers is $d_{a,sn} = \frac{(\theta(\hat{\varepsilon})+1)(\varepsilon_{\theta=1}-\hat{\varepsilon})}{2} + 1 - \varepsilon_{\theta=1} = \frac{2p_s(\hat{\varepsilon}-p_2)(\tau-1)-(\tau-1)^2{p_s}^2-\hat{\varepsilon}^2+2\hat{\varepsilon}(p_2-v)-{p_2}^2+2v}{2v}$.

In period two, the reserved consumers purchase used products under the condition $\theta v - p_s > \max\{0, v-p_2\}$ but new products when $v - p_2 > \max\{0, \theta v - p_s\}$. Since $p_2 \le v$, each of them will purchase a product and no consumers leave. Then, $\theta = 1 - \frac{p_2-p_s}{v} \Leftrightarrow \theta v - p_s = v - p_2$ is the perceived quality level of used product at which a consumer is indifferent between purchasing a used and a new product. A reserved consumer purchases a used product when the perceived quality level is low, i.e., $\theta > 1 - \frac{p_2-p_s}{v}$, but purchases a new product otherwise. This is illustrated as the horizontal dashed line for the segment for the reserved consumers in $[0,\hat{\varepsilon}]$ in Figure B.2. The number of "buy used" segment of the reserved consumers is $d_{r,u} = \hat{\varepsilon}\left(1-\left(1-\frac{p_2-p_s}{v}\right)\right) = \frac{\hat{\varepsilon}(p_2-p_s)}{v}$, and that of "buy new" segment of the reserved consumers is $d_{r,n} = \hat{\varepsilon}\left(1-\frac{p_2-p_s}{v}\right)$.



Notes. "U" denotes the choice "buy used" and "N" denotes the choice "buy new".

Figure B.2: Segmentation of reserved consumers

To derive $p_s^*(p_2)$, we let the "resell and buy new" segment of the active consumers (used-product supply) equal in number to "buy used" segment of the reserved consumers (used-product demand), i.e., $d_{a,sn} = d_{r,u}$. Since $d_{a,sn}$ is different under constraints (a) and (b), we derive $p_s^*(p_2)$ under constraints (a) and (b) respectively. In the following analysis, we prove that the market outcome under constraint (b) is inferior to the market outcome under constraint (a).

1. under constraint (a) $\hat{\varepsilon} \geq \varepsilon_{\theta=1}$: $d_{a,sn} = 1 - \hat{\varepsilon}$ and $d_{r,u} = \frac{\hat{\varepsilon}(p_2 - p_s)}{v}$. $d_{a,sn} = d_{r,u} \Rightarrow p_s^*(p_2) = \frac{\hat{\varepsilon}(v+p_2)-v}{\hat{\varepsilon}} = p_2 - \frac{1-\hat{\varepsilon}}{\hat{\varepsilon}} v$.

2. under constraint (b) $\hat{\varepsilon} < \varepsilon_{\theta=1}$: $d_{a,sn} = \frac{2p_s(\hat{\varepsilon}-p_2)(\tau-1)-(\tau-1)^2 {p_s}^2 - \hat{\varepsilon}^2 + 2\hat{\varepsilon}(p_2 - v) - {p_2}^2 + 2v}{2v}$ and $d_{r,u} = \frac{\hat{\varepsilon}(p_2-p_s)}{v}$. From $d_{a,sn} = d_{r,u}$, we can derive the function that $p_s^*(p_2) = \frac{\tau(\hat{\varepsilon}-p_2)+p_2-\sqrt{\hat{\varepsilon}^2(2\tau-1)-2\hat{\varepsilon}(\tau(v+p_2)-v)(\tau-1)+2v(\tau-1)^2}}{(\tau-1)^2}$.

We first derive the period-two new-product price which maximizes $r_2 = d_2 p_2$, where $d_2 = d_{a,sn} + d_{r,n}$. Under constraint (a), $d_2 = 1 - \hat{\varepsilon} + \hat{\varepsilon}\left(1 - \frac{p_2 - p_s^*(p_2)}{v}\right)$. Substituting $p_s^*(p_2) = \frac{\hat{\varepsilon}(v+p_2)-v}{\hat{\varepsilon}}$ and $d_2 = \hat{\varepsilon}$. Under constraint (b), we know $d_2 = \frac{2p_s^*(p_2)(\hat{\varepsilon}-p_2)(\tau-1)-(\tau-1)^2 p_s^*(p_2)^2 - \hat{\varepsilon}^2 + 2\hat{\varepsilon}(p_2-v) - {p_2}^2 + 2v}{2v} + \hat{\varepsilon}\left(1 - \frac{p_2 - p_s^*(p_2)}{v}\right)$. Substituting $p_s^*(p_2) = \frac{\tau(\hat{\varepsilon}-p_2)+p_2-\sqrt{\hat{\varepsilon}^2(2\tau-1)-2\hat{\varepsilon}(\tau(v+p_2)-v)(\tau-1)+2v(\tau-1)^2}}{(\tau-1)^2}$, we have $d_2 = \hat{\varepsilon}$. Thus, period-two new-product demands are the same under the two constraints; the period-two revenue is $r_2 = \hat{\varepsilon} p_2$. Then, we derive the subgame equilibrium period-two revenue under different constraints.

(1) Subgame under constraint (a) $\hat{\varepsilon} \geq \varepsilon_{\theta=1}$

Constraint (a) $\hat{\varepsilon} \geq \varepsilon_{\theta=1} = p_2 - (1-\tau)p_s \Rightarrow p_2 \leq \frac{\hat{\varepsilon}^2 - v(1-\tau)(1-\hat{\varepsilon})}{\hat{\varepsilon}\tau}$, since $p_s^*(p_2) = \frac{\hat{\varepsilon}(v+p_2)-v}{\hat{\varepsilon}}$. The retailer's problem is: $\max_{p_2} r_2 = \hat{\varepsilon} p_2$, s.t. $p_2 \leq \frac{\hat{\varepsilon}^2 - v(1-\tau)(1-\hat{\varepsilon})}{\hat{\varepsilon}\tau}$ and $p_2 \leq v$. Adding Lagrange multipliers λ_1 and λ_2, we have $L(p_2, \lambda_1, \lambda_2) = \hat{\varepsilon} p_2 + \lambda_1\left(\frac{\hat{\varepsilon}^2 - v(1-\tau)(1-\hat{\varepsilon})}{\hat{\varepsilon}\tau} - p_2\right) + \lambda_2(v - p_2)$. $\lambda_1\left(\frac{\hat{\varepsilon}^2 - v(1-\tau)(1-\hat{\varepsilon})}{\hat{\varepsilon}\tau} - p_2\right) = 0$, $\lambda_2(v-p_2) = 0$ and $\lambda_1, \lambda_2 \geq 0$. Since $\frac{\partial L}{\partial p_2} = \hat{\varepsilon} - \lambda_1\tau - \lambda_2 \geq 0$ and $\frac{\partial^2 L}{\partial {p_2}^2} = 0$, $L(p_2, \lambda_1, \lambda_2)$ increases linearly. We consider three boundary solutions as follows.

1. when $\lambda_1 \neq 0$ and $\lambda_2 = 0$: $p_2^* = \frac{\hat{\varepsilon}^2 - v(1-\tau)(1-\hat{\varepsilon})}{\hat{\varepsilon}\tau}, \lambda_1 = \frac{\hat{\varepsilon}}{\tau}, d_2^* = \hat{\varepsilon}$, and $r_2^* =$

$\frac{\hat{\varepsilon}^2 - v(1-\tau)(1-\hat{\varepsilon})}{\tau}$. To satisfy the constraints, i.e., $0 < p_2^* < v$, we obtain the boundary condition for $\hat{\varepsilon}$ as $\left(\frac{v(2\tau-1)+C_6}{2}\right) > \hat{\varepsilon} > \frac{v(\tau-1)+\sqrt{v(\tau-1)(v(\tau-1)-4)}}{2}$.

2. when $\lambda_1 = 0$ and $\lambda_2 \neq 0 : p_2^* = v$, $\lambda_2 = \hat{\varepsilon}$, $d_2^* = \hat{\varepsilon}$, and $r_2^* = \hat{\varepsilon} v$. To ensure that the result satisfies constraints, i.e., $0 < p_2^* < \frac{\hat{\varepsilon}^2 - v(1-\tau)(1-\hat{\varepsilon})}{\hat{\varepsilon}\tau}$, $\hat{\varepsilon} > \frac{v(2\tau-1)+C_6}{2}$;

3. when $\lambda_1 \neq 0$ and $\lambda_2 \neq 0$: $p_2^* = v$, $\lambda_1\,(\lambda_2) = \frac{v(2\tau-1)+C_6-2\lambda_2}{2\tau}$, $d_2^* = \hat{\varepsilon}$, and $r_2^* = \hat{\varepsilon} v$, where $\hat{\varepsilon} = \left(\frac{v(2\tau-1)+C_6}{2}\right)$.

To simplify expressions, we divide the feasible domain of $\hat{\varepsilon}$ as shown in Figure B.3, where $\underline{\varepsilon} = \frac{v(\tau-1)+\sqrt{v(\tau-1)(v(\tau-1)-4)}}{2}$ and $\bar{\varepsilon} = \left(\frac{v(2\tau-1)+C_6}{2}\right)$. To check the feasibility of $\underline{\varepsilon}$ and $\bar{\varepsilon}$, we need to ensure that the square root in the formulas are non-negative. For $\underline{\varepsilon}$, $v(\tau-1)\,(v(\tau-1)-4) \geq 0$ since $v(\tau-1) \leq 0$ and $v(\tau-1)-4 < 0$ for $\tau \in [0,1]$ and $v \in [0,1]$. For $\bar{\varepsilon}$, $v\left(\tau - \frac{1}{2}\right)^2 - \tau + 1 \geq 0$ when $v \geq \frac{4(\tau-1)}{(2\tau-1)^2}$, which is always the case since $\frac{4(\tau-1)}{(2\tau-1)^2} \leq 0$ for $\tau \in [0,1]$. It can be verified that $\bar{\varepsilon} > \underline{\varepsilon}$ when $\tau \neq 0$, and $\bar{\varepsilon} = \underline{\varepsilon}$ when $\tau = 0$.

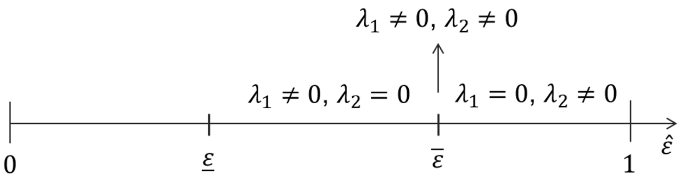


Figure B.3: The feasible domain of different boundary solutions

Comparing period-two revenues in different conditions, we have:

1. when $\lambda_1 = 0$ and $\lambda_2 \neq 0$: $r_2^* = \hat{\varepsilon} v$ with $\hat{\varepsilon} > \bar{\varepsilon}$ exceeds period-two revenue in the case where $\lambda_1 \neq 0$ and $\lambda_2 \neq 0$, i.e., $r_2^* = \bar{\varepsilon} v$;

2. when $\lambda_1 \neq 0$ and $\lambda_2 = 0$: $r_2^* = \frac{\hat{\varepsilon}^2 - v(1-\tau)(1-\hat{\varepsilon})}{\tau}$ with $\hat{\varepsilon} \in (\underline{\varepsilon}, \bar{\varepsilon})$. When $\lambda_1 = 0$ and $\lambda_2 \neq 0$, $r_2^* = \hat{\varepsilon} v$ with $\hat{\varepsilon} > \bar{\varepsilon}$. Instead of directly comparing $r_2^* = \frac{\hat{\varepsilon}^2 - v(1-\tau)(1-\hat{\varepsilon})}{\tau}$ with $\hat{\varepsilon} \in (\underline{\varepsilon}, \bar{\varepsilon})$ and $r_2^* = \hat{\varepsilon} v$ with $\hat{\varepsilon} > \bar{\varepsilon}$, under constraint (a), we list possible subgame equilibria in Table B.3 and consider both cases in period one.

(2) Subgame under constraint (b) $\hat{\varepsilon} < \varepsilon_{\theta=1}$

Constraint (b) $\hat{\varepsilon} < \varepsilon_{\theta=1} = p_2 - (1-\tau)\,p_s \Rightarrow p_2 > \frac{\hat{\varepsilon}^2 - v(1-\tau)(1-\hat{\varepsilon})}{\hat{\varepsilon}\tau}$ since $p_s^*\,(p_2) = \frac{\tau(\hat{\varepsilon}-p_2)+p_2-\sqrt{\hat{\varepsilon}^2(2\tau-1)-2\hat{\varepsilon}(\tau(v+p_2)-v)(\tau-1)+2v(\tau-1)^2}}{(\tau-1)^2}$. The period-two problem is: $\max_{p_2} r_2 = \hat{\varepsilon}p_2$, s.t. $p_2 > \frac{\hat{\varepsilon}^2 - v(1-\tau)(1-\hat{\varepsilon})}{\hat{\varepsilon}\tau}$ and $p_2 \leq v$. Adding Lagrange multipliers, we have $L\,(p_2, \lambda_1, \lambda_2) = \hat{\varepsilon}p_2 + \lambda_1 \left(p_2 - \frac{\hat{\varepsilon}^2 - v(1-\tau)(1-\hat{\varepsilon})}{\hat{\varepsilon}\tau}\right) + \lambda_2\,(v - p_2)$, with $\lambda_2\,(v - p_2) = 0$, $\lambda_1, \lambda_2 \geq 0$, and $\lambda_1 \left(p_2 - \frac{\hat{\varepsilon}^2 - v(1-\tau)(1-\hat{\varepsilon})}{\hat{\varepsilon}\tau}\right) = 0$. Since $p_2 > \frac{\hat{\varepsilon}^2 - v(1-\tau)(1-\hat{\varepsilon})}{\hat{\varepsilon}\tau}$, $\lambda_1 = 0$. $\frac{\partial L}{\partial p_2}\,(\lambda_1 = 0) = \hat{\varepsilon} - \lambda_2 = 0, \frac{\partial^2 L}{\partial {p_2}^2} = 0$. Thus, $L\,(p_2, \lambda_1, \lambda_2)$ is linear and monotonically increases in p_2. Then, we have:

1. when $\hat{\varepsilon} = \lambda_2 = 0$, all consumers purchase new products in period one and keep them in period two. Transactions on CRP do not exist.

2. when $\hat{\varepsilon} = \lambda_2 \neq 0$, $p_2^* = v$, $p_s^* = \frac{\tau(\hat{\varepsilon}-p_2)+p_2-\sqrt{\hat{\varepsilon}^2(2\tau-1)-2\hat{\varepsilon}(\tau(v+p_2)-v)(\tau-1)+2v(\tau-1)^2}}{(\tau-1)^2}$, $\lambda_2 = \hat{\varepsilon}$, $d_2^* = \hat{\varepsilon}$, and $r_2^* = \hat{\varepsilon}v$. In this case, the constraint $p_2^* > \frac{\hat{\varepsilon}^2 - v(1-\tau)(1-\hat{\varepsilon})}{\hat{\varepsilon}\tau}$ should be satisfied, which leads to $v > \frac{\hat{\varepsilon}^2 - v(1-\tau)(1-\hat{\varepsilon})}{\hat{\varepsilon}\tau}$, i.e., $\hat{\varepsilon} < \bar{\varepsilon}$. Note that under constraint (a), when Lagrange multipliers $\lambda_1 = 0$ and $\lambda_2 \neq 0$, the retailer's period-two revenue is $r_2^* = \hat{\varepsilon}v$ with $\hat{\varepsilon} > \bar{\varepsilon}$. It exceeds the period-two revenue in this case, i.e., $r_2^* = \hat{\varepsilon}v$ with $\hat{\varepsilon} < \bar{\varepsilon}$. Therefore, the retailer set prices that meet constraint (a) to maximize period-two revenue.

In the following analysis, we focus on the subgame equilibrium derived from constraint (a), as summarized in Table B.3. The option "resell and buy new" always dominates the options "keep" and "resell and leave" for the active consumers; and the reserved consumers only choose from two options, "buy used" and "buy new". No consumers leave without purchase and the market is fully covered.

Substituting each subgame equilibrium into Equation 4.2, the inverse function of p_1 about $\hat{\varepsilon}$ is $p_1(\hat{\varepsilon}) = \frac{2\hat{\varepsilon}^3 - v\hat{\varepsilon}^2(\tau-2)+2v\hat{\varepsilon}(2\tau-1)-v\tau}{2\tau\hat{\varepsilon}^2}$ when Lagrange multipliers $\lambda_1 \neq 0$ and $\lambda_2 = 0$, $\hat{\varepsilon} \in (\underline{\varepsilon}, \bar{\varepsilon})$, and $p_1(\hat{\varepsilon}) = \frac{\hat{\varepsilon}^2(3\tau v+2)+2v\hat{\varepsilon}(1-\tau)+v(\tau-2)}{2\tau\hat{\varepsilon}^2}$ when Lagrange multipliers $\lambda_1 = 0$ and $\lambda_2 \neq 0$, $\hat{\varepsilon} > \bar{\varepsilon}$. Finally, we solve problem $\max_{p_1} r = p_1 d_1 + r_2^*\,(\hat{\varepsilon})$, where

Table B.3: Subgame equilibrium outcomes

	When Lagrange multipliers $\lambda_1 \neq 0$ and $\lambda_2 = 0$, $\hat{\varepsilon} \in (\underline{\varepsilon}, \bar{\varepsilon})$	When Lagrange multipliers $\lambda_1 = 0$ and $\lambda_2 \neq 0$, $\hat{\varepsilon} > \bar{\varepsilon}$
Period-two new-product price	$p_2^*(\hat{\varepsilon}) = \frac{\hat{\varepsilon}^2 - v(1-\tau)(1-\hat{\varepsilon})}{\hat{\varepsilon}\tau}$	$p_2^*(\hat{\varepsilon}) = v$
Period-two new-product demand	$d_2^*(\hat{\varepsilon}) = \hat{\varepsilon}$	$d_2^*(\hat{\varepsilon}) = \hat{\varepsilon}$
Used-product price	$p_s^*(\hat{\varepsilon}) = \frac{\hat{\varepsilon}^2 - v(1-\hat{\varepsilon})}{\hat{\varepsilon}\tau}$	$p_s^*(\hat{\varepsilon}) = \frac{\hat{\varepsilon}^2 - v(1-\hat{\varepsilon})}{\hat{\varepsilon}\tau}$
Used-product demand	$d_s^*(\hat{\varepsilon}) = 1 - \hat{\varepsilon}$	$d_s^*(\hat{\varepsilon}) = 1 - \hat{\varepsilon}$
Period-two revenue	$r_2^*(\hat{\varepsilon}) = \frac{\hat{\varepsilon}^2 - v(1-\tau)(1-\hat{\varepsilon})}{\tau}$	$r_2^*(\hat{\varepsilon}) = \hat{\varepsilon}v$

d_1 equals $1 - \hat{\varepsilon}$ and $r_2^*(\hat{\varepsilon})$ is the period-two revenue in subgame equilibrium. When Lagrange multipliers $\lambda_1 \neq 0$ and $\lambda_2 = 0$, we solve:

$$\max_{\hat{\varepsilon}} r = p_1 d_1 + r_2^*(\hat{\varepsilon}) = \frac{\hat{\varepsilon}^3 (2 - \tau v) + v\hat{\varepsilon}^2 (2 - 3\tau) + v\hat{\varepsilon} (5\tau - 2) - v\tau}{2\tau\hat{\varepsilon}^2}, \text{ s.t. } \hat{\varepsilon} \in (\underline{\varepsilon}, \bar{\varepsilon}).$$

In this case, we find $\frac{\mathrm{d}r}{\mathrm{d}\hat{\varepsilon}} = \frac{\hat{\varepsilon}^3(2-\tau v)+v\hat{\varepsilon}(2-5\tau)+2v\tau}{2\tau\hat{\varepsilon}^3} > 0$, implying that total revenue r is monotonically increasing with $\hat{\varepsilon}$ in $(\underline{\varepsilon}, \bar{\varepsilon})$. Otherwise, when Lagrange multipliers $\lambda_1 = 0$ and $\lambda_2 \neq 0$, we solve:

$$\max_{\hat{\varepsilon}} r = p_1 d_1 + r_2^*(\hat{\varepsilon}) = \frac{-\hat{\varepsilon}^3 (\tau v + 2) + \hat{\varepsilon}^2 (2 + (5\tau - 2) v) + v\hat{\varepsilon} (4 - 3\tau) + v(\tau - 2)}{2\tau\hat{\varepsilon}^2}$$

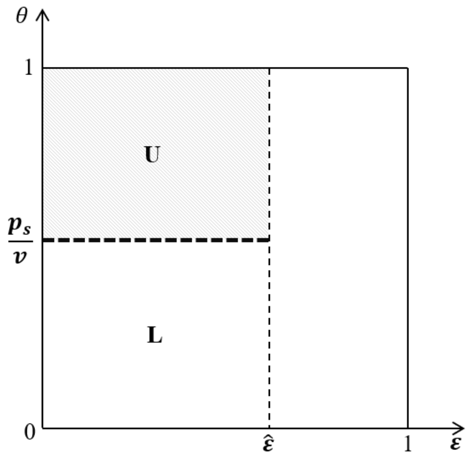
where $\hat{\varepsilon} \in (\bar{\varepsilon}, 1)$. In this case, $\frac{\mathrm{d}r}{\mathrm{d}\hat{\varepsilon}} = \frac{-\hat{\varepsilon}^3(\tau v+2)+v\hat{\varepsilon}(3\tau-4)-2v(\tau-2)}{2\tau\hat{\varepsilon}^3} = 0$, if

$$\hat{\varepsilon} = \hat{\varepsilon}_r = \frac{3\sqrt[3]{3}\left(\begin{array}{l} \frac{1}{3}\left(-9v(\tau v+2)^2\left(-\frac{\sqrt{6}}{9}\sqrt{\frac{27\tau^2-18\tau(v+6)+4(8v+27)}{\tau v+2}}+\tau-2\right)\right)^{\frac{2}{3}} + \\ \sqrt[3]{3}\left(v^2\left(\tau^2-\frac{4\tau}{3}\right)+v\left(2\tau-\frac{8}{3}\right)\right) \end{array}\right)}{\left(-9v(\tau v+2)^2\left(-\frac{\sqrt{6}}{9}\sqrt{\frac{27\tau^2-18\tau(v+6)+4(8v+27)}{\tau v+2}}+\tau-2\right)\right)^{\frac{2}{3}}(6+3\tau v)} < \bar{\varepsilon}.$$

Moreover, $\frac{\mathrm{d}r}{\mathrm{d}\hat{\varepsilon}} < 0$ for $\hat{\varepsilon} \in (\bar{\varepsilon}, 1)$, i.e., total revenue r monotonically decreases in $\hat{\varepsilon}$ in $(\bar{\varepsilon}, 1)$. In the equilibrium, $\hat{\varepsilon}^* = \bar{\varepsilon}$. The outcomes are summarized in Table 4.3.

B.2.2 Partially Covered Market

Under the condition $v + \varepsilon \geq p_2 > v$, for active consumers, the market segmentation mirrors that of the main model. The sole exception is that $\varepsilon_{\theta=0}$ can be greater than zero, although this does not affect the segment sizes. Specifically, when $\hat{\varepsilon} \geq \varepsilon_{\theta=1} \Leftrightarrow p_2 \leq (1-\tau)p_s + \hat{\varepsilon}$, as Figure B.1(a) shown, all the active consumers choose the option "resell and buy new" and no one keeps the product, i.e., $d_{a,sn} = 1 - \hat{\varepsilon}$. Otherwise, when $\hat{\varepsilon} < \varepsilon_{\theta=1} \Leftrightarrow p_2 > (1-\tau)p_s + \hat{\varepsilon}$, as shown in Figure B.1(b), most active consumers choose the "resell and buy new" option and the remaining active consumers choose the "keep the used" option, i.e., $d_{a,sn} = \frac{(\theta(\hat{\varepsilon})+1)(\varepsilon_{\theta=1}-\hat{\varepsilon})}{2} + 1 - \varepsilon_{\theta=1}$. For reserved consumers, Figure B.4 illustrates its segmentation. The horizontal dashed line is $\theta = \frac{p_s}{v}$, at which the reserved consumer is indifferent between "buy used" and "leave". A reserved consumer purchases a used product when $\theta > \frac{p_s}{v}$ but leaves market when $\theta < \frac{p_s}{v}$.



Notes. "U" denotes the choice "buy used" and "L" denotes the choice "leave".

Figure B.4: Segmentation of reserved consumers under $p_2 > v$

The number of "buy used" segment of the reserved consumers is $d_{r,u} = \hat{\varepsilon}\left(1 - \frac{p_s}{v}\right)$. Given the period-two new-product price p_2, a market-clearing price $p_s^*(p_2)$ exists at which used-product supply equals used-product demand, i.e., $d_{a,sn} = d_{r,u}$. The period-two revenue is $r_2 = d_2 p_2$, s.t. $v + \hat{\varepsilon} \geq p_2 > v$, where $d_2 = d_{a,sn}$. In period one, the marginal consumer type $\hat{\varepsilon}$ can be derived by setting $u_a = u_r$. Then, we maximize total revenue $\max_{p_1(\hat{\varepsilon})} r = p_1(\hat{\varepsilon})d_1 + r_2^*(\hat{\varepsilon})$, where $d_1 = 1 - \hat{\varepsilon}$, to derive the optimal period-one price p_1. We resort to a numerical study as shown in Section 4.6.

B.3 Proofs for Lemmas, Propositions, and Corollaries

Proof of Lemma 4.1 and Lemma 4.2. Please refer to Appendix B.2.1 for details. □

Proof of Lemma 4.3. The market-clearing price of used products is $p_s^* = \frac{{\hat{\varepsilon}^*}^2 - v(1-\hat{\varepsilon}^*)}{\hat{\varepsilon}^* \tau}$. $\frac{\partial p_s^*}{\partial v} = 0$ when $v = \tilde{v}_{p_s^*} = \frac{(\tau-1)(2\tau+2\sqrt{2(1-\tau)}-3)}{\sqrt{2(1-\tau)}(2\tau-1)^2}$. $p_s^* = 0$ when $v = \bar{v}_{p_s^*} = \frac{1}{2}$. For $\tau \in [0,1]$, $\tilde{v}_{p_s^*} < \bar{v}_{p_s^*}$. When $v \in [0,1]$, (i) for $v \in \left(0, \tilde{v}_{p_s^*}\right)$, $\frac{\partial p_s^*}{\partial v} < 0$, $p_s^* < 0$; (ii) for $v = \tilde{v}_{p_s^*}$, $\frac{\partial p_s^*}{\partial v} = 0$, $p_s^* < 0$; (iii) for $v \in \left(\tilde{v}_{p_s^*}, \bar{v}_{p_s^*}\right)$, $\frac{\partial p_s^*}{\partial v} > 0$, $p_s^* < 0$; (iv) for $v = \bar{v}_{p_s^*} = \frac{1}{2}$, $\frac{\partial p_s^*}{\partial v} > 0$, $p_s^* = 0$; (v) for $v \in \left(\bar{v}_{p_s^*}, 1\right)$, $\frac{\partial p_s^*}{\partial v} > 0$, $p_s^* > 0$. $\tilde{v}_{p_s^*}$ is the stationary point and $p_s^*\left(v = \tilde{v}_{p_s^*}\right)$ is the local minimum. Thus, $p_s^* < 0$ for $v \in \left(0, \frac{1}{2}\right)$; and $\frac{\partial p_s^*}{\partial v} > 0$ and $p_s^* > 0$ for $v \in \left(\frac{1}{2}, 1\right)$. Thus, the CRP functions only when $v \in \left(\frac{1}{2}, 1\right)$. □

Proof of Lemma 4.4. By the equilibrium outcomes, we know

$$p_1^* - p_2^* = \frac{2{\hat{\varepsilon}^*}^3 - v{\hat{\varepsilon}^*}^2(\tau-2) + 2v\hat{\varepsilon}^*(2\tau-1) - v\tau}{2\tau{\hat{\varepsilon}^*}^2} - v$$

$\frac{\partial(p_1^*-p_2^*)}{\partial v} > 0$, i.e., $p_1^* - p_2^*$ monotonically increases in v with $(p_1^*-p_2^*)|_{v=0} < 0$ and $(p_1^*-p_2^*)|_{v=1} = \frac{(2\tau+1)C_7+4\tau^2-2\tau-1}{(2\tau-1+C_7)^2}$. $p_1^* = p_2^*$ when $v = \bar{v}_{p_1^*=p_2^*} = \frac{1}{2+\sqrt{2}-\tau} < \frac{1}{2}$. We find $\frac{\mathrm{d}(p_1^*-p_2^*)|_{v=1}}{\mathrm{d}\tau} > 0$, i.e., $(p_1^*-p_2^*)|_{v=1}$ monotonically increases in τ, with $(p_1^*-p_2^*)|_{v=1,\tau=0} = \frac{1}{\sqrt{5}-1} > 0$. Thus, $(p_1^*-p_2^*)|_{v=1} > 0$. Then, $\frac{\partial(p_1^*-p_2^*)}{\partial v} > 0$ and $p_1^* > p_2^*$ for $v \in \left(\frac{1}{2}, 1\right)$. Moreover, it can be verified that $\frac{\partial p_1^*}{\partial v} > 0$, $\frac{\partial p_2^*}{\partial v} > 0$, $\frac{\partial(p_1^*-p_2^*)}{\partial v} > 0$, and $\frac{\partial p_s^*}{\partial v} > 0$ when $v \in \left(\frac{1}{2}, 1\right)$. The number of reserved consumers is $d_r = \hat{\varepsilon}^*$ and the number of active consumers is $d_a = 1 - \hat{\varepsilon}^*$. $\frac{\partial \hat{\varepsilon}^*}{\partial v} = \tau - \frac{1}{2} + \frac{\left(\tau-\frac{1}{2}\right)^2 + \frac{(1-\tau)}{2}}{\frac{C_6}{2}} > 0$ and $\frac{\partial \hat{\varepsilon}^*}{\partial \tau} = \frac{v(v(2\tau-1)-1+C_6)}{C_6} > 0$ when $v \in \left(\frac{1}{2}, 1\right)$. □

Proof of Proposition 4.1. Denote $\Delta p_1 = p_1^* - p_1^{B*} = \frac{2{\hat{\varepsilon}^*}^3 - v{\hat{\varepsilon}^*}^2(\tau-2) + 2v\hat{\varepsilon}^*(2\tau-1) - v\tau}{2\tau{\hat{\varepsilon}^*}^2} - \frac{3v}{2}$. $\frac{\partial \Delta p_1}{\partial v} > 0$, i.e., Δp_1 increases in v, with $\Delta p_1|_{v=1} = \frac{{C_7}^3 - \left(4\tau^2-12\tau+5\right)C_7 + 8\tau(\tau-1)}{2\tau(2\tau-1+C_7)^2}$ and $\Delta p_1|_{v=0} < 0$. $\Delta p_1 = 0$ when $v = \bar{v}_{\Delta p_1} = \frac{1}{2}$. $\frac{\mathrm{d}\,\Delta p_1|_{v=1}}{\mathrm{d}\tau} > 0$, i.e., $\Delta p_1|_{v=1}$ increases with τ. Since $\Delta p_1|_{v=1,\tau=0} > 0$, $\Delta p_1|_{v=1} > 0$. Thus, $\frac{\partial \Delta p_1}{\partial v} > 0$ and $\Delta p_1 > 0$, i.e., $p_1^* > p_1^{B*}$ for $v \in \left(\frac{1}{2}, 1\right)$. Moreover, $\Delta p_2 = p_2^* - p_2^{B*} = v - v = 0$. Let $\Delta p_d = (p_1^* - p_2^*) - \left(p_1^{B*} - p_2^{B*}\right) = \frac{2\hat{\varepsilon}^{*3} - v\hat{\varepsilon}^{*2}(\tau-2) + 2v\hat{\varepsilon}^*(2\tau-1) - v\tau}{2\tau\hat{\varepsilon}^{*2}} - v - \left(\frac{3v}{2} - v\right)$. $\frac{\partial \Delta p_d}{\partial v} > 0$ for $v \in [0,1]$, i.e., Δp_d increases in v, with $\Delta p_d|_{v=1} = \frac{C_7{}^3 - \left(4\tau^2 - 12\tau + 5\right)C_7 + 8\tau(\tau-1)}{2\tau(2\tau-1+C_7)^2}$ and $\Delta p_d|_{v=0} < 0$. $\Delta p_d = 0$ when $v = \bar{v}_{\Delta p_d} = \frac{1}{2}$. $\frac{\mathrm{d}\,\Delta p_d|_{v=1}}{\mathrm{d}\tau} > 0$ in $\tau \in [0,1]$, i.e., $\Delta p_d|_{v=1}$ increases in τ, with lower bound $\Delta p_d|_{v=1,\tau=0} > 0$, so that $\Delta p_d|_{v=1} > 0$. Then, $\frac{\partial \Delta p_d}{\partial v} > 0$, $\Delta p_d > 0 \Rightarrow p_d^* > p_d^{B*}$ when $v \in \left(\frac{1}{2}, 1\right)$. Denote $\Delta d_1 = d_1^* - d_1^{B*} = 1 - \hat{\varepsilon}^* - \frac{1}{2}$. $\frac{\partial \Delta d_1}{\partial v} < 0$, i.e., Δd_1 decreases in v, with $\Delta d_1|_{v=0} = \frac{1}{2} > 0$ and $\Delta d_1|_{v=1} = 1 - \tau - \frac{C_7}{2}$. $\Delta d_1 = 0$ when $v = \bar{v}_{\Delta d_1} = \frac{1}{2}$. $\frac{\mathrm{d}\,\Delta d_1|_{v=1}}{\mathrm{d}\tau} < 0$, i.e., $\Delta d_1|_{v=1}$ decreases in τ. As $\Delta d_1|_{v=1,\tau=0} = 1 - \frac{\sqrt{5}}{2} < 0$, $\Delta d_1|_{v=1} < 0$. Thus, $\frac{\partial \Delta d_1}{\partial v} < 0$, $\Delta d_1 < 0 \Rightarrow d_1^* < d_1^{B*}$ when $v \in \left(\frac{1}{2}, 1\right)$. Denote $\Delta d_2 = d_2^* - d_2^{B*} = \hat{\varepsilon}^* - \frac{1}{2}$. $\frac{\partial \Delta d_2}{\partial v} > 0$, i.e., Δd_2 is monotonically increasing in v, with $\Delta d_2|_{v=1} = \tau - 1 + \frac{C_7}{2}$ and $\Delta d_2|_{v=0} = -\frac{1}{2} < 0$. $\Delta d_2 = 0$ when $v = \bar{v}_{\Delta d_2} = \frac{1}{2}$. $\frac{\mathrm{d}\,\Delta d_2|_{v=1}}{\mathrm{d}\tau} > 0$, i.e., $\Delta d_2|_{v=1}$ monotonically increases in τ, with $\Delta d_2|_{v=1,\tau=0} = \frac{\sqrt{5}}{2} - 2 > 0$. Thus, $\Delta d_2|_{v=1} > 0$ and $\Delta d_2 > 0$, i.e., $d_2^* > d_2^{B*}$ when $v \in \left(\frac{1}{2}, 1\right)$. □

Proof of Corollary 4.1. We first prove the existence of the cannibalization effect. Denote $\Delta r_1 = r_1^* - r_1^{B*} = \frac{\left(2\hat{\varepsilon}^{*3} - v\hat{\varepsilon}^{*2}(\tau-2) + 2v\hat{\varepsilon}^*(2\tau-1) - v\tau\right)(1-\hat{\varepsilon}^*)}{2\tau\hat{\varepsilon}^{*2}} - \frac{3v}{4}$. $\frac{\partial \Delta r_1}{\partial v} = 0$ when $v = \tilde{v}_{\Delta r_1}$. Specifically, when $v \in [0,1]$, (i) for $v \in (0, \tilde{v}_{\Delta r_1})$, $\frac{\partial \Delta r_1}{\partial v} > 0$, $\Delta r_1 < 0$; (ii) for $v = \tilde{v}_{\Delta r_1}$, $\frac{\partial \Delta r_1}{\partial v} = 0$, $\Delta r_1 (v = \tilde{v}_{\Delta r_1}) < 0$; (iii) for $v \in (\tilde{v}_{\Delta r_1}, 1)$, $\frac{\partial \Delta r_1}{\partial v} < 0$, $\Delta r_1 < 0$. Then, $\tilde{v}_{\Delta r_1}$ is the stationary point and $\Delta r_1 (v = \tilde{v}_{\Delta r_1})$ is the local maximum. Since $\Delta r_1 (v = \tilde{v}_{\Delta r_1}) < 0$, $\Delta r_1 < 0$ in $v \in [0,1]$, i.e., $r_1^* < r_1^{B*}$. Next, we prove the existence of the enhancement effect. Denote $\Delta r_2 = r_2^* - r_2^{B*} = \hat{\varepsilon}^* v - \frac{v}{2}$. $\frac{\partial \Delta r_2}{\partial v} = 0$ when $v = \tilde{v}_{\Delta r_2} = \frac{20\tau - 19 + \sqrt{-256\tau^3 + 912\tau^2 - 1080\tau + 425}}{8(4\tau^2 - 4\tau + 1)}$. $\Delta r_2 = 0$ when $v = 0$ or $v = \frac{1}{2}$. $0 < \tilde{v}_{\Delta r_2} < \frac{1}{2}$ for $\tau \in [0,1]$. Then, (i) for $v \in (0, \tilde{v}_{\Delta r_2})$, $\frac{\partial \Delta r_2}{\partial v} < 0$, $\Delta r_2 < 0$; (ii) for $v = \tilde{v}_{\Delta r_2}$, $\frac{\partial \Delta r_2}{\partial v} = 0$, $\Delta r_2 < 0$; (iii) for $v \in \left(\tilde{v}_{\Delta r_2}, \frac{1}{2}\right)$, $\frac{\partial \Delta r_2}{\partial v} > 0$, $\Delta r_2 < 0$; (iv) for $v \in \left(\frac{1}{2}, 1\right)$, $\frac{\partial \Delta r_2}{\partial v} > 0$, $\Delta r_2 > 0$. Thus, $\tilde{v}_{\Delta r_2}$ is the stationary point and $\Delta r_2 (v = \tilde{v}_{\Delta r_2})$ is the local minimum. Specifically, $\Delta r_2 > 0 \Rightarrow r_2^* > r_2^{B*}$ for $v \in \left(\frac{1}{2}, 1\right)$. □

Proof of Proposition 4.2. Denote $\Delta r = r_1^* - r_1^{B*} + \left(r_2^* - r_2^{B*}\right) = r^* - r^{B*} = \frac{\hat{\varepsilon}^{*3}(2-\tau v)+v\hat{\varepsilon}^{*2}(2-3\tau)+v\hat{\varepsilon}^*(5\tau-2)-v\tau}{2\tau\hat{\varepsilon}^{*2}} - \frac{5v}{4}$ to indicate the difference in total revenue in the CRP model relative to that in the benchmark. $\Delta r = 0$, when $v = \tilde{v}^r(\tau)$, which is shown in B.1. Note that $\tilde{v}^r(\tau) = 1$ when $\tau = \bar{\tau}^r = \frac{\sqrt{3}}{3}$ and $\tilde{v}^r(1) = \bar{v}^r = \frac{2}{\sqrt{3}+1}$. Specifically, when $\tau \in (\bar{\tau}^r, 1)$ and $v \in (\bar{v}^r, 1)$, $\tilde{v}^r(\tau) < 1$, (i) for (τ, v) in the closed area delimited by $\tilde{v}^r(\tau)$, $\tau = \bar{\tau}^r$, and $v = \bar{v}^r$, $\frac{\mathrm{d}\Delta r}{\mathrm{d}\tau} < 0$, $r^* > r^{B*}$; (ii) for (τ, v) in the closed area delimited by $\tilde{v}^r(\tau)$, $\tau = 1$, and $v = 1$, $\frac{\mathrm{d}\Delta r}{\mathrm{d}\tau} < 0$, $r^* < r^{B*}$. Otherwise, $\tilde{v}^r(\tau) = 1$ when $\tau \in (0, \bar{\tau}^r)$, and $\tilde{v}^r(\tau) > 1$ when $v \in \left(\frac{1}{2}, \bar{v}^r\right)$. In either case, $r^* \geq r^{B*}$. $\square$

Proof of Corollary 4.2. Let $r^* = \frac{\hat{\varepsilon}^{*3}(2-\tau v)+v\hat{\varepsilon}^{*2}(2-3\tau)+v\hat{\varepsilon}^*(5\tau-2)-v\tau}{2\tau\hat{\varepsilon}^{*2}}$. $\frac{\partial r^*}{\partial \tau} = 0$, when $\tau = \tilde{\tau}^{r*} = \frac{C_1{}^2+C_1(2-v)+7v^2-10v+1}{3C_1 v}$. The range of $\tilde{\tau}^{r*}$ is $0 \leq \frac{C_1{}^2+C_1(2-v)+7v^2-10v+1}{3C_1 v} \leq 1$, which can be expressed as $v \in (\tilde{v}_1^{r*}, \tilde{v}_2^{r*})$. $\frac{\partial r^*}{\partial \tau} = 0$ when $v = \tilde{v}_{r^*} = \frac{1}{2}$. For $\tau \in [0,1]$ and $v \in \left(\frac{1}{2}, 1\right)$, we consider three cases: (1) when $v \in \left(\frac{1}{2}, \tilde{v}_1^{r*}\right)$, $\frac{\partial r^*}{\partial \tau} > 0$; (2) when $v \in (\tilde{v}_1^{r*}, \tilde{v}_2^{r*})$: (i) for $\tau \in (0, \tilde{\tau}^{r*})$, $\frac{\partial r^*}{\partial \tau} > 0$; (ii) for $\tau = \tilde{\tau}^{r*}$, $\frac{\partial r^*}{\partial \tau} = 0$; (iii) for $\tau \in (\tilde{\tau}^{r*}, 1)$, $\frac{\partial r^*}{\partial \tau} < 0$; (3) when $v \in (\tilde{v}_2^{r*}, 1]$, $\frac{\partial r^*}{\partial \tau} < 0$. Therefore, $\frac{\partial r^*}{\partial \tau} > 0$ when $\tau \in (0, \tilde{\tau}^{r*})$ and $v \in (\tilde{v}_1^{r*}, \tilde{v}_2^{r*})$, or $\tau \in [0,1]$ and $v \in \left(\frac{1}{2}, \tilde{v}_1^{r*}\right)$. $\square$

Proof of Proposition 4.3. Denote

$$\Delta cs = cs - cs^B = \frac{\left(\begin{array}{l} \hat{\varepsilon}^{*4}\tau - 2\hat{\varepsilon}^{*3}(\tau+1) + \hat{\varepsilon}^{*2}\left(\tau\left(5v+1\right)-2v\right) + \\ 2v\hat{\varepsilon}^*\left(1-2\tau\right) + v\tau \end{array}\right)}{2\tau\hat{\varepsilon}^{*2}} - \frac{v}{8}.$$

When $\Delta cs = 0$, the corresponding consumer valuation is $\tilde{v}^c(\tau)$, which is shown in Table B.1. We have the following properties:

1. $\tilde{v}^c(\tau)$ changes monotonically with τ and v;
2. if $v = 1$, $\tilde{v}^c(\tau) = 1$ is achieved at $\tau = \bar{\tau}^c = \frac{27+\sqrt{5}-\sqrt{118\sqrt{5}-98}}{32} \approx 0.5112$; if $\tau = 1$, $\tilde{v}^c(1)$ is achieved at $v = \bar{v}^c$, where $\bar{v}^c$ is a root to $4v^4 - 5v^3 - 4v^2 + 4v = 0$ and $\bar{v}^c \approx 0.7242$;

3. when $\tau \in (\bar{\tau}^c, 1)$ and $v \in (\bar{v}^c, 1)$, $\tilde{v}^c(\tau) < 1$. (i) for (τ, v) in the closed area delimited by $\tilde{v}^c(\tau)$, $\tau = \bar{\tau}^c$, and $v = \bar{v}^c$, $\frac{\mathrm{d}\Delta cs}{\mathrm{d}\tau} < 0$, $\Delta cs > 0$; (ii) for (τ, v) in the closed area delimited by $\tilde{v}^c(\tau)$, $\tau = 1$, and $v = 1$, $\frac{\mathrm{d}\Delta cs}{\mathrm{d}\tau} < 0$, $\Delta cs < 0$;

4. $\tilde{v}^c(\tau) = 1$ when $\tau \in (0, \bar{\tau}^c)$, and $\tilde{v}^c(\tau) > 1$ when $v \in \left(\frac{1}{2}, \bar{v}^c\right)$. In either case, $\Delta cs \geq 0$;

5. when $\tilde{v}^r(\tau) < 1$ and $\tilde{v}^c(\tau) < 1$, the property $\tilde{v}^r(\tau) > \tilde{v}^c(\tau)$ exists. Specifically, $\bar{v}^c < \bar{v}^r$, i.e., $0.7242 < \frac{2}{\sqrt{3}+1}$, and $\bar{\tau}^c < \bar{\tau}^r$, i.e., $0.5112 < \frac{\sqrt{3}}{3}$.

Furthermore, $\Delta sw = sw - sw^B = \frac{\hat{\varepsilon}^*\left(6v - \hat{\varepsilon}^{*2} - 3\hat{\varepsilon}^* v + 1\right) - v}{2\hat{\varepsilon}^*} - \frac{11v}{8}$. $\Delta sw = 0$ when $v = \tilde{v}^s(\tau)$, which is shown in Table B.1. The following properties exist:

1. $\tilde{v}^s(\tau)$ changes monotonically with τ and v;

2. if $v = 1$, $\tilde{v}^s(\tau) = 1$ is achieved at $\tau = \bar{\tau}^s \approx 0.7073$, which is solved by:

$$\frac{16\left(\tau^2(\tau+1) + C_7\right) + \tau\left(4C_7^2 + 4C_7 - 82\right) - 2C_7^2 - 21C_7 + 55}{48\tau^2 + \tau\left(24C_7 - 98\right) - 25C_7 + 57} = 0$$

if $\tau = 1$, $\tilde{v}^s(1)$ is achieved at $v = \bar{v}^s = \frac{13}{16} = 0.8125$;

3. when $\tau \in (\bar{\tau}^s, 1)$ and $v \in (\bar{v}^s, 1)$, $\tilde{v}^s(\tau) < 1$. (i) for (τ, v) in the closed area delimited by $\tilde{v}^s(\tau)$, $\tau = \bar{\tau}^s$, and $v = \bar{v}^s$, $\frac{\mathrm{d}\Delta sw}{\mathrm{d}\tau} < 0$, $\Delta sw > 0$; (ii) for (τ, v) in the closed area delimited by $\tilde{v}^s(\tau)$, $\tau = 1$, and $v = 1$, $\frac{\mathrm{d}\Delta sw}{\mathrm{d}\tau} < 0$, $\Delta sw < 0$;

4. $\tilde{v}^s(\tau) = 1$ when $\tau \in (0, \bar{\tau}^s)$, and $\tilde{v}^s(\tau) > 1$ when $v \in \left(\frac{1}{2}, \bar{v}^s\right)$. In either case, $\Delta sw \geq 0$;

5. when $\tilde{v}^r(\tau) < 1$, $\tilde{v}^c(\tau) < 1$, and $\tilde{v}^s(\tau)$ <1, the property $\tilde{v}^s(\tau) > \tilde{v}^r(\tau) > \tilde{v}^c(\tau)$ exists. Specifically, $\bar{v}^c < \bar{v}^r < \bar{v}^s$, i.e., $0.7242 < \frac{2}{\sqrt{3}+1} < \frac{13}{16}$, and $\bar{\tau}^c < \bar{\tau}^r < \bar{\tau}^s$, i.e., $0.5112 < \frac{\sqrt{3}}{3} < 0.7073$.

□

B.4 Collaboration Strategy

B.4.1 Self-Managing Platform Strategy

If the retailer builds a self-owned platform, the period-two revenue becomes $r_2^O = p_2^O d_2^O + \left(\tau p_s^O - c\right) d_s^O$. Other model settings remain unchanged. Thus, we only list the main differences of calculation process. In subgame, the retailer's maximum period-two revenue is:

$$\max_{p_2^O} r_2^O = p_2^O d_2^O + \left(\tau p_s^O - c\right) d_s^O, \text{ s.t. } p_2^O \leq v.$$

The subgame equilibrium is summarized in Table B.4.

Table B.4: Subgame equilibrium outcomes of strategy O

	Subgame equilibrium
Used-product price and demand	$p_s^{O*}(\hat{\varepsilon}^O) = \frac{\hat{\varepsilon}^{O^2}+v(\hat{\varepsilon}^O-1)}{\hat{\varepsilon}^O\tau}$ and $d_s^{O*}(\hat{\varepsilon}^O) = 1-\hat{\varepsilon}^O$
Period-two new-product price and demand	$p_2^{O*}(\hat{\varepsilon}^O) = \frac{\hat{\varepsilon}^{O^2}-v(\tau-1)(\hat{\varepsilon}^O-1)}{\hat{\varepsilon}^O\tau}$ and $d_2^{O*}(\hat{\varepsilon}^O) = \hat{\varepsilon}^O$
Period-two revenue	$r_2^{O*}(\hat{\varepsilon}^O) = \frac{\hat{\varepsilon}^{O^3}(1-\tau)+\hat{\varepsilon}^{O^2}(\tau(c-2v+1)+v)+\hat{\varepsilon}^O(\tau(3v-c)-v)-v\tau}{\hat{\varepsilon}^O\tau}$

Consider period one and let $u_a^O = u_r^O$, the marginal consumer type can be derived as:

$$\hat{\varepsilon}^O = p_s^{O*}(\tau-1) + p_2^{O*} - v + \sqrt{v^2 + 2v\left(p_2^{O*} - p_1\right) - \left(p_2^{O*} - p_s^{O*}\right)^2}. \tag{B.1}$$

Substituting the subgame equilibrium into Equation B.1, the inverse function of period-one new-product price p_1^O with respect to indifferent consumer type $\hat{\varepsilon}^O$ is:

$$p_1^O(\hat{\varepsilon}^O) = \frac{2\hat{\varepsilon}^{O^3} - v\hat{\varepsilon}^{O^2}(\tau-2) + 2v\hat{\varepsilon}^O(2\tau-1) - v\tau}{2\tau\hat{\varepsilon}^{O^2}}.$$

Finally, we solve the equilibrium by solving the problem:

$$\max_{\hat{\varepsilon}^O} r^O = p_1^O d_1^O + r_2^{O*}, \text{ s.t. } \hat{\varepsilon}^O \in \left(\underline{\varepsilon}^O, \bar{\varepsilon}^O\right)$$

where $d_1^O = 1 - \hat{\varepsilon}^O$, $\underline{\varepsilon}^O = \underline{\varepsilon}$, $\bar{\varepsilon}^O = \bar{\varepsilon}$. $\frac{\mathrm{d}r^O}{\mathrm{d}\hat{\varepsilon}^O} = \frac{-4\tau\hat{\varepsilon}^{O^4}+\bar{\varepsilon}^{O^3}(\tau(2c-3v+2)+2)+v\hat{\varepsilon}^O(2-3\tau)+2v\tau}{2\tau\hat{\varepsilon}^{O^3}}$. $\frac{\mathrm{d}r^O}{\mathrm{d}\hat{\varepsilon}^O} = 0$ when $\hat{\varepsilon}^O = \hat{\varepsilon}_{r^O} < \underline{\varepsilon}^O$. Then, (i) for $\hat{\varepsilon}^O < \hat{\varepsilon}_{r^O}$, $\frac{\mathrm{d}r^O}{\mathrm{d}\hat{\varepsilon}^O} > 0$; (ii) for $\hat{\varepsilon}^O = \hat{\varepsilon}_{r^O}$, $\frac{\mathrm{d}r^O}{\mathrm{d}\hat{\varepsilon}^O} = 0$; (iii) for $\hat{\varepsilon}^O \in \left(\hat{\varepsilon}_{r^O}, \underline{\varepsilon}^O\right)$, $\frac{\mathrm{d}r^O}{\mathrm{d}\hat{\varepsilon}^O} > 0$; (iv) for $\hat{\varepsilon}^O \in \left(\underline{\varepsilon}^O, \bar{\varepsilon}^O\right)$, $\frac{\mathrm{d}r^O}{\mathrm{d}\hat{\varepsilon}^O} > 0$. Total revenue r^O monotonically increases in $\hat{\varepsilon}^O \in (\underline{\varepsilon}^O, \bar{\varepsilon}^O)$. We use $\hat{\varepsilon}^{O*} = \bar{\varepsilon}^O = \bar{\varepsilon}$ as the equilibrium outcome.

Proof of Proposition 4.4. Denote $\Delta r^O = r_1^{O*} + r_2^{O*} - (r_1^* + r_2^*) = r_2^{O*} - r_2^* = \frac{-\hat{\varepsilon}^{O*^3}+\hat{\varepsilon}^{O*^2}(1+c)+\hat{\varepsilon}^{O*}(2v-c)-v}{\hat{\varepsilon}^{O*}} - \hat{\varepsilon}^* v$. $\frac{\partial \Delta r^O}{\partial c} = \hat{\varepsilon}^{O*} - 1 < 0$, i.e., Δr^O monotonically decreases with c. $\frac{\partial \Delta r^O|_{c=0}}{\partial v} = 0$ when $v_{1,\Delta r^O|_{c=0}} < \frac{1}{2}$ and $v_{2,\Delta r^O|_{c=0}} > \frac{1}{2}$. Note that $v_{2,\Delta r^O|_{c=0}}$ can be larger than 1. However, it does not affect further analysis. The point $\Delta r^O{}_{c=0}\left(v = v_{2,\Delta r^O|_{c=0}}\right)$ is still the local maximum. Besides, $\Delta r^O\big|_{c=0} = 0$ when $v = \frac{1}{2}$. If $v \in \left(0, v_{1,\Delta r^O|_{c=0}}\right)$, $\frac{\partial \Delta r^O|_{c=0}}{\partial v} < 0$, $\Delta r^O\big|_{c=0} < 0$; if $v \in \left(v_{1,\Delta r^O|_{c=0}}, \frac{1}{2}\right)$, $\frac{\partial \Delta r^O|_{c=0}}{\partial v} > 0$, $\Delta r^O\big|_{c=0} < 0$, where $\Delta r^O\big|_{c=0}\left(v = v_{1,\Delta r^O|_{c=0}}\right)$ is the local minimum; if $v \in \left(\frac{1}{2}, v_{2,\Delta r^O|_{c=0}}\right)$, $\frac{\partial \Delta r^O|_{c=0}}{\partial v} > 0$, $\Delta r^O\big|_{c=0} > 0$, where $\Delta r^O\big|_{c=0}\left(v = v_{2,\Delta r^O|_{c=0}}\right)$ is the local maximum; if $v \in \left(v_{2,\Delta r^O|_{c=0}}, 1\right)$, $\frac{\partial \Delta r^O|_{c=0}}{\partial v} < 0$, $\Delta r^O\big|_{c=0} > 0$. $\Delta r^O\big|_{c=0} > 0$. $\Delta r^O = 0$ when $c^O = \frac{2\tau v(C_6+v(2\tau-1)-1)}{C_6+v(2\tau-1)}$. In summary, when CRP functions, i.e., $v \in \left(\frac{1}{2}, 1\right)$, if $c \in \left(0,\ c^O\right)$, $r^{O*} > r^*$ and $r_2^{O*} > r_2^*$; otherwise, if $c \in (c^O, 1]$, $r^{O*} < r^*$ and $r_2^{O*} < r_2^*$. □

B.4.2 Price Subsidy Strategy

Using backward induction, for active consumers in period two, they compare options 'keep', 'resell and buy new', and 'resell and leave' with utilities θv, $v + \varepsilon - (1-m)p_2^D + (1-\tau)\,p_s^D$, and $(1-\tau)\,p_s^D$ respectively. Note that 'resell and buy new' option always dominates the 'resell and leave' option since $v + \varepsilon - (1-m)p_2^D + (1-\tau)\,p_s^D \geq (1-\tau)\,p_s^D \Leftrightarrow p_2^D \leq \frac{v+\varepsilon}{1-m}$. We compare 'keep' and 'resell and buy new' options. The quality level of used products at which the consumer is indifferent between the options is $\theta = \frac{\varepsilon}{v} + \frac{v-(1-m)p_2^D+(1-\tau)p_s^D}{v}$. The active consumer chooses 'keep' at low quality level of used products, i.e., $\theta > \frac{\varepsilon}{v} + \frac{v-(1-m)p_2^D+(1-\tau)p_s^D}{v}$, but chooses 'resell and buy new' at high quality level of used products, i.e., $\theta < \frac{\varepsilon}{v} + \frac{v-(1-m)p_2^D+(1-\tau)p_s^D}{v}$.

It is intuitive that the discounted new-product price still exceeds the used-product price, i.e., $p_2^D > \frac{p_s^D}{1-m}$. Under assumption $p_2^D \leq v$, for $p_2^D > \frac{p_s^D}{1-m}$, the line $\theta = \frac{\varepsilon}{v} + \frac{v-(1-m)p_2^D+(1-\tau)p_s^D}{v}$ intercepts the horizontal axis at $\varepsilon_{\theta=0}^D = (1-m)p_2^D - (1-\tau)\,p_s^D - v < 0$; and the horizontal line $\theta = 1$ at $\varepsilon_{\theta=1}^D = (1-m)p_2^D - (1-\tau)\,p_s^D > 0$. $\varepsilon_{\theta=1}^D > \varepsilon_{\theta=0}^D$ since $\varepsilon_{\theta=1}^D - \varepsilon_{\theta=0}^D = v$. The line intercepts $\varepsilon = 1$ at $\theta = \frac{\varepsilon}{v} + \frac{v-(1-m)p_2^D+(1-\tau)p_s^D}{v} > 1$ since $p_2^D > \frac{p_s^D}{1-m}$. $[\hat{\varepsilon}^D, 1]$ is the range of the types for active consumers. To compare $\hat{\varepsilon}^D$ and $\varepsilon_{\theta=1}^D$, we consider two possible scenarios for active consumers: (a) all active consumers choose 'resell and buy new' option, i.e., $d_{p,sn}^D = 1 - \hat{\varepsilon}^D$; (b) active consumers choose 'resell and buy new' or 'keep', i.e., $d_{p,sn}^D = \frac{\left(\frac{\hat{\varepsilon}^D}{v} + \frac{v-(1-m)p_2^D+(1-\tau)p_s^D}{v} + 1\right)\left(\varepsilon_{\theta=1}^D - \hat{\varepsilon}^D\right)}{2} + 1 - \varepsilon_{\theta=1}^D$. For reserved consumers, the number of 'buy used' segment is $d_{w,u}^D = \hat{\varepsilon}^D\left(1 - \left(1 - \frac{p_2^D - p_s^D}{v}\right)\right) = \frac{\hat{\varepsilon}^D(p_2^D - p_s^D)}{v}$ and the number of 'buy new' segment is $d_{w,n}^D = \hat{\varepsilon}^D\left(1 - \frac{p_2^D - p_s^D}{v}\right)$. To derive $p_s^{D*}(p_2^D)$, let $d_{p,sn}^D = d_{w,u}^D$. $p_s^{D*}(p_2^D) = p_2^D - \frac{1-\hat{\varepsilon}^D}{\hat{\varepsilon}^D}v$ when $d_{p,sn}^D = 1 - \hat{\varepsilon}^D$; $p_s^{D*}(p_2^D) = \frac{\tau\left(\hat{\varepsilon}+(m-1)p_2^D\right)+(1-m)p_2^D-\sqrt{\hat{\varepsilon}^2(2\tau-1)+2\hat{\varepsilon}\left(p_2^D(m-\tau)-v(\tau-1)\right)(\tau-1)+2v(\tau-1)^2}}{(\tau-1)^2}$ when $d_{p,sn}^D = \frac{\left(\frac{\hat{\varepsilon}^D}{v} + \frac{v-(1-m)p_2^D+(1-\tau)p_s^D}{v} + 1\right)\left(\varepsilon_{\theta=1}^D - \hat{\varepsilon}^D\right)}{2} + 1 - \varepsilon_{\theta=1}^D$.

By comparing different market segmentation, we maximize the period-two revenue:

$$\max_{p_2^D} r_2^D = p_2^D d_2^D - m p_2^D d_s^D, \text{ s.t. } p_2^D \leq v.$$

The subgame equilibrium outcomes as shown in Table B.5. Under assumption $0 \leq p_2^D \leq v$, the boundary condition for $\hat{\varepsilon}^D$ is $\frac{v(\tau-1)+\sqrt{v(\tau-1)(v(\tau-1)-4)}}{2} \leq \hat{\varepsilon}^D \leq \frac{v(2\tau-m-1)+\sqrt{v\left(v(m-2\tau+1)^2-4(\tau-1)\right)}}{2}$. For simplicity, we denote the lower bound as $\underline{\varepsilon}^D$ and the upper bound as $\bar{\varepsilon}^D$. To check the feasibility of $\underline{\varepsilon}^D$ and $\bar{\varepsilon}^D$, we need to ensure the square root in the formulas is non-negative. For $\underline{\varepsilon}^D$, $v(\tau-1)(v(\tau-1)-4) \geq 0$ since $v(\tau-1) \leq 0$ and $v(\tau-1) - 4 < 0$ when $\tau \in [0,1]$ and $v \in [0,1]$. For $\bar{\varepsilon}^D$, $v(v\,(m-2\tau+1)^2 - 4(\tau-1)) \geq 0$ since $v \geq \frac{4(\tau-1)}{(m-2\tau+1)^2}$ which is always the case when $\tau \in [0,1]$, that is, $\frac{4(\tau-1)}{(m-2\tau+1)^2} \leq 0$. To maintain $\bar{\varepsilon}^D > \underline{\varepsilon}^D$, the condition of $m > \tau$ must hold. Thus, the feasible domain of discount factor m is $[\tau, 1]$.

Table B.5: Subgame equilibrium of strategy D

	Subgame equilibrium
Used-product price and demand	$p_s^{D*}(\hat{\varepsilon}^D) = \frac{v(m-1)(\hat{\varepsilon}^D-1)-\hat{\varepsilon}^{D^2}}{\hat{\varepsilon}^D(m-\tau)}$ and $d_s^{D*}(\hat{\varepsilon}^D) = 1-\hat{\varepsilon}^D$
Period-two new-product price and demand	$p_2^{D*}(\hat{\varepsilon}^D) = \frac{v(\tau-1)\left(\hat{\varepsilon}^D-1\right)-\hat{\varepsilon}^{D^2}}{\hat{\varepsilon}^D(m-\tau)}$ and $d_2^{D*}(\hat{\varepsilon}^D) = \hat{\varepsilon}$
Period-two revenue	$r_2^{D*}(\hat{\varepsilon}^D) = \frac{\left(v(\tau-1)\left(\hat{\varepsilon}^D-1\right)-\hat{\varepsilon}^{D^2}\right)\left(\hat{\varepsilon}^D(m+1)-m\right)}{\hat{\varepsilon}^D(m-\tau)}$

In period one, letting $u_p^D = u_w^D$, the marginal consumer type can be derived as:

$$
\begin{aligned}
\hat{\varepsilon}^D = {} & p_s^{D*}(\hat{\varepsilon}^D)(\tau-1) + (1-m)p_2^{D*}(\hat{\varepsilon}^D) - v \\
& + \sqrt{2v\left(p_1^D - p_2^{D*}(\hat{\varepsilon}^D)\right) - v^2 + \left(p_2^{D*}(\hat{\varepsilon}^D) - p_s^{D*}(\hat{\varepsilon}^D)\right)^2}.
\end{aligned} \tag{B.2}
$$

Substituting the subgame equilibrium into Equation B.2, the inverse function of period-one new-product price p_1^D with respect to indifferent consumer type $\hat{\varepsilon}^D$ is:

$$
p_1^D(\hat{\varepsilon}^D) = \frac{-2\hat{\varepsilon}^{D^3} + v\hat{\varepsilon}^{D^2}(m+\tau-2) + 2v\hat{\varepsilon}^D(m-2\tau+1) - v(m-\tau)}{2(m-\tau)\hat{\varepsilon}^{D^2}}.
$$

Finally, we solve the problem:

$$
\max_{\hat{\varepsilon}^D} r^D = p_1^D d_1^D + r_2^{D*}(\hat{\varepsilon}^D), \text{ s.t. } \hat{\varepsilon}^D \in (\underline{\varepsilon}^D, \bar{\varepsilon}^D).
$$

$\frac{\mathrm{d}r^D}{\mathrm{d}\hat{\varepsilon}^D} = 0$, when $\hat{\varepsilon}^D = \hat{\varepsilon}_{r^D} < \underline{\varepsilon}^D$. Then, (i) for $\hat{\varepsilon}^D < \hat{\varepsilon}_{r^D}$, $\frac{\mathrm{d}r^D}{\mathrm{d}\hat{\varepsilon}^D} > 0$; (ii) for $\hat{\varepsilon}^D = \hat{\varepsilon}_{r^D}$, $\frac{\mathrm{d}r^D}{\mathrm{d}\hat{\varepsilon}^D} = 0$; (iii) for $\hat{\varepsilon}^D \in \left(\hat{\varepsilon}_{r^D}, \underline{\varepsilon}^D\right)$, $\frac{\mathrm{d}r^D}{\mathrm{d}\hat{\varepsilon}^D} > 0$; (iv) for $\hat{\varepsilon}^D \in \left(\underline{\varepsilon}^D, \bar{\varepsilon}^D\right)$, $\frac{\mathrm{d}r^D}{\mathrm{d}\hat{\varepsilon}^D} > 0$. Total revenue r^D monotonically increases in $\hat{\varepsilon}^D \in (\underline{\varepsilon}^D, \bar{\varepsilon}^D)$. We use $\hat{\varepsilon}^{D*} = \bar{\varepsilon}^D$ as the equilibrium outcome.

The market-clearing price of used products in strategy D is $p_s^{D*} = \frac{v(m-1)(\hat{\varepsilon}^{D*}-1)-\hat{\varepsilon}^{D*^2}}{\hat{\varepsilon}^{D*}(m-\tau)}$. $\frac{\partial p_s^{D*}}{\partial v} = 0$ when $v = \tilde{v}_{p_s^{D*}} = \frac{(\tau-1)\sqrt{2}\left(\sqrt{2}(m-1)\sqrt{\frac{\tau-1}{m-1}} - \frac{1}{2}(m+2\tau-3)\right)}{\sqrt{\frac{\tau-1}{m-1}}(m-1)(m-2\tau+1)^2}$. $p_s^{D*} = 0$ when $v = \bar{v}_{p_s^{D*}} = \frac{1}{2(1-m)}$. For $\tau \in [0,1]$, $\tilde{v}_{p_s^{D*}} < \bar{v}_{p_s^{D*}}$ when $m \in [\tau, 1]$. Then, (i) for $v \in \left(0, \tilde{v}_{p_s^{D*}}\right)$, $\frac{\partial p_s^{D*}}{\partial v} < 0$, $p_s^{D*} < 0$; (ii) for $v = \tilde{v}_{p_s^{D*}}$, $\frac{\partial p_s^{D*}}{\partial v} = 0$, $p_s^{D*} < 0$; (iii) for $v \in \left(\tilde{v}_{p_s^{D*}}, \bar{v}_{p_s^{D*}}\right)$, $\frac{\partial p_s^{D*}}{\partial v} > 0$, $p_s^{D*} < 0$; (iv) for $v = \bar{v}_{p_s^{D*}} = \frac{1}{2(1-m)}$, $\frac{\partial p_s^{D*}}{\partial v} > 0$, $p_s^{D*} = 0$; (v) for $v \in \left[\bar{v}_{p_s^{D*}}, 1\right]$,

$\frac{\partial p_s^{D*}}{\partial v} > 0$, $p_s^{D*} > 0$. $\tilde{v}_{p_s^{D*}}$ is the stationary point and $p_s^{D*}\left(v = \tilde{v}_{p_s^{D*}}\right)$ is the local minimum. Thus, for $v \in \left[0, \frac{1}{2(1-m)}\right)$, $p_s^{D*} < 0$; for $v \in \left(\frac{1}{2(1-m)}, 1\right]$, $p_s^{D*} > 0$. Our focus is only on the region $p_s^{D*} > 0$. Since $m \in [\tau, 1]$ and $\tau \in [0,1]$, we have $\frac{1}{2(1-m)} \in \left[\frac{1}{2}, 1\right]$. It implies that the valid area for $p_s^{D*} > 0$ is $v \in \left[\frac{1}{2}, 1\right]$, which is consistent with Lemma 4.3.

Proof of Proposition 4.5. Denote

$$\Delta r^D = r^{D*} - r^* = \frac{\left(\begin{array}{l} -2m\hat{\varepsilon}^{D*^4} + 2\hat{\varepsilon}^{D*^3}\left(2(m-1) + v\left((2\tau-3)m + \tau\right)\right) - \\ 4v\hat{\varepsilon}^{D*^2}\left(\left(\tau - \frac{3}{4}\right)m - \frac{3}{4}\tau + \frac{1}{2}\right) + \\ 2v\hat{\varepsilon}^{D*}\left(m\left(\tau + \frac{1}{2}\right) - \frac{5}{2}\tau + 1\right) - v(m-\tau) \end{array}\right)}{2(m-\tau)\hat{\varepsilon}^{D*^2}}$$
$$- \frac{\hat{\varepsilon}^{*^3}(2 - \tau v) + v\hat{\varepsilon}^{*^2}(2 - 3\tau) + v\hat{\varepsilon}^*(5\tau - 2) - v\tau}{2\tau\hat{\varepsilon}^{*^2}}$$

$\frac{\mathrm{d}\Delta r^D}{\mathrm{d}m} < 0$, i.e., Δr^D decreases in $m \in [\tau, 1]$. Since $\Delta r^D|_{m=0,\tau=0} = 0$, $\Delta r^D \le 0 \Rightarrow r^{D*} \le r^*$. Denote $\Delta p_1^D = p_1^{D*} - p_1^* = \frac{-2\hat{\varepsilon}^{D*^3} + v\hat{\varepsilon}^{D*^2}(m+\tau-2) + 2v\hat{\varepsilon}^{D*}(m-2\tau+1) - v(m-\tau)}{2(m-\tau)\hat{\varepsilon}^{D*^2}} - \frac{2\hat{\varepsilon}^{*^3} - v\hat{\varepsilon}^{*^2}(\tau-2) + 2v\hat{\varepsilon}^*(2\tau-1) - v\tau}{2\tau\hat{\varepsilon}^{*^2}}$. $\frac{\mathrm{d}\Delta p_1^D}{\mathrm{d}m} < 0$, i.e., Δp_1^D decreases in m with $\Delta p_1^D|_{m=0,\tau=0} = 0$, which implies that $\Delta p_1^D = p_1^{D*} - p_1^* \le 0$. We find $\Delta p_2^D = p_2^{D*} - p_2^* = v - v = 0$. Denote $\Delta p_d^D = p_1^{D*} - p_2^{D*} - (p_1^* - p_2^*) = p_1^{D*} - p_1^* \le 0$. Let $\Delta p_s^D = p_s^{D*} - p_s^* = \frac{v(m-1)\left(\hat{\varepsilon}^{D*} - 1\right) - \hat{\varepsilon}^{D*^2}}{\hat{\varepsilon}^{D*}(m-\tau)} - \frac{\hat{\varepsilon}^{*^2} - v(1-\hat{\varepsilon}^*)}{\hat{\varepsilon}^*\tau}$. $\frac{\mathrm{d}\Delta p_s^D}{\mathrm{d}m} < 0$, i.e., Δp_s^D decreases in $m \in [\tau, 1]$ with $\Delta p_s^D\big|_{m=0,\tau=0} = 0$. Then, $\Delta p_s^D \le 0$, i.e., $\Delta p_s^D = p_s^{D*} - p_s^* \le 0$. Denote $\Delta d_1^D = d_1^{D*} - d_1^* = 1 - \hat{\varepsilon}^{D*} - (1 - \hat{\varepsilon}^*)$. $\frac{\mathrm{d}\Delta d_1^D}{\mathrm{d}m} > 0$, i.e., Δd_1^D increases in $m \in [\tau, 1]$ with $\Delta d_1^D|_{m=0,\tau=0} = 0$. Then, $\Delta d_1^D \ge 0$, i.e., $\Delta d_1^D = d_1^{D*} - d_1^* \ge 0$. Let $\Delta d_2^D = d_2^{D*} - d_2^* = \hat{\varepsilon}^{D*} - \hat{\varepsilon}^*$. $\frac{\mathrm{d}\Delta d_2^D}{\mathrm{d}m} < 0$, i.e., Δd_2^D decreases in $m \in [\tau, 1]$ with $\Delta d_2^D\big|_{m=0,\tau=0} = 0$. Thus, $\Delta d_2^D \le 0$, i.e., $\Delta d_2^D \le 0$. Besides, $\Delta d^D = d^{D*} - d^* = 0$. $\square$

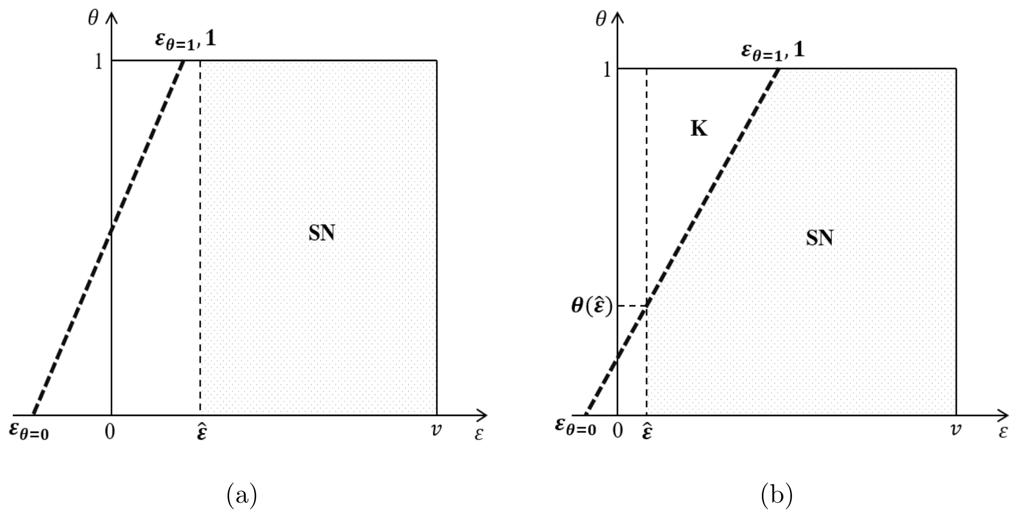
B.4.3 Optimal Commission Rate Strategy

Proof of Proposition 4.6. The platform first sets a commission rate, responding to which the retailer sets new-product prices across periods. Based on the equilibrium outcomes (Table 4.3), the platform's revenue $r_p = \tau p_s^* d_s^* = r_p = \frac{1-\hat{\varepsilon}^*\left(\hat{\varepsilon}^{*2}-v(1-\hat{\varepsilon}^*)\right)}{\hat{\varepsilon}^*\tau}$. $\frac{\partial r_p}{\partial \tau} = 0$ when $\tau = \tilde{\tau}^p = \frac{\left(2v^2+6v+1\right)C_5{}^2-\left(v^3-3v^2-10v\right)C_5+v^4+3v^3-5v^2-4v}{12v^2C_5{}^2+\left(6v^3+12v^2\right)C_5+6v^2}$. We know (i) when $\tau \in (0, \tilde{\tau}^p)$, $\frac{\partial r_p}{\partial \tau} > 0$; (ii) when $\tau = \tilde{\tau}^p$, $\frac{\partial r_p}{\partial \tau} = 0$; (iii) when $\tau \in (\tilde{\tau}^p, 1)$, $\frac{\partial r_p}{\partial \tau} < 0$. Then, $\tau = \tilde{\tau}^p$ is a stationary point, i.e., $\tau^* = \tilde{\tau}^p$. Note that $\tilde{\tau}^p \leq 1$. Additionally, $\tilde{\tau}^p = 1$ when $v = \bar{v}_p = \frac{2}{\sqrt{13}-1}$, and $v = 1$ when $\tau = \bar{\tau}_p = \frac{5\sqrt[3]{6912^2}+120\sqrt[3]{6912}+1440}{6\sqrt[3]{6912^2}+168\sqrt[3]{6912}+2304} \approx 0.7212$. We can summarize that if $v \in \left(\frac{1}{2}, \bar{v}_p\right)$, $\tau^* = \tilde{\tau}^p = 1$; otherwise, if $v \in (\bar{v}_p, 1)$ and $\tau \in (\bar{\tau}_p, 1)$, $\frac{\partial \tilde{\tau}^p}{\partial v} < 0$, $\tau^* = \tilde{\tau}^p < 1$. Moreover, we find that, when $\tilde{v}^r(\tau) < 1$ and $\tilde{\tau}^p < 1$, $\tilde{\tau}^p > \tilde{v}^{r^{-1}}(v)$, where $\tilde{v}^{r^{-1}}(\cdot)$ is the inverse function of $\tilde{v}^r(\cdot)$. Specifically, $\bar{v}_p > \bar{v}^r$, i.e., $\frac{2}{\sqrt{13}-1} > \frac{2}{\sqrt{3}+1}$, and $\bar{\tau}_p > \bar{\tau}^r$, i.e., $0.7212 > \frac{\sqrt{3}}{3}$. □

B.5 Robustness

B.5.1 Interrelated Product Valuation and Utility Dependence

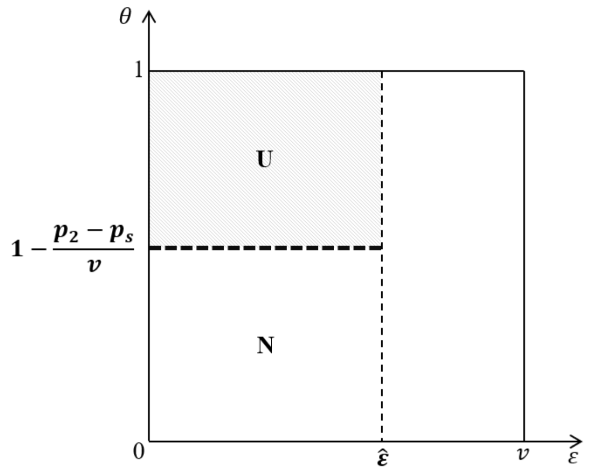
Following the calculation process demonstrated in Appendix B.2.1, two possible segments of the active consumers, as defined in Table B.2, are illustrated in Figure B.5.



Notes. "SN" denotes the choice "resell and buy new" and "K" denotes the choice "keep".

Figure B.5: Segmentation of active consumers when $\varepsilon \in [0, v]$

When $\varepsilon \in [0, v]$, under constraint (a), as shown in Figure B.5(a), the number of active consumers who choose the "resell and buy new" option is $d_{a,sn} = \frac{v-\hat{\varepsilon}}{v}$. Under constraint (b), as shown in Figure B.5(b), the number of "resell and buy new" segment of the active consumers is $d_{a,sn} = \frac{(\theta(\hat{\varepsilon})+1)(\varepsilon_{\theta=1}-\hat{\varepsilon})}{2v} + \frac{v-\varepsilon_{\theta=1}}{v}$. For reserved consumers, the segmentation is shown in Figure B.6. The number of "buy used" segment of the reserved consumers is $d_{r,u} = \frac{\hat{\varepsilon}\left(1-\left(1-\frac{p_2-p_s}{v}\right)\right)}{v}$, and that of "buy new" segment of the reserved consumers is $d_{r,n} = \frac{\hat{\varepsilon}\left(1-\frac{p_2-p_s}{v}\right)}{v}$.



Notes. "U" denotes the choice "buy used" and "N" denotes the choice "buy new".

Figure B.6: Segmentation of reserved consumers when $\varepsilon \in [0, v]$

To derive $p_s^*(p_2)$, we let $d_{a,sn} = d_{r,u}$ under two constraints:

1. under constraint (a) $\hat{\varepsilon} \geq \varepsilon_{\theta=1}$: $d_{a,sn} = \frac{v-\hat{\varepsilon}}{v}$ and $d_{r,u} = \frac{\hat{\varepsilon}\left(1-\left(1-\frac{p_2-p_s}{v}\right)\right)}{v}$. $d_{a,sn} = d_{r,u} \Rightarrow p_s^*(p_2) = \frac{\hat{\varepsilon}(v+p_2)-v^2}{\hat{\varepsilon}} = p_2 - \frac{v-\hat{\varepsilon}}{\hat{\varepsilon}}v$.

2. under constraint (b) $\hat{\varepsilon} < \varepsilon_{\theta=1}$: we have $d_{a,sn} = \frac{(\theta(\hat{\varepsilon})+1)(\varepsilon_{\theta=1}-\hat{\varepsilon})}{2v} + \frac{v-\varepsilon_{\theta=1}}{v}$ and $d_{r,u} = \frac{\hat{\varepsilon}\left(1-\left(1-\frac{p_2-p_s}{v}\right)\right)}{v}$. From the condition $d_{a,sn} = d_{r,u}$, we can derive that $p_s^*(p_2) = \frac{\tau(\hat{\varepsilon}-p_2)+p_2-\sqrt{\hat{\varepsilon}^2(2\tau-1)-2\hat{\varepsilon}(\tau(v+p_2)-v)(\tau-1)+2v^2(\tau-1)^2}}{(\tau-1)^2}$.

Then, we derive the period-two new-product price by maximizing period-two revenue $r_2 = d_2 p_2$, where $d_2 = d_{a,sn} + d_{r,n}$. Similar to the calculation logic in Appendix

B.2.1, if $f(\varepsilon) = \frac{1}{v}$, we find that the market outcome under constraint (b) is inferior to the market outcome under constraint (a). The subgame equilibrium is, given marginal consumer type $\hat{\varepsilon}$, the new-product price is $p_2^*(\hat{\varepsilon}) = \frac{\hat{\varepsilon}^2 - v(1-\tau)(v-\hat{\varepsilon})}{\hat{\varepsilon}\tau}$ and the transaction price for used products on the CRP is $p_s^*(\hat{\varepsilon}) = \frac{\hat{\varepsilon}^2 - v(v-\hat{\varepsilon})}{\hat{\varepsilon}\tau}$, with $p_s^*(\hat{\varepsilon}) = p_2^*(\hat{\varepsilon}) - \frac{v-\hat{\varepsilon}}{\hat{\varepsilon}}v$. Moreover, the new-product demand is $d_2^*(\hat{\varepsilon}) = \frac{\varepsilon}{v}$ and the used-product demand is $d_s^*(\hat{\varepsilon}) = 1 - \frac{\hat{\varepsilon}}{v}$. The period-two revenue is $r_2^*(\hat{\varepsilon}) = \frac{\hat{\varepsilon}^2 - v(1-\tau)(v-\hat{\varepsilon})}{\tau v}$.

In period one, when $\varepsilon \in [0, v]$, the indifferent consumer type $\hat{\varepsilon}$ can be represented by Equation 4.2, similar to the main model. Substituting the subgame equilibrium into Equation 4.2, the inverse function of period-one new-product price p_1 of marginal consumer type $\hat{\varepsilon}$ is $p_1(\hat{\varepsilon}) = \frac{2\hat{\varepsilon}^3 - v\hat{\varepsilon}^2(\tau-2) + 2v^2\hat{\varepsilon}(2\tau-1) - v^3\tau}{2\tau\hat{\varepsilon}^2}$. Finally, we solve problem $\max_{\hat{\varepsilon}} r = p_1 d_1 + r_2^*(\hat{\varepsilon})$, where $d_1 = \frac{v-\hat{\varepsilon}}{v}$. The equilibrium outcomes are summarized in Table 4.7.

The market-clearing price for used products is $p_s^* = \frac{\hat{\varepsilon}^2 - v(v-\hat{\varepsilon})}{\hat{\varepsilon}\tau}$. $\frac{\partial p_s^*}{\partial v} = \frac{4(\tau-1)+2C_7}{2\tau-1+C_7} > 0$, i.e., p_s^* monotonically increases in v and has a minimum of $p_s^*|_{v=0} = 0$. Thus, the CRP always functions. Besides, we find $p_1^* - p_2^* \geq 0$ and $\frac{\partial(p_1^* - p_2^*)}{\partial v} > 0$. Moreover, $\frac{\partial p_1^*}{\partial v} > 0$, $\frac{\partial p_2^*}{\partial v} > 0$, $\frac{\partial p_s^*}{\partial v} > 0$, $\frac{\partial d_r^*}{\partial \tau} > 0$, and $\frac{\partial d_a^*}{\partial \tau} < 0$.

Comparing the prices with the benchmark, for period-one price difference $\Delta p_1 = p_1^* - p_1^{B*}$, we find $\frac{\partial \Delta p_1}{\partial v} > 0$ with a minimum of $\Delta p_1|_{v=0} = 0$. Thus, $\Delta p_1 \geq 0$. For period-two price, $\Delta p_2 = p_2^* - p_2^{B*} = v - v = 0$. Moreover, for intertemporal price difference $\Delta p_d = (p_1^* - p_2^*) - \left(p_1^{B*} - p_2^{B*}\right)$, we find $\frac{\partial \Delta p_d}{\partial v} > 0$ with a minimum of $\Delta p_d|_{v=0} = 0$, which means $\Delta p_1 \geq 0$. Comparing the demands with the benchmark, for period-one demand difference $\Delta d_1 = d_1^* - d_1^{B*}$, we have $\frac{\partial \Delta d_1}{\partial \tau} < 0$ with a maximum of $\Delta d_1|_{\tau=0} = 1 - \frac{\sqrt{5}}{2} \approx -0.1180$. Thus, $\Delta d_1 < 0$. For period-two demand difference $\Delta d_2 = d_2^* - d_2^{B*}$, $\frac{\partial \Delta d_2}{\partial \tau} > 0$ with a minimum of $\Delta d_2|_{\tau=0} = \frac{\sqrt{5}}{2} - 1 > 0 \approx 0.1180$, which means $\Delta d_2 > 0$.

We compare the retailer's revenue with the benchmark, for period-one revenue difference $\Delta r_1 = r_1^* - r_1^{B*}$, $\frac{\partial \Delta r_1}{\partial v} < 0$ with a maximum of $\Delta r_1|_{v=0} = 0$. Thus, $\Delta r_1 \leq 0$.

The cannibalization effect is consistent with the main model. For period-two revenue difference $\Delta r_1 = r_2^* - r_2^{B*}$, we find $\frac{\partial \Delta r_2}{\partial v} > 0$ with a minimum of $\Delta r_2|_{v=0} = 0$. It means $\Delta r_2 \geq 0$. The enhancement effect persists. For the difference of the total revenue in the two periods $\Delta r = r^* - r^{B*}$, we have $\frac{\partial \Delta r}{\partial \tau} \leq 0$. Besides, $\Delta r = 0$ when $\tau = \frac{\sqrt{3}}{3}$. Thus, $\Delta r > 0$ if $\tau > \frac{\sqrt{3}}{3}$ and $\Delta r \leq 0$ if $\tau \leq \frac{\sqrt{3}}{3}$.

B.5.2 Vertical Differentiation

When $p_2 \leq v + \delta$, the option "resell the used original version and purchase the upgraded version" dominates the option "resell the used original version and leave" for active consumers; the option "purchase the upgraded version" dominates the option "leave" for reserved consumers. Then, the period-two demand equals $d_2 = d_{a,sn} + d_{r,n}$. Otherwise, if $p_2 > v + \delta$, the option "resell the used original version and leave" dominates the option "resell the used original version and purchase the upgraded version" for active consumers; the option "leave" dominates the option "purchase the upgraded version" for reserved consumers. In the latter case, there will be transactions of used original version on the CRP but no demand for upgraded version from the retailer, i.e., $d_2 = 0$.

To maximize the period-two revenue $r_2 = p_2 d_2$, the retailer will charge a price p_2 no higher than $v + \delta$ to maintain a positive demand. Thus, the option "resell the used original version and leave" for active consumers as well as the option "leave" for reserved consumers are both dominated. The perceived quality level of used product at which active consumer is indifferent between the two options "keep" and "resell the used original version and purchase the upgraded version" is $\theta_a = 1 + \frac{\delta - p_2 + (1-\tau)p_s}{v}$, and at which reserved consumer is indifferent between the two options "purchase the used original version" and "purchase the upgraded version" is $\theta_r = 1 + \frac{\delta - p_2 + p_s}{v}$.

As shown in Figure B.7, the indifferent consumer type of reserved consumer θ_r intersects with $\theta = 1$ at $\delta^1_{\theta=1} = p_2 - p_s$ and with $\theta = 0$ at $\delta^1_{\theta=0} = p_2 - p_s - v$. The

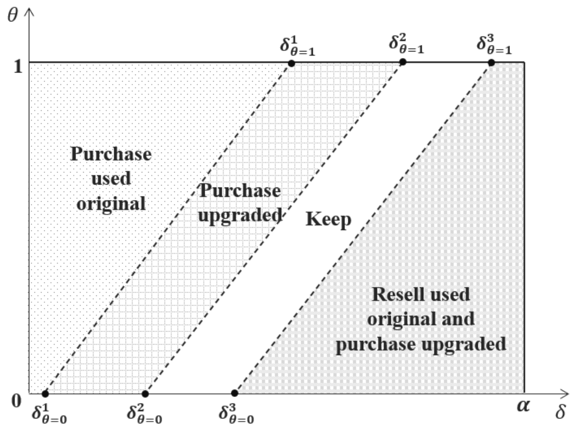


Figure B.7: Market segmentation with vertical differentiation in subgame

indifferent consumer type of active consumer θ_a intersects with $\theta = 1$ at $\delta^3_{\theta=1} = p_2 - (1-\tau)p_s$ and with $\theta = 0$ at $\delta^3_{\theta=0} = p_2-(1-\tau)p_s-v$. Besides, the indifferent consumer type between active and reserved consumer $f(\hat{\delta}, \hat{\theta})$ intersects with $\theta = 1$ at $\delta^2_{\theta=1}$ and with $\theta = 0$ at $\delta^2_{\theta=0}$. The number of reserved consumers choosing "purchase the used original version" and "purchase the upgraded version", respectively, is $d_{r,u} = \frac{\delta^1_{\theta=1}+\delta^1_{\theta=0}}{2\alpha}$ and $d_{r,n} = \frac{\delta^2_{\theta=1}+\delta^2_{\theta=0}}{2\alpha} - d_{r,u}$. For active consumers, the demand for the options "resell the used original version and purchase the upgraded version" and "keep", respectively, is $d_{a,sn} = \frac{\alpha-\delta^3_{\theta=1}+\alpha-\delta^3_{\theta=0}}{2\alpha}$ and $d_{a,k} = \frac{\alpha-\delta^2_{\theta=1}+\alpha-\delta^2_{\theta=0}}{2\alpha} - d_{a,sn}$. As such, the period-two new-product demand is $d_2 = d_{r,n} + d_{a,sn}$ and the volume of used products on the CRP is $d_s = d_{r,u} = d_{a,sn}$. We solve the problem $r_2 = p_2d_2$ under the constraint $p_2 \leq v + \delta$ to derive the subgame equilibrium.

In period one, the indifferent consumer type $f(\hat{\delta}, \hat{\theta})$ can be expressed by $v - p_1 + \hat{\theta}v = v + \hat{\delta} - p_2$. Then, we maximize the total revenue $r = p_1d_1 + p_2d_2$ to derive the equilibrium outcomes. The segmentation in equilibrium is illustrated in Figure B.8, where $\delta^{1*}_{\theta=1} = \frac{(\alpha+v)(1-\tau)}{2-\tau}$, $\delta^{1*}_{\theta=0} = \frac{\alpha(1-\tau)-v}{2-\tau}$, $\delta^{3*}_{\theta=1} = \frac{\alpha+v}{2-\tau}$, and $\delta^{3*}_{\theta=0} = \frac{\alpha-v(1-\tau)}{2-\tau}$. In equilibrium, all the reserved consumers purchase used original products from the CRP, whereas active consumers choose from keeping the original version and reselling then purchasing the upgrade version. The outcomes are as follows. The new-product prices in the two periods are $p_1^* = v$ and $p_2^* = \alpha + v$, respectively, and the market-

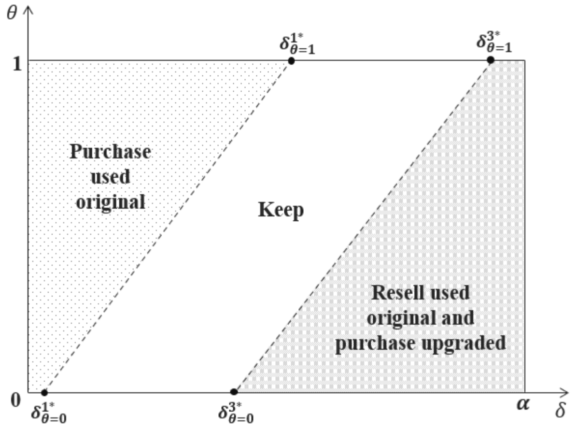


Figure B.8: Market segmentation with vertical differentiation

clearing price for used products on the CRP is $p_s^* = \frac{\alpha+v}{2-\tau}$. The new-product demands in the two periods are $d_1^* = \frac{2\alpha+v\tau}{2\alpha(2-\tau)}$ and $d_2^* = \frac{\alpha-v(1-\tau)}{\alpha(1-\tau)}$, respectively, and the demand for the used version on the CRP is $d_s^* = \frac{2\alpha(1-\tau)-v\tau}{2\alpha(2-\tau)}$.

By the equilibrium outcomes, the intertemporal price difference $p_1^* - p_2^* = -\alpha \leq 0$. By taking the derivative of α, we find $\frac{\partial p_2}{\partial \alpha} > 0$, $\frac{\partial p_s}{\partial \alpha} > 0$, $\frac{\partial d_1}{\partial \alpha} \leq 0$, $\frac{\partial d_2}{\partial \alpha} \geq 0$, and $\frac{\partial d_s}{\partial \alpha} \geq 0$.

Appendix C

Supplementary Material for Chapter 5

C.1 Equilibrium of Main Model

Using backward induction, we first solve the subgame equilibrium at time 1. By Table 5.4, the properties $v_{rp,rl} = v_{n,l}$, $v_{rp,k} \geq v_{n,s}$, and $v_{s,l} \geq v_{k,rl}$ exist. It leads to that the choice 'Resell V1 and leave' for early-adopters and the choice 'Purchase V2' for followers cannot coexist. Additionally, $v_{n,s} \geq v_{n,l} \geq v_{s,l} \Rightarrow p_2 \geq \frac{\alpha p_s}{\theta}$ exists to ensure the dominance of the choice 'Purchase used V1', sustaining the positive transactions on the secondary platform. These formulate the market segmentation at time 1, as Figure C.1 depicted.

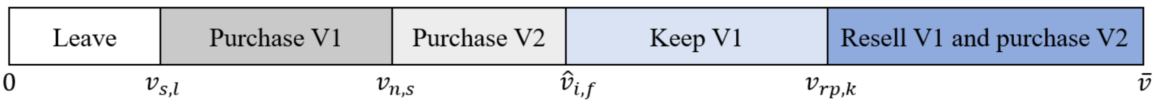


Figure C.1: Market segmentation at time 1

Early-adopters choose between 'Keep' and 'Resell V1 and purchase V2' with demand $d_k = \frac{v_{rp,k} - \hat{v}}{\bar{v}}$ and $d_{rp} = \frac{\bar{v} - v_{rp,k}}{\bar{v}}$, respectively. Followers choose between 'Purchase

V2', 'Purchase V1', and 'Leave' with demand $d_n = \frac{\hat{v}-v_{n,s}}{\bar{v}}$, $d_s = \frac{v_{n,s}-v_{s,l}}{\bar{v}}$, and $d_l = \frac{v_{s,l}}{\bar{v}}$, respectively. The new product demand is $d_2 = d_{rp} + d_n$. To coincide secondhand supply and demand on the platform, $d_{rp} = d_s \Rightarrow p_s(p_2) = \frac{\theta(2p_2-\beta\bar{v}(\alpha-\theta))}{\alpha+\theta(1-\tau)}$. Substituting $p_s(p_2)$ into d_2, the manufacturer maximizes period-two profit:

$$\max \pi_2 = p_2 d_2, \text{ s.t. } p_2 \geq \frac{\alpha p_s}{\theta} \Leftrightarrow p_2 \leq \frac{\beta\alpha\bar{v}(\alpha-\theta)}{\alpha-\theta(1-\tau)}.$$

Adding Lagrange multiplier λ, $L(p_2,\lambda) = p_2 d_2 + \lambda\left(\frac{\beta\alpha\bar{v}(\alpha-\theta)}{\alpha-\theta(1-\tau)} - p_2\right)$, $\lambda \geq 0$, and $\lambda\left(\frac{\beta\alpha\bar{v}(\alpha-\theta)}{\alpha-\theta(1-\tau)} - p_2\right) = 0$. $\frac{\partial^2 L(p_2,\lambda)}{\partial p_2{}^2} < 0$ and $\frac{\partial L(p_2,\lambda)}{\partial p_2} = 0 \Rightarrow p_2^*(\hat{v},\lambda) = \frac{\beta(\hat{v}(\alpha+\theta(1-\tau))+\bar{v}(\alpha-\theta))}{4} - \lambda$.

If $\lambda = 0$, $p_2^*(\hat{v}) = \frac{\beta(\hat{v}(\alpha+\theta(1-\tau))+\bar{v}(\alpha-\theta))}{4}$, $\pi_2^*(\hat{v}) = \frac{\beta(\hat{v}(\alpha+\theta(1-\tau))+\bar{v}(\alpha-\theta))^2}{8\bar{v}(\alpha+\theta(1-\tau))}$.

If $\lambda > 0$, $p_2^*(\hat{v}) = \frac{\beta\alpha\bar{v}(\alpha-\theta)}{\alpha-\theta(1-\tau)}$, $\pi_2^*(\hat{v}) = \frac{\beta\alpha\bar{v}(\alpha-\theta)(\hat{v}(\alpha-\theta(1-\tau))-(\alpha-\theta))}{(\alpha+\theta(\tau-1))^2}$.

The $\pi_2^*(\hat{v})$ derived under $\lambda > 0$ is always less than that under $\lambda = 0$. Thus, the subgame equilibrium outcomes are: $p_2^*(\hat{v}) = \frac{\beta(\hat{v}(\alpha+\theta(1-\tau))+\bar{v}(\alpha-\theta))}{4}$, $p_s^*(\hat{v}) = \frac{\beta\theta(\hat{v}(\alpha+\theta(1-\tau)))}{2(\alpha+\theta(1-\tau))} - \frac{\bar{v}(\alpha-\theta)}{2(\alpha+\theta(1-\tau))}$, $d_2^*(\hat{v}) = \frac{\beta(\hat{v}(\alpha+\theta(1-\tau))+\bar{v}(\alpha-\theta))}{2\bar{v}(\alpha+\theta(1-\tau))}$, and $\pi_2^*(\hat{v}) = \frac{\beta(\hat{v}(\alpha+\theta(1-\tau))+\bar{v}(\alpha-\theta))^2}{8\bar{v}(\alpha+\theta(1-\tau))}$.

Back to time 0, the marginal consumer with the threshold $\hat{v}_{e,f}$ identified in Table 5.2 is indifferent between purchasing V1 at time 0 and postponing the purchase to time 1. A consumer purchases V1 at time 0 if $v \geq \hat{v}_{e,f}$ but postpones purchase to time 1 if $v < \hat{v}_{e,f}$. The demand at time 0 is $d_1 = \frac{\bar{v}-\hat{v}}{\bar{v}}$. The manufacturer capitalizes on consumers' time-inconsistent behavior and strategically manages prices to establish an optimal threshold, thereby maximizing total profit over the two periods:

$$\hat{v}_{e,f}^* = \arg\max \pi(\hat{v}) \tag{C.1}$$

where $\hat{v}_{e,f} \in \{\hat{v}_{k,n}, \hat{v}_{k,s}, \hat{v}_{k,l}, \hat{v}_{rp,n}, \hat{v}_{rp,s}, \hat{v}_{rp,l}, \hat{v}_{rl,n}, \hat{v}_{rl,s}, \hat{v}_{rl,l}\}$ and $\pi(\hat{v}) = p_1 d_1(\hat{v}) + \pi_2^*(\hat{v}) - \frac{K(\alpha^2-1)}{2}$. Next, we will systematically examine each potential value of $\hat{v}_{e,f}$ and elucidate the corresponding equilibrium for each case.

Case 1: $\hat{v}_{e,f} = \hat{v}_{k,n}$. Substituting $p_2(\hat{v}_{k,n})$ into $\hat{v}_{k,n} = \frac{p_1-\beta p_2}{\beta(1-(\alpha-\theta))}$, we can derive

$\hat{v}_{k,n}(p_1) = \frac{4p_1-\beta^2\bar{v}(\alpha-\theta)}{\beta(\beta(\alpha+\theta(1-\tau))-4(\alpha-\theta-1))}$. The manufacturer maximizes the total profit:

$$\max_{\hat{v}_{k,n}} \pi = p_1 d_1(\hat{v}_{k,n}) + \pi_2^*(\hat{v}_{k,n}) - \frac{K\left(\alpha^2-1\right)}{2}$$

where $d_1(\hat{v}_{k,n}) = \frac{\bar{v}-\hat{v}_{k,n}}{\bar{v}}$ and $\pi_2^*(\hat{v}_{k,n}) = \frac{\beta\left(\hat{v}_{k,n}(\alpha+\theta(1-\tau))+\bar{v}(\alpha-\theta)\right)^2}{8\bar{v}(\alpha+\theta(1-\tau))}$. When $\frac{\mathrm{d}^2\pi}{\mathrm{d}\hat{v}_{k,n}^2} < 0$, $\frac{\mathrm{d}\pi}{\mathrm{d}\hat{v}_{k,n}} = 0 \Rightarrow \hat{v}_{k,n}^* = \frac{\bar{v}(4-3\alpha)-\theta\bar{v}(\beta(\tau-2)-3)}{\theta(2\beta(1-\tau)+\tau+7)+2\alpha\beta-9\alpha+8}$.

Case 2: $\hat{v}_{e,f} = \hat{v}_{k,s}$. Substituting $p_s(\hat{v}_{k,s})$ into $\hat{v}_{k,s} = \frac{p_1-\beta p_s}{\beta}$, we can derive $\hat{v}_{k,s}(p_1) = \frac{2\alpha p_1+\theta\left(\alpha\beta^2\bar{v}-2p_1(\tau-1)\right)-\beta^2\theta^2\bar{v}}{\beta(\alpha+\theta(1-\tau))4(\beta\theta+2)}$. The manufacturer maximizes the total profit:

$$\max_{\hat{v}_{k,s}} \pi = p_1 d_1(\hat{v}_{k,s}) + \pi_2^*(\hat{v}_{k,s}) - \frac{K\left(\alpha^2-1\right)}{2}$$

where $d_1(\hat{v}_{k,s}) = \frac{\bar{v}-\hat{v}_{k,s}}{\bar{v}}$ and $\pi_2^*(\hat{v}_{k,s}) = \frac{\beta\left(\hat{v}_{k,s}(\alpha+\theta(1-\tau))+\bar{v}(\alpha-\theta)\right)^2}{8\bar{v}(\alpha+\theta(1-\tau))}$. $\frac{\mathrm{d}^2\pi}{\mathrm{d}\hat{v}_{k,s}^2} < 0$, $\frac{\mathrm{d}\pi}{\mathrm{d}\hat{v}_{k,s}} = 0 \Rightarrow \hat{v}_{k,s}^* = \frac{\bar{v}\left(\theta^2(\tau(1-2\beta)-1)+\theta(\alpha(4\beta-\tau)-4(\tau-1))+\alpha^2+4\alpha\right)}{(\alpha+\theta(1-\tau))(8-\theta(1-4\beta-\tau)-\alpha)}$.

Case 3: $\hat{v}_{e,f} = \hat{v}_{k,l}$. We know $\hat{v}_{k,l}(p_1) = \frac{p_1}{\beta(1+\theta)}$. The manufacturer maximizes the total profit:

$$\max_{\hat{v}_{k,l}} \pi = p_1 d_1(\hat{v}_{k,l}) + \pi_2^*(\hat{v}_{k,l}) - \frac{K\left(\alpha^2-1\right)}{2}$$

where $d_1(\hat{v}_{k,l}) = \frac{\bar{v}-\hat{v}_{k,l}}{\bar{v}}$ and $\pi_2^*(\hat{v}_{k,l}) = \frac{\beta\left(\hat{v}_{k,l}(\alpha+\theta(1-\tau))+\bar{v}(\alpha-\theta)\right)^2}{8\bar{v}(\alpha+\theta(1-\tau))}$. $\frac{\mathrm{d}^2\pi}{\mathrm{d}\hat{v}_{k,l}^2} < 0$, $\frac{\mathrm{d}\pi}{\mathrm{d}\hat{v}_{k,l}} = 0 \Rightarrow \hat{v}_{k,l}^* = \frac{\bar{v}(3\theta+4+\alpha)}{8-\alpha+\theta(\tau+7)}$.

Case 4: $\hat{v}_{e,f} = \hat{v}_{rp,n}$. Substituting $p_s(\hat{v}_{rp,n})$ into $\hat{v}_{rp,n} = \frac{p_1-\beta p_s(1-\tau)}{\beta}$, we can derive

$$\hat{v}_{rp,n}(p_1) = \frac{\beta^2\theta^2\bar{v}(1-\tau)+\theta(\tau-1)\left(\alpha\beta^2\bar{v}+2p_1\right)-2\alpha p_1}{\beta\left(\beta\theta(\tau-1)-2\right)\left(\alpha+\theta(1-\tau)\right)}.$$

The manufacturer maximizes the total profit:

$$\max_{\hat{v}_{rp,n}} \pi = p_1 d_1(\hat{v}_{rp,n}) + \pi_2^*(\hat{v}_{rp,n}) - \frac{K\left(\alpha^2-1\right)}{2}$$

where $d_1(\hat{v}_{rp,n}) = \frac{\bar{v}-\hat{v}_{rp,n}}{\bar{v}}$ and $\pi_2^*(\hat{v}_{rp,n}) = \frac{\beta(\hat{v}_{rp,n}(\alpha+\theta(1-\tau))+\bar{v}(\alpha-\theta))^2}{8\bar{v}(\alpha+\theta(1-\tau))}$. $\frac{\mathrm{d}^2\pi}{\mathrm{d}\hat{v}_{rp,n}^2} < 0$, $\frac{\mathrm{d}\pi}{\mathrm{d}\hat{v}_{rp,n}} = 0 \Rightarrow \hat{v}_{rp,n}^* = \frac{\bar{v}\left(2\theta^2(\tau-1)\left(\beta\tau+\frac{1}{2}\right)+\theta(4\alpha\beta+4-\tau(\alpha(4\beta+1)+4))+\alpha(\alpha+4)\right)}{(8-\theta(\tau(4\beta-1)-4\beta+1)-\alpha)(\alpha+\theta(1-\tau))}$.

Case 5: $\hat{v}_{e,f} = \hat{v}_{rp,s}$. Substituting $p_2(\hat{v}_{rp,s})$ and $p_s(\hat{v}_{rp,s})$ into $\hat{v}_{rp,s} = \frac{p_1+\beta p_2-\beta p_s(2-\tau)}{\beta(1+\alpha-\theta)}$, we can derive $\hat{v}_{rp,s}(p_1) = \frac{3\beta^2\theta^2\bar{v}\left(\frac{5}{3}-\tau\right)+\theta\left(3\alpha\beta^2\bar{v}\left(\tau-\frac{4}{3}\right)+4p_1(\tau-1)\right)-\alpha^2\beta^2\bar{v}-4\alpha p_1}{\beta(\alpha+\theta(1-\tau))(\theta(4+\beta(\tau-3))+\alpha\beta-4(\alpha+1))}$. The manufacturer maximizes the total profit:

$$\max_{\hat{v}_{rp,s}} \pi = p_1 d_1(\hat{v}_{rp,s}) + \pi_2^*(\hat{v}_{rp,s}) - \frac{K\left(\alpha^2-1\right)}{2}$$

where $d_1(\hat{v}_{rp,s}) = \frac{\bar{v}-\hat{v}_{rp,s}}{\bar{v}}$ and $\pi_2^*(\hat{v}_{rp,s}) = \frac{\beta(\hat{v}_{rp,s}(\alpha+\theta(1-\tau))+\bar{v}(\alpha-\theta))^2}{8\bar{v}(\alpha+\theta(1-\tau))}$. $\frac{\mathrm{d}^2\pi}{\mathrm{d}\hat{v}_{rp,s}^2} < 0$, $\frac{\mathrm{d}\pi}{\mathrm{d}\hat{v}_{rp,s}} = 0 \Rightarrow \hat{v}_{rp,s}^* = \frac{5\bar{v}\left(\theta^2\left(\frac{\beta\tau^2}{5}+\tau\left(1-\frac{\beta}{5}\right)-\frac{2\beta}{5}-1\right)-\theta\left(\tau\left(\alpha\left(1+\frac{3\beta}{5}\right)+\frac{4}{5}\right)-\frac{6\alpha\beta}{5}-\frac{4}{5}\right)+\alpha^2+\frac{4\alpha}{5}\right)}{2(\alpha+\theta(1-\tau))\left(\theta\left(\tau\left(\beta-\frac{1}{2}\right)-3\beta+\frac{9}{2}\right)+\alpha\left(\beta-\frac{7}{2}\right)-4\right)}$.

Case 6: $\hat{v}_{e,f} = \hat{v}_{rp,l}$. Substituting $p_2(\hat{v}_{rp,l})$ and $p_s(\hat{v}_{rp,l})$ into $\hat{v}_{rp,l} = \frac{p_1+\beta p_2-\beta p_s(1-\tau)}{\beta(1+\alpha)}$, we can derive $\hat{v}_{rp,l}(p_1) = \frac{3\beta^2\theta^2\bar{v}(1-\tau)+\theta\left(3\alpha\beta^2\bar{v}\left(\tau-\frac{2}{3}\right)+4p_1(\tau-1)\right)-\alpha^2\beta^2\bar{v}-4\alpha p_1}{\beta(\alpha+\theta(1-\tau))(\theta\beta(\tau-1)+\alpha\beta-4(\alpha+1))}$. The manufacturer maximizes the total profit:

$$\max_{\hat{v}_{rp,l}} \pi = p_1 d_1(\hat{v}_{rp,l}) + \pi_2^*(\hat{v}_{rp,l}) - \frac{K\left(\alpha^2-1\right)}{2}$$

where $d_1(\hat{v}_{rp,l}) = \frac{\bar{v}-\hat{v}_{rp,l}}{\bar{v}}$ and $\pi_2^*(\hat{v}_{rp,l}) = \frac{\beta\left(\hat{v}_{rp,l}(\alpha+\theta(1-\tau))+\bar{v}(\alpha-\theta)\right)^2}{8\bar{v}(\alpha+\theta(1-\tau))}$. $\frac{\mathrm{d}^2\pi}{\mathrm{d}\hat{v}_{rp,l}^2} < 0$, $\frac{\mathrm{d}\pi}{\mathrm{d}\hat{v}_{rp,l}} = 0 \Rightarrow \hat{v}_{rp,l}^* = \frac{5\bar{v}\left(\frac{\theta^2}{5}(\tau-1)(\beta(\tau+2)+1)-\theta\left(\alpha\left(\frac{2\beta}{5}-\tau\left(1+\frac{3\beta}{5}\right)+\frac{4}{5}\right)-\frac{4}{5}(\tau-1)\right)-\alpha^2-\frac{4\alpha}{5}\right)}{2\left(\alpha+\theta(1-\tau)\left(\theta\left(\beta-\frac{1}{2}\right)(\tau-1)+\alpha\left(\beta-\frac{7}{2}\right)-4\right)\right)}$.

Case 7: $\hat{v}_{e,f} = \hat{v}_{rl,n}$. The existence of $\hat{v}_{rl,n}$ violates the 'Existence' and 'Dominance' conditions mentioned in Table 5.4. The equilibrium is not available.

Case 8: $\hat{v}_{e,f} = \hat{v}_{rl,s}$. Substituting $p_s(\hat{v}_{rl,s})$ into $\hat{v}_{rl,s} = \frac{p_1-\beta p_s(2-\tau)}{\beta(1-\theta)}$, we can derive

$$\hat{v}_{rl,s}(p_1) = \frac{\beta^2\theta^2\bar{v}\,(2-\tau)+\theta\left(\alpha\beta^2\bar{v}\,(\tau-2)+2p_1(\tau-1)\right)-2\alpha p_1}{\beta\left(\theta\left(\beta\left(\tau-2\right)+2\right)-2\right)\left(\alpha+\theta(1-\tau)\right)}.$$

The manufacturer maximizes the total profit:

$$\max_{\hat{v}_{rl,s}} \pi = p_1 d_1(\hat{v}_{rl,s}) + \pi_2^*(\hat{v}_{rl,s}) - \frac{K\left(\alpha^2-1\right)}{2}$$

where $d_1(\hat{v}_{rl,s}) = \frac{\bar{v}-\hat{v}_{rl,s}}{\bar{v}}$ and $\pi_2^*(\hat{v}_{rl,s}) = \frac{\beta\left(\hat{v}_{rl,s}(\alpha+\theta(1-\tau))+\bar{v}(\alpha-\theta)\right)^2}{8\bar{v}(\alpha+\theta(1-\tau))}$. $\frac{\mathrm{d}^2\pi}{\mathrm{d}\hat{v}_{rl,s}^2} < 0$, $\frac{\mathrm{d}\pi}{\mathrm{d}\hat{v}_{rl,s}} = 0 \Rightarrow \hat{v}_{rl,s}^* = \frac{\bar{v}\left(\theta^2\left(\tau(5-4\beta)+2\beta\tau^2-5\right)+\theta(4\alpha(2\beta-1)+4-\tau(\alpha(4\beta+1)+4))+\alpha(\alpha+4)\right)}{(8-\theta(\tau(4\beta-1)-8\beta+9)-\alpha)(\alpha+\theta(1-\tau))}$.

Case 9: $\hat{v}_{e,f} = \hat{v}_{rl,l}$. The equilibrium is the same as the case $\hat{v}_{e,f} = \hat{v}_{rp,n}$.

Upon comparing the total profit π obtained with different thresholds $\hat{v}_{e,f}$ at time 0, we find that $\hat{v}_{e,f} = \hat{v}_{rp,l}$ emerges as the predominant case, while $\hat{v}_{e,f} = \hat{v}_{k,l}$ represents a weakly dominant case when both β and θ are exceptionally high. The case $\hat{v}^* = \hat{v}_{rp,l}$ offers more comprehensive theoretical explanations and implications that adequately capture the demand effects observed in the $\hat{v}^* = \hat{v}_{k,l}$ case. Therefore, we employ $\hat{v}^* = \hat{v}_{rp,l}$ for our analysis. The equilibrium outcomes is summarized in Table 5.5.

C.2 Equilibrium of Scenario R

Using backward induction, we first solve the subgame equilibrium at time 1. By Table 5.6, the properties $v^R_{rp,rl} = v^R_{n,l}$, $v^R_{rp,k} \geq v^R_{n,s}$, and $v^R_{s,l} \geq v^R_{k,rl}$ exist. It leads to that the choice 'Resell V1 and leave' for early-adopters and the choice 'Purchase V2' for followers cannot coexist. Additionally, $v^R_{n,s} \geq v^R_{n,l} \geq v^R_{s,l} \Rightarrow p^R_2 \geq \frac{\alpha p^R_s}{\theta}$ exists to ensure the dominance of the choice 'Purchase used V1', sustaining the positive transactions on the secondary platform. These formulate the market segmentation of scenario R, as Figure 5.5 depicted.

The demand of 'Keep' and 'Resell V1 and purchase V2' for early-adopters is $d^R_k = \frac{v^R_{rp,k} - \hat{v}^R}{\bar{v}}$ and $d^R_{rp} = \frac{\bar{v} - v^R_{rp,k}}{\bar{v}}$, respectively. The demand of 'Purchase V2', 'Purchase V1', and 'Leave' for followers is $d^R_n = \frac{\hat{v}^R - v^R_{n,s}}{\bar{v}}$, $d^R_s = \frac{v^R_{n,s} - v^R_{s,l}}{\bar{v}}$, and $d^R_l = \frac{v^R_{s,l}}{\bar{v}}$, respectively. The new product demand is $d^R_2 = d^R_{rp} + d^R_n$. To coincide secondhand supply and demand on the platform, $d^R_{rp} = d^R_s \Rightarrow p^R_s(p^R_2) = \frac{\theta\left(2p^R_2 - \bar{v}(\alpha-\theta)\right)}{\alpha+\theta(1-\tau)}$. Substituting $p^R_s(p^R_2)$ into d^R_2, the manufacturer maximizes period-two profit:

$$\max \pi^R_2 = p^R_2 d^R_2, \text{ s.t. } p^R_2 \geq \frac{\alpha p^R_s}{\theta} \Leftrightarrow p^R_2 \leq \frac{\alpha\bar{v}(\alpha-\theta)}{\alpha-\theta(1-\tau)}.$$

Adding Lagrange multiplier λ, $L(p^R_2, \lambda) = p^R_2 d^R_2 + \lambda\left(\frac{\alpha\bar{v}(\alpha-\theta)}{\alpha-\theta(1-\tau)} - p^R_2\right)$, $\lambda \geq 0$, and $\lambda\left(\frac{\alpha\bar{v}(\alpha-\theta)}{\alpha-\theta(1-\tau)} - p^R_2\right) = 0$. $\frac{\partial^2 L(p^R_2,\lambda)}{\partial {p^R_2}^2} < 0$ and $\frac{\partial L(p^R_2,\lambda)}{\partial p^R_2} = 0 \Rightarrow p^{R*}_2(\hat{v}^R, \lambda) =$

$\frac{\left(\hat{v}^R(\alpha+\theta(1-\tau))+\bar{v}(\alpha-\theta)\right)}{4} - \lambda$.

If $\lambda = 0$, $p_2^{R*}(\hat{v}^R) = \frac{\left(\hat{v}^R(\alpha+\theta(1-\tau))+\bar{v}(\alpha-\theta)\right)}{4}$, $\pi_2^{R*}(\hat{v}^R) = \frac{\left(\hat{v}^R(\alpha+\theta(1-\tau))+\bar{v}(\alpha-\theta)\right)^2}{8\bar{v}(\alpha+\theta(1-\tau))}$.

If $\lambda > 0$, $p_2^{R*}(\hat{v}^R) = \frac{\alpha\bar{v}(\alpha-\theta)}{\alpha-\theta(1-\tau)}$, $\pi_2^{R*}(\hat{v}^R) = \frac{\alpha\bar{v}(\alpha-\theta)\left(\hat{v}^R(\alpha-\theta(1-\tau))-(\alpha-\theta)\right)}{(\alpha+\theta(\tau-1))^2}$.

The $\pi_2^{R*}(\hat{v}^R)$ derived under $\lambda > 0$ is always less than that under $\lambda = 0$. Thus, the subgame equilibrium outcomes are: $p_2^{R*}(\hat{v}^R) = \frac{\left(\hat{v}^R(\alpha+\theta(1-\tau))+\bar{v}(\alpha-\theta)\right)}{4}$, $p_s^{R*}(\hat{v}^R) = \frac{\theta\left(\hat{v}^R(\alpha+\theta(1-\tau))-\bar{v}(\alpha-\theta)\right)}{2(\alpha+\theta(1-\tau))}$, $d_2^{R*}(\hat{v}^R) = \frac{\left(\hat{v}^R(\alpha+\theta(1-\tau))+\bar{v}(\alpha-\theta)\right)}{2\bar{v}(\alpha+\theta(1-\tau))}$, $\pi_2^{R*}(\hat{v}^R) = \frac{\left(\hat{v}^R(\alpha+\theta(1-\tau))+\bar{v}(\alpha-\theta)\right)^2}{8\bar{v}(\alpha+\theta(1-\tau))}$.

Back to time 0, the marginal consumer is indifferent between 'Purchase V1 at time 0 and keep it at time 1' and 'Postpone the purchase at time 0 and purchase V2 at time 1'. Then, the threshold $\hat{v}_{e,f}^R$ can be derived from $\hat{v}^R - p_1^R + \theta\hat{v}^R = \alpha\hat{v}^R - p_2^R \Rightarrow \hat{v}^R = \frac{p_1^R - p_2^R}{1-\alpha+\theta}$.

Substituting the subgame equilibrium $p_2^{R*}(\hat{v}^R)$ into $\hat{v}_{e,f}^R = \frac{p_1^R - p_2^R}{1-\alpha+\theta}$, we can derive $p_1^R(\hat{v}^R) = \frac{\hat{v}^R(\theta(5-\tau)-3\alpha+4)+\bar{v}(\alpha-\theta)}{4}$. The manufacturer maximizes the total profit:

$$\max_{\hat{v}^R} \pi^R = p_1^R d_1^R(\hat{v}^R) + \pi_2^{R*}(\hat{v}^R) - \frac{K\left(\alpha^2-1\right)}{2}$$

where $d_1^R(\hat{v}^R) = \frac{\bar{v}-\hat{v}^R}{\bar{v}}$. By $\frac{\mathrm{d}^2\pi^R}{\mathrm{d}\hat{v}^{R2}} < 0$ when $\alpha < \frac{8+\theta(9-\tau)}{7}$, we know $\frac{\mathrm{d}\pi^R}{\mathrm{d}\hat{v}^R} = 0 \Rightarrow \hat{v}^{R*} = \frac{\bar{v}(\theta(\tau-5)+3\alpha-4)}{\theta(\tau-9)+7\alpha-8}$. The equilibrium outcome is summarized into Table 5.7.

Note that $p_s^{R*} = 0$ when $\theta = \underline{\theta}^R(\alpha,\tau)$. $\frac{\partial p_s^{R*}}{\partial\theta} = 0$ when $\theta = \bar{\theta}_{p_s^{R*}}(\alpha,\tau)$; $\bar{\theta}_{p_s^{R*}}(\alpha,\tau) < \underline{\theta}^R(\alpha,\tau)$. For $\theta \in \left[0, \bar{\theta}_{p_s^{R*}}\right)$, $\frac{\partial p_s^{R*}}{\partial\theta} < 0$, $p_s^{R*} < 0$; for $\theta \in \left[\bar{\theta}_{p_s^{R*}}, \underline{\theta}^R\right)$, $\frac{\partial p_s^{R*}}{\partial\theta} \geq 0$, $p_s^{R*} < 0$; and for $\theta \in \left[\underline{\theta}^R, 1\right]$, $\frac{\partial p_s^{R*}}{\partial\theta} > 0$, $p_s^{R*} \geq 0$. Moreover, we find that $\underline{\theta}(\beta,\alpha,\tau) > \underline{\theta}^R(\alpha,\tau)$.

C.3 Equilibrium of Scenario N

Using backward induction, we first solve the subgame equilibrium at time 1. By Table 5.9, the properties $v_{rp,rl}^N = v_{n,l}^N$, $v_{rp,k}^N \geq v_{n,s}^N$, and $v_{s,l}^N \geq v_{k,rl}^N$ exist. It leads to that the choice 'Resell V1 and leave' for early-adopters and the choice 'Purchase new V1' for followers cannot coexist. Additionally, $v_{n,s}^N \geq v_{n,l}^N \geq v_{s,l}^N \Rightarrow p_2^N \geq \frac{p_s^N}{\theta}$ exists to ensure the dominance of the choice 'Purchase used V1', sustaining the positive transactions on the secondary platform. These formulate the market segmentation at time 1 of scenario N, as Figure C.2 depicted.

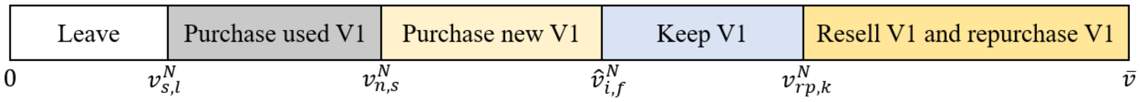


Figure C.2: Market segmentation at time 1 of scenario N

The demand of 'Keep' and 'Resell V1 and repurchase V1' for early-adopters is $d_k^N = \frac{v_{rp,k}^N - \hat{v}^N}{\bar{v}}$ and $d_{rp}^N = \frac{\bar{v} - v_{rp,k}^N}{\bar{v}}$, respectively. The demand of 'Purchase new V1', 'Purchase used V1', and 'Leave' for followers is $d_n^N = \frac{\hat{v}^N - v_{n,s}^N}{\bar{v}}$, $d_s^N = \frac{v_{n,s}^N - v_{s,l}^N}{\bar{v}}$, and $d_l^N = \frac{v_{s,l}^N}{\bar{v}}$, respectively. The new product demand is $d_2^N = d_{rp}^N + d_n^N$. To coincide secondhand supply and demand on the platform, $d_{rp}^N = d_s^N \Rightarrow p_s^N(p_2^N) = \frac{\theta\left(2p_2^N - \beta\bar{v}(1-\theta)\right)}{1+\theta(1-\tau)}$. Substituting $p_s^N(p_2^N)$ into d_2^N, the manufacturer maximizes period-two profit:

$$\max \pi_2^N = p_2^N d_2^N, \text{ s.t. } p_2^N \geq \frac{p_s^N}{\theta} \Leftrightarrow p_2^N \leq \frac{\beta\bar{v}(1-\theta)}{1-\theta(1-\tau)}.$$

Adding Lagrange multiplier λ, $L(p_2^N, \lambda) = p_2^N d_2^N + \lambda\left(\frac{\beta\bar{v}(1-\theta)}{1-\theta(1-\tau)} - p_2^N\right)$, $\lambda \geq 0$, and $\lambda\left(\frac{\beta\bar{v}(1-\theta)}{1-\theta(1-\tau)} - p_2^N\right) = 0$. $\frac{\partial^2 L\left(p_2^N,\lambda\right)}{\partial {p_2^N}^2} < 0$ and $\frac{\partial L\left(p_2^N,\lambda\right)}{\partial p_2^N} = 0 \Rightarrow p_2^{N*}(\hat{v}^N, \lambda) = \frac{\beta\left(\hat{v}^N(1+\theta(1-\tau)) + \bar{v}(1-\theta)\right)}{4} - \lambda$.

If $\lambda = 0$, $p_2^{N*}(\hat{v}^N) = \frac{\beta\left(\hat{v}^N(1+\theta(1-\tau)) + \bar{v}(1-\theta)\right)}{4}$, $\pi_2^{N*}(\hat{v}^N) = \frac{\beta\left(\hat{v}^N(1+\theta(1-\tau)) + \bar{v}(1-\theta)\right)^2}{8\bar{v}(1+\theta(1-\tau))}$.

If $\lambda > 0$, $p_2^{N*}(\hat{v}^N) = \frac{\beta\bar{v}(1-\theta)}{1-\theta(1-\tau)}$, $\pi_2^{N*}(\hat{v}^N) = \frac{\beta\bar{v}(1-\theta)\left(\hat{v}^N(1-\theta(1-\tau)) - (1-\theta)\right)}{(1+\theta(\tau-1))^2}$.

The $\pi_2^{N*}(\hat{v}^N)$ derived under $\lambda > 0$ is always less than that under $\lambda = 0$. Thus, the subgame equilibrium outcomes are: $p_2^{N*}(\hat{v}^N) = \frac{\beta\left(\hat{v}^N(1+\theta(1-\tau)) + \bar{v}(1-\theta)\right)}{4}$, $p_s^{N*}(\hat{v}^N) = \frac{\beta\theta\left(\hat{v}^N(1+\theta(1-\tau)) - \bar{v}(1-\theta)\right)}{2(1+\theta(1-\tau))}$, $d_2^{N*}(\hat{v}^N) = \frac{\beta\left(\hat{v}^N(1+\theta(1-\tau)) + \bar{v}(1-\theta)\right)}{2\bar{v}(1+\theta(1-\tau))}$, $\pi_2^{N*}(\hat{v}^N) = \frac{\beta\left(\hat{v}^N(1+\theta(1-\tau)) + \bar{v}(1-\theta)\right)^2}{8\bar{v}(1+\theta(1-\tau))}$.

Back to time 0, the marginal consumer with the threshold $\hat{v}_{e,f}^N$ identified in Table 5.8 is indifferent between purchasing V1 at time 0 and postponing the purchase to time 1. A consumer purchases V1 at time 0 if $v \geq \hat{v}_{e,f}^N$ but postpones purchase to time 1 if $v < \hat{v}_{e,f}^N$. The demand at time 0 is $d_1^N(\hat{v}^N) = \frac{\bar{v} - \hat{v}^N}{\bar{v}}$. The manufacturer capitalizes on consumers' time-inconsistent behavior and strategically manages prices to establish an optimal threshold, thereby maximizing total profit over the two periods:

$$\hat{v}_{e,f}^{N*} = \arg\max \pi^N(\hat{v}^N) \tag{C.2}$$

where $\hat{v}_{e,f}^N \in \{\hat{v}_{k,n}^N, \hat{v}_{k,s}^N, \hat{v}_{k,l}^N, \hat{v}_{rp,n}^N, \hat{v}_{rp,s}^N, \hat{v}_{rp,l}^N, \hat{v}_{rl,s}^N, \hat{v}_{rl,l}^N\}$ and $\pi^N(\hat{v}^N) = p_1^N d_1^N(\hat{v}^N) + \pi_2^{N*}(\hat{v}^N)$. Next, we will systematically examine each potential value of $\hat{v}_{e,f}^N$ and elucidate the corresponding equilibrium for each case.

Case 1: $\hat{v}_{e,f}^N = \hat{v}_{k,n}^N$. Substituting $p_2^N(\hat{v}_{k,n}^N)$ into $\hat{v}_{k,n}^N = \frac{p_1^N - \beta p_2^N}{\beta\theta}$, we can derive $\hat{v}_{k,n}^N(p_1^N) = \frac{4p_1^N - \beta^2\bar{v}(1-\theta)}{\beta(4\theta+\beta(1+\theta(1-\tau)))}$. The manufacturer maximizes the total profit:

$$\max_{\hat{v}_{k,n}^N} \pi^N = p_1^N d_1(\hat{v}_{k,n}^N) + \pi_2^{N*}(\hat{v}_{k,n}^N)$$

where $d_1^N(\hat{v}_{k,n}^N) = \frac{\bar{v}-\hat{v}_{k,n}^N}{\bar{v}}$ and $\pi_2^{N*}(\hat{v}_{k,n}^N) = \frac{\beta\left(\hat{v}^N(1+\theta(1-\tau))+\bar{v}(1-\theta)\right)^2}{8\bar{v}(1+\theta(1-\tau))}$. $\frac{\mathrm{d}^2\pi^N}{\mathrm{d}\hat{v}_{k,n}^{N2}} < 0$, $\frac{\mathrm{d}\pi^N}{\mathrm{d}\hat{v}_{k,n}^N} = 0 \Rightarrow \hat{v}_{k,n}^{N*} = \frac{\bar{v}(\theta(\beta(\tau-2)-3)-1)}{\theta(2\beta(\tau-1)-\tau-7)-2\beta+1}$.

Case 2: $\hat{v}_{e,f}^N = \hat{v}_{k,s}^N$. Substituting $p_s^N(\hat{v}_{k,s}^N)$ into $\hat{v}_{k,s}^N = \frac{p_1^N - \beta p_s^N}{\beta}$, we can derive $\hat{v}_{k,s}^N(p_1^N) = \frac{2p_1^N + \theta\left(\beta^2\bar{v} - 2p_1^N(\tau-1)\right) - \beta^2\theta^2\bar{v}}{\beta(1+\theta(1-\tau))(\beta\theta+2)}$. The manufacturer maximizes the total profit:

$$\max_{\hat{v}_{k,s}^N} \pi^N = p_1^N d_1(\hat{v}_{k,s}^N) + \pi_2^{N*}(\hat{v}_{k,s}^N)$$

where $d_1^N(\hat{v}_{k,s}^N) = \frac{\bar{v}-\hat{v}_{k,s}^N}{\bar{v}}$ and $\pi_2^{N*}(\hat{v}_{k,s}^N) = \frac{\beta\left(\hat{v}^N(1+\theta(1-\tau))+\bar{v}(1-\theta)\right)^2}{8\bar{v}(1+\theta(1-\tau))}$. $\frac{\mathrm{d}^2\pi^N}{\mathrm{d}\hat{v}_{k,s}^{N2}} < 0$, $\frac{\mathrm{d}\pi^N}{\mathrm{d}\hat{v}_{k,s}^N} = 0 \Rightarrow \hat{v}_{k,s}^{N*} = \frac{\bar{v}\left(\theta^2(\tau(1-2\beta)-1)+\theta(4\beta-5\tau+4)+5\right)}{(1+\theta(1-\tau))(\theta(4\beta+\tau-1)+7)}$.

Case 3: $\hat{v}_{e,f}^N = \hat{v}_{k,l}^N$. We know $\hat{v}_{k,l}^N(p_1^N) = \frac{p_1^N}{\beta(1+\theta)}$. The manufacturer maximizes the total profit:

$$\max_{\hat{v}_{k,l}^N} \pi^N = p_1^N d_1(\hat{v}_{k,l}^N) + \pi_2^{N*}(\hat{v}_{k,l}^N)$$

where $d_1^N(\hat{v}_{k,l}^N) = \frac{\bar{v}-\hat{v}_{k,l}^N}{\bar{v}}$ and $\pi_2^{N*}(\hat{v}_{k,l}^N) = \frac{\beta\left(\hat{v}^N(1+\theta(1-\tau))+\bar{v}(1-\theta)\right)^2}{8\bar{v}(1+\theta(1-\tau))}$. $\frac{\mathrm{d}^2\pi^N}{\mathrm{d}\hat{v}_{k,l}^{N2}} < 0$, $\frac{\mathrm{d}\pi^N}{\mathrm{d}\hat{v}_{k,l}^N} = 0 \Rightarrow \hat{v}_{k,l}^{N*} = \frac{\bar{v}(3\theta+5)}{7+\theta(\tau+7)}$.

Case 4: $\hat{v}_{e,f}^N = \hat{v}_{rp,n}^N$. Substituting $p_s^N(\hat{v}_{rp,n}^N)$ into $\hat{v}_{rp,n}^N = \frac{p_1^N - \beta p_s^N(1-\tau)}{\beta}$, we can derive $\hat{v}_{rp,n}^N(p_1^N) = \frac{\beta^2\theta^2\bar{v}(1-\tau)+\theta(\tau-1)\left(\beta^2\bar{v}+2p_1^N\right)-2p_1^N}{\beta(\beta\theta(\tau-1)-2)(1+\theta(1-\tau))}$. The manufacturer maximizes the total profit:

$$\max_{\hat{v}^N_{rp,n}} \pi^N = p^N_1 d_1(\hat{v}^N_{rp,n}) + \pi^{N*}_2(\hat{v}^N_{rp,n})$$

where $d^N_1(\hat{v}^N_{rp,n}) = \frac{\bar{v}-\hat{v}^N_{rp,n}}{\bar{v}}$ and $\pi^{N*}_2(\hat{v}^N_{rp,n}) = \frac{\beta\left(\hat{v}^N(1+\theta(1-\tau))+\bar{v}(1-\theta)\right)^2}{8\bar{v}(1+\theta(1-\tau))}$. $\frac{\mathrm{d}^2\pi^N}{\mathrm{d}\hat{v}^{N2}_{rp,n}} < 0$, $\frac{\mathrm{d}\pi^N}{\mathrm{d}\hat{v}^N_{rp,n}} = 0 \Rightarrow \hat{v}^{N*}_{rp,n} = \frac{\bar{v}\left(\theta^2(\tau-1)\left(\beta\tau+\frac{1}{2}\right)+\theta\left(2(\beta+1)-2\tau\left(\beta+\frac{5}{4}\right)\right)+\frac{5}{2}\right)}{2(\theta(\tau-1)-1)\left(\theta(\tau-1)(\beta-\frac{1}{4})-\frac{7}{4}\right)}$.

Case 5: $\hat{v}^N_{e,f} = \hat{v}^N_{rp,s}$. Substituting $p^N_2(\hat{v}^N_{rp,s})$ and $p^N_s(\hat{v}^N_{rp,s})$ into $\hat{v}^N_{rp,s} = \frac{p^N_1+\beta p^N_2-\beta p^N_s(2-\tau)}{\beta(2-\theta)}$, we can derive $\hat{v}^N_{rp,s}(p^N_1) = \frac{3\beta^2\theta^2\bar{v}\left(\frac{5}{3}-\tau\right)+\theta\left(3\beta^2\bar{v}\left(\tau-\frac{4}{3}\right)+4p^N_1(\tau-1)\right)-\beta^2\bar{v}-4p^N_1}{\beta(1+\theta(1-\tau))(\theta(4+\beta(\tau-3))+\beta-8)}$. The manufacturer maximizes the total profit:

$$\max_{\hat{v}^N_{rp,s}} \pi^N = p^N_1 d_1(\hat{v}^N_{rp,s}) + \pi^{N*}_2(\hat{v}^N_{rp,s})$$

where $d^N_1(\hat{v}^N_{rp,s}) = \frac{\bar{v}-\hat{v}^N_{rp,s}}{\bar{v}}$ and $\pi^{N*}_2(\hat{v}^N_{rp,s}) = \frac{\beta\left(\hat{v}^N(1+\theta(1-\tau))+\bar{v}(1-\theta)\right)^2}{8\bar{v}(1+\theta(1-\tau))}$. $\frac{\mathrm{d}^2\pi^N}{\mathrm{d}\hat{v}^{N2}_{rp,s}} < 0$, $\frac{\mathrm{d}\pi^N}{\mathrm{d}\hat{v}^N_{rp,s}} = 0 \Rightarrow \hat{v}^{N*}_{rp,s} = \frac{5\bar{v}\left(\theta^2\left(\frac{\beta\tau^2}{5}+\tau\left(1-\frac{\beta}{5}\right)-\frac{2\beta}{5}-1\right)+\theta\left(\frac{3\beta}{5}(2-\tau)-\frac{9\tau}{5}+\frac{4}{5}\right)\right)}{2(1+\theta(1-\tau))\left(\theta\left(\tau\left(\beta-\frac{1}{2}\right)-3\beta+\frac{9}{2}\right)+\beta-\frac{15}{2}\right)}$.

Case 6: $\hat{v}^N_{e,f} = \hat{v}^N_{rp,l}$. Substituting $p^N_2(\hat{v}^N_{rp,l})$ and $p^N_s(\hat{v}^N_{rp,l})$ into $\hat{v}^N_{rp,l} = \frac{p^N_1+\beta p^N_2-\beta p^N_s(1-\tau)}{2\beta}$, we can derive $\hat{v}^N_{rp,l}(p^N_1) = \frac{3\beta^2\theta^2\bar{v}(1-\tau)+\theta\left(3\beta^2\bar{v}\left(\tau-\frac{2}{3}\right)+4p^N_1(\tau-1)\right)-\beta^2\bar{v}-4p^N_1}{\beta(1+\theta(1-\tau))(\theta\beta(\tau-1)+\beta-8)}$. The manufacturer maximizes the total profit:

$$\max_{\hat{v}^N_{rp,l}} \pi^N = p^N_1 d_1(\hat{v}^N_{rp,l}) + \pi^{N*}_2(\hat{v}^N_{rp,l})$$

where $d^N_1(\hat{v}^N_{rp,l}) = \frac{\bar{v}-\hat{v}^N_{rp,l}}{\bar{v}}$ and $\pi^{N*}_2(\hat{v}^N_{rp,l}) = \frac{\beta\left(\hat{v}^N(1+\theta(1-\tau))+\bar{v}(1-\theta)\right)^2}{8\bar{v}(1+\theta(1-\tau))}$. $\frac{\mathrm{d}^2\pi^N}{\mathrm{d}\hat{v}^{N2}_{rp,l}} < 0$, $\frac{\mathrm{d}\pi^N}{\mathrm{d}\hat{v}^N_{rp,l}} = 0 \Rightarrow \hat{v}^{N*}_{rp,l} = \frac{\bar{v}\left(\theta^2(\tau-1)(\beta(\tau+2)+1)+\theta(\beta(2-3\tau)-9\tau+8)\right)}{2(\theta(\tau-1)-1)\left(\theta\left(\beta-\frac{1}{2}\right)(\tau-1)+\beta-\frac{15}{2}\right)}$.

Case 7: $\hat{v}^N_{e,f} = \hat{v}^N_{rl,s}$. Substituting $p^N_s(\hat{v}^N_{rl,s})$ into $\hat{v}^N_{rl,s} = \frac{p^N_1-\beta p^N_s(2-\tau)}{\beta(1-\theta)}$, we can derive $\hat{v}^N_{rl,s}(p^N_1) = \frac{\beta^2\theta^2\bar{v}(2-\tau)+\theta\left(\beta^2\bar{v}(\tau-2)+2p^N_1(\tau-1)\right)-2p^N_1}{\beta(\theta(\beta(\tau-2)+2)-2)(1+\theta(1-\tau))}$. The manufacturer maximizes the total profit:

$$\max_{\hat{v}^N_{rl,s}} \pi^N = p^N_1 d_1(\hat{v}^N_{rl,s}) + \pi^{N*}_2(\hat{v}^N_{rl,s})$$

where $d^N_1(\hat{v}^N_{rl,s}) = \frac{\bar{v}-\hat{v}^N_{rl,s}}{\bar{v}}$ and $\pi^N(\hat{v}^N_{rl,s}) = \frac{\beta\left(\hat{v}^N(1+\theta(1-\tau))+\bar{v}(1-\theta)\right)^2}{8\bar{v}(1+\theta(1-\tau))}$. $\frac{\mathrm{d}^2\pi^N}{\mathrm{d}\hat{v}^{N2}_{rl,s}} < 0$, $\frac{\mathrm{d}\pi^N}{\mathrm{d}\hat{v}^N_{rl,s}} = 0 \Rightarrow \hat{v}^{N*}_{rl,s} = \frac{\bar{v}\left(\theta^2\left(\beta\tau^2+\tau\left(\frac{5}{2}-2\beta\right)+\frac{5}{2}\right)+\theta\left(4\beta-\tau\left(2\beta+\frac{5}{2}\right)\right)\right)}{2(\theta(\tau-1)-1)\left(\theta\left(\tau\left(\beta-\frac{1}{4}\right)-2\beta+\frac{9}{4}\right)-\frac{7}{4}\right)}$.

Case 8: $\hat{v}_{e,f}^{N} = \hat{v}_{rl,l}^{N}$. The equilibrium is the same as the case $\hat{v}_{e,f}^{N} = \hat{v}_{rp,n}^{N}$.

Comparing the total profit π^N received with different thresholds $\hat{v}_{e,f}^{N}$ at time 0, we find $\hat{v}_{e,f}^{N} = \hat{v}_{rp,l}^{N}$ is the predominant case and $\hat{v}_{e,f}^{N} = \hat{v}_{k,l}^{N}$ is a weakly dominant case when both β and θ are extremely high. The case $\hat{v}^{*} = \hat{v}_{rp,l}^{N}$ contains more theoretical explanations and implications that can adequately account for the possible demand effects in the case $\hat{v}^{N*} = \hat{v}_{k,l}^{N}$. Overall, we use $\hat{v}^{N*} = \hat{v}_{rp,l}^{N}$ for analysis. The equilibrium outcomes is summarized in Table 5.10.

Note that $p_s^{N*} = 0$ when $\theta = \underline{\theta}^N(\beta,\tau)$. $\frac{\partial p_s^{N*}}{\partial \theta} = 0$ when $\theta = \bar{\theta}_{p_s^{N*}}(\beta,\tau)$; $\bar{\theta}_{p_s^{N*}}(\beta,\tau) < \underline{\theta}^N(\beta,\tau)$. For $\theta \in \left[0, \bar{\theta}_{p_s^{N*}}\right)$, $\frac{\partial p_s^{N*}}{\partial \theta} < 0$, $p_s^{N*} < 0$; for $\theta \in \left[\bar{\theta}_{p_s^{N*}}, \underline{\theta}^N\right)$, $\frac{\partial p_s^{N*}}{\partial \theta} \geq 0$, $p_s^{N*} < 0$; and for $\theta \in \left[\underline{\theta}^N, 1\right]$,$\frac{\partial p_s^{N*}}{\partial \theta} > 0$, $p_s^{N*} \geq 0$. Moreover, we find that $\underline{\theta}(\beta,\alpha,\tau) > \underline{\theta}^N(\beta,\tau)$.

C.4 Equilibrium of Scenario O

The equilibrium for scenario O can be derived by setting $\alpha = 1$ in scenario R, which is summarized in Table 5.11. Note that $p_s^{O*} = 0$ when $\theta = \underline{\theta}^O(\tau)$. $\frac{\partial p_s^{O*}}{\partial \theta} = 0$ when $\theta = \bar{\theta}_{p_s^{O*}}(\tau)$; $\bar{\theta}_{p_s^{O*}}(\tau) < \underline{\theta}^O(\tau)$. For $\theta \in \left[0, \bar{\theta}_{p_s^{O*}}\right)$, $\frac{\partial p_s^{O*}}{\partial \theta} < 0$, $p_s^{O*} < 0$; for $\theta \in \left[\bar{\theta}_{p_s^{O*}}, \underline{\theta}^O\right)$, $\frac{\partial p_s^{O*}}{\partial \theta} \geq 0$, $p_s^{O*} < 0$; and for $\theta \in \left[\underline{\theta}^O, 1\right]$,$\frac{\partial p_s^{O*}}{\partial \theta} > 0$, $p_s^{O*} \geq 0$.

C.5 Proofs for Lemmas, Propositions, and the Corollary

Proofs of Lemma 5.1 and Lemma 5.2. Please refer to Appendix C.1 for details. □

Proofs of Lemma 5.3, Lemma 5.4, Lemma 5.5, and Lemma 5.6. The magnitudes of demand vanishing, migration, and expansion effects are $d_{vanishing} = \frac{v_{rp,k}^{*} - \hat{v}^{*}}{\bar{v}}$, $d_{migration} = \frac{v_{n,s}^{*} - v_{s,l}^{*}}{\bar{v}}$, and $d_{expansion} = \frac{\hat{v}^{*} - v_{n,s}^{*}}{\bar{v}}$, respectively. Upon differentiating with respect to α and β, we find that $\frac{\partial d_{vanishing}}{\partial \alpha} < 0$, $\frac{\partial d_{migration}}{\partial \alpha} > 0$, and $\frac{\partial d_{expansion}}{\partial \alpha} > 0$; likewise, $\frac{\partial d_{vanishing}}{\partial \beta} < 0$, $\frac{\partial d_{migration}}{\partial \beta} > 0$, and $\frac{\partial d_{expansion}}{\partial \beta} > 0$. By the equilibrium outcomes, $p_d = p_1^* - p_2^* > 0$. It can be verified that $\frac{\partial p_d}{\partial \beta} > 0$ and $\frac{\partial p_d}{\partial \alpha} > 0$. Additionally, by the equilibrium outcomes, the number of early-adopters is $d_E^* = \frac{\bar{v} - \hat{v}^*}{\bar{v}}$, and the number of followers is $d_F^* = \frac{\hat{v}^*}{\bar{v}}$. Since $\frac{\partial \hat{v}^*}{\partial \beta} > 0$, we know $\frac{\partial d_E^*}{\partial \beta} < 0$ and $\frac{\partial d_F^*}{\partial \beta} > 0$. It can be verified that $\frac{\partial p_1^*}{\partial \beta} > 0$, $\frac{\partial p_2^*}{\partial \beta} > 0$, $\frac{\partial p_s^*}{\partial \beta} > 0$, $\frac{\partial d_s^*}{\partial \beta} < 0$, and $\frac{\partial d_{F,l}^*}{\partial \beta} > 0$. Furthermore, by $\frac{\partial \hat{v}^*}{\partial \alpha} > 0$, we know $\frac{\partial d_E^*}{\partial \alpha} < 0$ and $\frac{\partial d_F^*}{\partial \alpha} > 0$. It can be verified that $\frac{\partial p_1^*}{\partial \alpha} > 0$, $\frac{\partial p_2^*}{\partial \alpha} > 0$, $\frac{\partial p_s^*}{\partial \alpha} < 0$, $\frac{\partial d_s^*}{\partial \alpha} > 0$, and $\frac{\partial d_{F,l}^*}{\partial \alpha} < 0$. $\square$

Proof of Lemma 5.7. $p_s^* = 0$ when $\theta = \underline{\theta}(\beta, \alpha, \tau)$. $\frac{\partial p_s^*}{\partial \theta} = 0$ when $\theta = \bar{\theta}_{p_s^*}(\beta, \alpha, \tau)$; $\bar{\theta}_{p_s^*}(\beta, \alpha, \tau) < \underline{\theta}(\beta, \alpha, \tau)$. For $\theta \in \left[0, \bar{\theta}_{p_s^*}\right)$, $\frac{\partial p_s^*}{\partial \theta} < 0$, $p_s^* < 0$; for $\theta \in \left[\bar{\theta}_{p_s^*}, \underline{\theta}\right)$, $\frac{\partial p_s^*}{\partial \theta} \geq 0$, $p_s^* < 0$; and for $\theta \in [\underline{\theta}, 1]$, $\frac{\partial p_s^*}{\partial \theta} > 0$, $p_s^* \geq 0$. $\square$

Proof of Proposition 5.1. Denote $\Delta p_1^R = p_1^* - p_1^{R*}$. $\frac{\partial \Delta p_1^R}{\partial \beta} > 0$, i.e., Δp_1^R monotonically increases in β, with its minimum $\Delta p_1^R\big|_{\beta=0} < 0$ and maximum $\Delta p_1^R\big|_{\beta=1} > 0$. $\Delta p_1^R = 0$ when $\beta = \tilde{\beta}_{p_1}^R(\theta, \alpha, \tau)$. As such, if $\beta \geq \tilde{\beta}_{p_1}^R(\theta, \alpha, \tau)$, $\Delta p_1^R \geq 0$. Otherwise, if $\beta < \tilde{\beta}_{p_1}^R(\theta, \alpha, \tau)$, $\Delta p_1^R < 0$. Denote $\Delta p_2^R = p_2^* - p_2^{R*}$. $\frac{\partial \Delta p_2^R}{\partial \beta} > 0$, i.e., Δp_2^R monotonically increases in β, with its maximum $\Delta p_2^R\big|_{\beta=1} < 0$. Thus, $\Delta p_2^R < 0$. Denote $\Delta p_d^R = p_1^* - p_2^* - \left(p_1^{R*} - p_2^{R*}\right)$. $\frac{\partial \Delta p_d^R}{\partial \beta} > 0$, i.e., Δp_d^R monotonically increases in β, with its minimum $\Delta p_d^R\big|_{\beta=0} < 0$ and maximum $\Delta p_d^R\big|_{\beta=1} > 0$. $\Delta p_d^R = 0$ when $\beta = \tilde{\beta}_{p_d}^R(\theta, \alpha, \tau)$. As such, if $\beta \geq \tilde{\beta}_{p_d}^R(\theta, \alpha, \tau)$, $\Delta p_d^R \geq 0$. Otherwise, if $\beta < \tilde{\beta}_{p_d}^R(\theta, \alpha, \tau)$, $\Delta p_d^R < 0$. Denote $\Delta d_1^R = d_1^* - d_1^{R*}$, $\Delta d_2^R = d_2^* - d_2^{R*}$, and $\Delta d^R = d^* - d^{R*}$. $\frac{\partial \Delta d_1^R}{\partial \beta} < 0$, i.e., Δd_1^R monotonically decreases in β, with its maximum $\Delta d_1^R\big|_{\beta=1} < 0$ and minimum $\Delta d_1^R\big|_{\beta=0} > 0$. $\frac{\partial \Delta d_2^R}{\partial \beta} > 0$, i.e., Δd_2^R monotonically increases in β, with its minimum $\Delta d_2^R\big|_{\beta=0} > 0$ and maximum $\Delta d_2^R\big|_{\beta=1} < 0$. $\frac{\partial \Delta d^R}{\partial \beta} < 0$, i.e., Δd^R monotonically decreases in β, with its maximum $\Delta d^R\big|_{\beta=1} < 0$ and minimum $\Delta d^R\big|_{\beta=0} > 0$. $\Delta d_1^R = \Delta d_2^R = \Delta d^R = 0$ when $\beta = \tilde{\beta}_d^R(\theta, \alpha, \tau)$. As such, if $\beta \geq \tilde{\beta}_d^R(\theta, \alpha, \tau)$, $\Delta d_1^R \geq 0$, $\Delta d_2^R < 0$, and $\Delta d^R \geq 0$. Otherwise, if $\beta < \tilde{\beta}_d^R(\theta, \alpha, \tau)$, $\Delta d_1^R < 0$, $\Delta d_2^R \geq 0$, and and $\Delta d^R < 0$. $\square$

Proof of Proposition 5.2. Denote $\Delta \pi^R = \pi^* - \pi^{R*}$. $\frac{\partial \Delta \pi^R}{\partial \beta} > 0$, i.e., $\Delta \pi^R$ monotonically increases in β, with its minimum $\Delta\pi^R\big|_{\beta=0} < 0$ and maximum $\Delta\pi^R\big|_{\beta=1} > 0$. $\Delta\pi^R = 0$ when $\beta = \tilde{\beta}^R_\pi(\theta, \alpha, \tau)$. As such, if $\beta \geq \tilde{\beta}^R_\pi(\theta, \alpha, \tau)$, $\Delta\pi^R \geq 0$. Otherwise, if $\beta < \tilde{\beta}^R_\pi(\theta, \alpha, \tau)$, $\Delta\pi^R < 0$. □

Proof of Lemma 5.8. The platform's revenue is $r_p = \tau p_s^* d_s^*$ when consumers are time-inconsistent. $\frac{\partial r_p}{\partial \tau} = 0$ when $\tau = \tilde{\tau}(\beta, \theta, \alpha)$. Differentiating $\tilde{\tau}$ with θ, we find that $\frac{\partial \tilde{\tau}}{\partial \theta} > 0$ when $\theta \in \big[\underline{\theta}, \bar{\theta}_1\big)$, $\frac{\partial \tilde{\tau}}{\partial \theta} = 0$ when $\theta \in \big[\bar{\theta}_1, \bar{\theta}_2\big]$, and $\frac{\partial \tilde{\tau}}{\partial \theta} < 0$ when $\theta \in \big(\bar{\theta}_2, 1\big]$. Note that $\bar{\theta}_1$ and $\bar{\theta}_2$ are the real roots to $\tilde{\tau}(\beta, \theta, \alpha) = 1$. To summarize, $\tau^* = 1$ if $\theta \in \big[\bar{\theta}_1, \bar{\theta}_2\big]$, while $\tau^* = \tilde{\tau}(\beta, \theta, \alpha) < 1$ if $\theta \in \big[\underline{\theta}, \bar{\theta}_1\big)$ and $\theta \in \big(\bar{\theta}_2, 1\big]$. The platform's revenue is $r_p^R = \tau p_s^{R*} d_s^{R*}$ when consumers are rational. $\frac{\partial r_p^R}{\partial \tau} = 0$ when $\tau = \tilde{\tau}^R(\theta, \alpha)$. Differentiating $\tilde{\tau}^R$ with θ, we find that $\frac{\partial \tilde{\tau}^R}{\partial \theta} > 0$ when $\theta \in \big[\underline{\theta}, \bar{\theta}_1^R\big)$, $\frac{\partial \tilde{\tau}^R}{\partial \theta} = 0$ when $\theta \in \big[\bar{\theta}_1^R, \bar{\theta}_2^R\big]$, and $\frac{\partial \tilde{\tau}^R}{\partial \theta} < 0$ when $\theta \in \big(\bar{\theta}_2^R, 1\big]$. Note that $\bar{\theta}_1^R$ and $\bar{\theta}_2^R$ are the real roots to $\tilde{\tau}^R(\theta, \alpha) = 1$. To summarize, $\tau^{R*} = 1$ if $\theta \in \big[\bar{\theta}_1^R, \bar{\theta}_2^R\big]$, while $\tau^{R*} = \tilde{\tau}^R(\theta, \alpha) < 1$ if $\theta \in \big[\underline{\theta}, \bar{\theta}_1^R\big)$ and $\theta \in \big(\bar{\theta}_2^R, 1\big]$. □

Proof of Proposition 5.3. We find $\bar{\theta}_2 > \bar{\theta}_2^R > \bar{\theta}_1 > \bar{\theta}_1^R$. From the properties of $\frac{\partial r_p}{\partial \tau}$ and $\frac{\partial r_p^R}{\partial \tau}$ with an increasing θ, we can summarize that when $\theta < \bar{\theta}_1$, $\tau^* < \tau^{R*}$; otherwise, when $\theta > \bar{\theta}_2^R$, $\tau^* > \tau^{R*}$. □

Proof of Lemma 5.9. Please refer to Appendix C.3 for details. □

Proof of Lemma 5.10. The magnitudes of demand vanishing, migration, and expansion effects in scenario N are $d^N_{vanishing} = \frac{v^{N*}_{rp,k} - \hat{v}^{N*}}{\bar{v}}$, $d^N_{migration} = \frac{v^{N*}_{n,s} - v^{N*}_{s,l}}{\bar{v}}$, and $d^N_{expansion} = \frac{\hat{v}^{N*} - v^{N*}_{n,s}}{\bar{v}}$, respectively. Comparing with the main model, we find that $d^N_{vanishing} > d_{vanishing}$, $d^N_{migration} < d_{migration}$, and $d^N_{expansion} < d_{expansion}$ provided that $\beta > \tilde{\beta}^N_{expansion}(\bar{v}, \theta, \alpha, \tau)$. Otherwise, when $\beta \leq \tilde{\beta}^N_{expansion}(\bar{v}, \theta, \alpha, \tau)$, $d^N_{expansion} \geq d_{expansion}$. □

Proof of Proposition 5.4. Denote $\Delta p_1^N = p_1^* - p_1^{N*}$. $\frac{\partial \Delta p_1^N}{\partial \beta} > 0$, i.e., Δp_1^N monotonically increases in β, with its minimum $\Delta p_1^N\big|_{\beta=0} > 0$. Thus, $\Delta p_1^N > 0$. Denote

$\Delta p_2^N = p_2^* - p_2^{N*}$. $\frac{\partial \Delta p_2^N}{\partial \beta} > 0$, i.e., Δp_2^N monotonically increases in β, with its minimum $\Delta p_2^N\big|_{\beta=0} > 0$. Thus, $\Delta p_2^N > 0$. Denote $\Delta p_d^N = p_1^* - p_2^* - \left(p_1^{N*} - p_2^{N*}\right)$. $\frac{\partial \Delta p_d^N}{\partial \beta} > 0$ when $\beta < \tilde{\beta}^N_{\Delta p_d^N}(\theta, \alpha, \tau)$ and $\frac{\partial \Delta p_d^N}{\partial \beta} < 0$ when $\beta \geq \tilde{\beta}^N_{\Delta p_d^N}(\theta, \alpha, \tau)$, i.e., Δp_d^N is unimodal with β and $\Delta p_d^N\big|_{\beta=0} = 0$. Moreover, $\Delta p_d^N = 0$ when $\beta = \tilde{\beta}^N_{p_d}(\theta, \alpha, \tau)$. From above properties, we know $\Delta p_d^N\big|_{\beta=1} > 0$ when $\beta < \tilde{\beta}^N_{p_d}(\theta, \alpha, \tau)$ and $\Delta p_d^N\big|_{\beta=1} \leq 0$ when $\beta \geq \tilde{\beta}^N_{p_d}(\theta, \alpha, \tau)$. Overall, if $\beta \geq \tilde{\beta}^N_{p_d}(\theta, \alpha, \tau)$, $\Delta p_d^N \leq 0$. Otherwise, if $\beta < \tilde{\beta}^N_{p_d}(\theta, \alpha, \tau)$, $\Delta p_d^N > 0$. Denote $\Delta d_1^N = d_1^* - d_1^{N*}$, $\Delta d_2^N = d_2^* - d_2^{N*}$, and $\Delta d^N = d^* - d^{N*}$. $\frac{\partial \Delta d_1^N}{\partial \beta} < 0$, i.e., Δd_1^N monotonically decreases in β, with its maximum $\Delta d_1^N\big|_{\beta=0} < 0$. $\frac{\partial \Delta d_2^N}{\partial \beta} > 0$, i.e., Δd_2^N monotonically increases in β, with its minimum $\Delta d_2^N\big|_{\beta=0} > 0$. $\frac{\partial \Delta d^N}{\partial \beta} < 0$, i.e., Δd^N monotonically decreases in β, with its minimum $\Delta d^N\big|_{\beta=1} > 0$. Thus, $\Delta d_1^N < 0$, $\Delta d_2^N > 0$, and $\Delta d^N > 0$. $\square$

Proof of Proposition 5.5. Denote $\Delta \pi^N = \pi^* - \pi^{N*}$. $\frac{\partial \Delta \pi^N}{\partial \beta} > 0$, i.e., $\Delta \pi^N$ monotonically increases in β, with its minimum $\Delta \pi^N\big|_{\beta=0} < 0$ and maximum $\Delta \pi^N\big|_{\beta=1} > 0$. $\Delta \pi^N = 0$ when $\beta = \tilde{\beta}^N_{\pi}(\bar{v}, \theta, \alpha, \tau, K)$. As such, if $\beta \geq \tilde{\beta}^N_{\pi}(\bar{v}, \theta, \alpha, \tau, K)$, $\Delta \pi^N \geq 0$. Otherwise, if $\beta < \tilde{\beta}^N_{\pi}(\bar{v}, \theta, \alpha, \tau, K)$, $\Delta \pi^N < 0$. $\square$

Proof of Proposition 5.6. $\frac{\partial \Delta \pi^N}{\partial K} < 0$, i.e., $\Delta \pi^N$ monotonically decreases in K, with its maximum $\Delta \pi^N\big|_{K=0} > 0$ and minimum $\Delta \pi^N\big|_{K=1} < 0$. $\Delta \pi^N = 0$ when $K = K_T^*(\beta, \theta, \alpha, \tau)$. As such, if $K < K_T^*(\beta, \theta, \alpha, \tau)$, $\Delta \pi^N > 0$. Otherwise, if $K \geq K_T^*(\beta, \theta, \alpha, \tau)$, $\Delta \pi^N \leq 0$. Let $\Delta \pi_R = \pi^{R*} - \pi^{O*}$. $\frac{\partial \Delta \pi_R}{\partial K} < 0$, i.e., $\Delta \pi_R$ monotonically decreases in K, with its maximum $\Delta \pi_R|_{K=0} > 0$ and minimum $\Delta \pi_R|_{K=1} < 0$. $\Delta \pi_R = 0$ when $K = K_R^*(\theta, \alpha, \tau)$. As such, if $K < K_R^*(\theta, \alpha, \tau)$, $\Delta \pi_R > 0$. Otherwise, if $K \geq K_R^*(\theta, \alpha, \tau)$, $\Delta \pi_R \leq 0$. Besides, $\frac{\partial K_T^*}{\partial \alpha} < 0$ and $\frac{\partial K_R^*}{\partial \alpha} > 0$. $\square$

Proof of Corollary 5.1. Let $\Delta K = K_T^* - K_R^*$. $\frac{\partial \Delta K}{\partial \alpha} < 0$, i.e., ΔK monotonically decreases in α, with its maximum $\Delta K|_{\alpha=1} > 0$ and minimum $\Delta K|_{\alpha=\bar{\alpha}} < 0$. $\Delta K = 0$ when $\alpha = \alpha_K$. As such, if $\alpha < \alpha_K$, $\Delta K > 0$. Otherwise, if $\alpha \geq \alpha_K$, $\Delta K \leq 0$. $\square$

Appendix D

A Survey on Consumers' Secondhand Transactions and Repeat Purchases

Dear respondents, welcome to our survey on secondhand transactions and repeat purchases. It will take approximately five minutes to complete the survey. We assure you that the survey data you provide will be used solely for academic research purposes. Besides, we guarantee the confidentiality of your data and promise not to disclose it with third parties. Thank you for your support.

1. How old are you? [Single choice]

Options	Count	Proportion
<18	18	1.66%
18~25	238	21.98%
26~30	238	21.98%
31~40	275	25.39%
41~50	159	14.68%
51~60	129	11.91%
>60	16	1.48%
Prefer not to say	10	0.92%
Number of Responses	**1083**	

2. What is your gender? [Single choice]

Options	Count	Proportion
Male	514	47.46%
Female	566	52.26%
Prefer not to say	3	0.28%
Number of Responses	**1083**	

3. What is your profession? [Single choice]

Options	Count	Proportion
Professional (e.g., teacher/doctor/lawyer, etc.)	259	23.92%
Service personnel (e.g., catering staff/driver/sales clerk, etc.)	22	2.03%
Freelancer (e.g., writer/artist/photographer/guide, etc.)	12	1.11%
Worker (e.g., factory worker/construction worker/urban sanitation worker, etc.)	18	1.66%
Company employee	310	28.62%
Institution/Civil servant/Government worker	92	8.49%
Housewife	28	2.59%
Student	246	22.71%
Wait for employment	10	0.92%
Retired	40	3.69%
Others	46	4.25%
Number of Responses	**1083**	

4. What is your annual income (in RMB, ten thousand yuan)? [Single choice]

Options	Count	Proportion
≤50,000	272	25.12%
50,001~100,000	147	13.57%
100,001~150,000	159	14.68%
150,001~200,000	121	11.17%
200,001~250,000	80	7.39%
250,001~300,000	60	5.54%
≥300,001	132	12.19%
Prefer not to say	112	10.34%
Number of Responses	**1083**	

5. What is your current location? [Single choice]

Options	Count	Proportion
Northeast China: Heilongjiang, Jilin, Liaoning	24	2.22%
North China: Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia	163	15.05%
Central China: Henan, Hunan, Hubei	120	11.08%
East China: Shandong, Jiangsu, Anhui, Shanghai, Zhejiang, Jiangxi, Fujian, Taiwan	250	23.08%
Southern China: Guangdong, Guangxi, Hainan, Hong Kong, Macau	147	13.57%
Northwest China: Shaanxi, Gansu, Ningxia, Qinghai, Xinjiang	263	24.28%
Southwest China: Sichuan, Guizhou, Yunnan, Chongqing, Tibet	87	8.03%
Overseas	22	2.03%
Prefer not to say	7	0.65%
Number of Responses	**1083**	

D.1 Secondhand Transactions

6. Have you ever participated in secondhand transactions online or offline (including as suppliers and/ or demanders)? [Single choice]

Options	Count	Proportion
Only online	326	30.1%
Only offline	101	9.33%
Both online and offline	313	28.9%
Neither	343	31.67%
Number of Responses	**1083**	

7. What online secondhand platforms have you participated in? [Multiple choice]

Options	Count	Proportion
goofish.com	299	91.72%
zhuanzhuan.com	36	11.04%
paipai.com	10	3.07%
cn.58.com	19	5.83%
guazi.com, renrenche.com	7	2.15%
zhaoliangji.com	1	0.31%
aihuishou.com, huishoubao.com	29	8.9%
hongbulin.com, goshare2.com	5	1.53%
duozhuayu.com/book, kongfz.com	32	9.82%
eBay, Craigslist, Facebook marketplace	8	2.45%
ThredUP, Depop, The RealReal	0	0%
Etsy, Mercari	0	0%
Retailer self-managing platform (e.g., IKEA Circular hub, COS resell, etc.)	4	1.23%
Online donation	21	6.44%
Others	17	5.21%
Social media	19	5.83%
Number of Responses	**326**	

8. What offline secondhand platforms have you participated in? [Multiple choice]

Options	Count	Proportion
Car dealer	13	12.87%
Secondhand bookstore	24	23.76%
Secondhand marketplace, vintage store	27	26.73%
Peer-to-peer exchange	37	36.63%
Offline donation	20	19.8%
Others	32	31.68%
Number of Responses	**101**	

9. What online/offline secondhand platforms have you participated in? [Multiple choice]

Options	Count	Proportion
goofish.com	263	84.03%
zhuanzhuan.com	49	15.65%
paipai.com	12	3.83%
cn.58.com	53	16.93%
guazi.com, renrenche.com	20	6.39%
zhaoliangji.com	7	2.24%
aihuishou.com, huishoubao.com	29	9.27%
hongbulin.com, goshare2.com	3	0.96%
duozhuayu.com/book, kongfz.com	47	15.02%
eBay, Craigslist, Facebook marketplace	12	3.83%
ThredUP, Depop, The RealReal	1	0.32%
Etsy; Mercari	1	0.32%
Retailer self-managing platform (e.g., IKEA Circular hub; COS resell, etc.)	16	5.11%
Online donation	31	9.9%
Car dealer	21	6.71%
Secondhand bookstore	99	31.63%
Secondhand marketplace, vintage store	76	24.28%
Peer-to-peer exchange	64	20.45%
Offline donation	57	18.21%
Others	48	15.34%
Social media	62	19.81%
Number of Responses	**313**	

10. How many times have you participated in secondhand transactions in the past six months? [Single choice]

Options	Count	Proportion
≤5	610	82.43%
6~10	93	12.57%
11~15	16	2.16%
16~20	11	1.49%
21~25	2	0.27%
≥26	8	1.08%
Number of Responses	**740**	

11. What product categories have you traded in secondhand transactions? [Multiple choice]

Options	Count	Proportion
Automotives	78	10.54%
Home appliances (e.g., washer and dryer, refrigerator, etc.)	188	25.41%
Furniture and home improvement (e.g., bookshelf, dining sets, bedding, curtains, etc.)	193	26.08%
Apparel, shoes, and accessories	201	27.16%
Consumer electronics (e.g., digital camera, smart phone, computers, etc.)	295	39.86%
Sports gears (e.g., tennis racket, football, bikes, etc.)	110	14.86%
Beauty and personal care（e.g., makeup, skin care, hair care, etc.）	95	12.84%
Books	362	48.92%
Keepsakes（e.g., blind box, autographs, etc.）	78	10.54%
Others	119	16.08%
Number of Responses	**740**	

12. What are the reasons for your participation in secondhand transactions? [Multiple choice]

Options	Count	Proportion
Cheaper price	478	64.59%
New product out of stock	93	12.57%
Trial product	49	6.62%
The quality and usage of used product meet my requirements	235	31.76%
Reap resale revenue	209	28.24%
Purchase new ones after reselling used ones	63	8.51%
Convenient resale channel (e.g., taobao-goofish one-click resale)	171	23.11%
Pursuit of environmental sustainability	122	16.49%
Social interactions	23	3.11%
Others	45	6.08%
Membership or coupon	5	0.68%
Number of Responses	**740**	

13. When purchasing secondhand products, to what extent does their quality or depreciation level affect your purchasing decision? [Single choice]

Options	Count	Proportion
Very unaffected	12	1.62%
Relatively unaffected	42	5.68%
Not sure	84	11.35%
Relatively affected	216	29.19%
Very affected	386	52.16%
Number of Responses	**740**	

14. Do you believe you can accurately estimate the quality or depreciation level of secondhand products? [Single choice]

Options	Count	Proportion
Very inaccurate	25	3.38%
Relatively inaccurate	107	14.46%
Not sure	306	41.35%
Relatively accurate	243	32.84%
Very accurate	59	7.97%
Number of Responses	**740**	

15. In your secondhand transactions, do you believe the perceived quality level of secondhand products matches their transaction prices? [Single choice]

Options	Count	Proportion
Very unmatched	7	0.95%
Relatively unmatched	40	5.41%
Not sure	257	34.73%
Relatively matched	367	49.59%
Very matched	69	9.32%
Number of Responses	**740**	

D.2 Repeat Purchases

Suppose you previously purchased product A from a retailer, which provided a satisfactory purchasing and usage experience. After some time, the retailer subsequently releases a similar product B. There is no significant quality upgrade or difference between new products A and B, but they differ in exterior color or size. Besides, product A, which you already own, has undergone some wear and tear from use.

16. If you have purchased and experienced product A from a retailer, what is the likelihood that you will purchase product B from that retailer again? [Single choice]

Options	Count	Proportion
Very unlikely	97	8.96%
Relatively unlikely	161	14.87%
Not sure	281	25.95%
Relatively likely	369	34.07%
Very likely	175	16.16%
Number of Responses	**1083**	

17. If you have resold product A through a secondhand platform, what is the likelihood that you will continue to purchase product B from that retailer after resale? [Single choice]

Options	Count	Proportion
Very unlikely	88	8.13%
Relatively unlikely	157	14.5%
Not sure	321	29.64%
Relatively likely	344	31.76%
Very likely	173	15.97%
Number of Responses	**1083**	

18. Why do you repeatedly purchase products from the same retailer? [Multiple choice]

Options	Count	Proportion
Lack of substitution	219	20.22%
Excellent experience	761	70.27%
Habit formation	406	37.49%
Loyal consumer	330	30.47%
Familiar with sophisticated functions, reduced learning cost	423	39.06%
Diversified choices (e.g., more colors or sizes, etc.)	105	9.7%
Gratification of owning new products continuously	45	4.16%
Others	62	5.72%
Membership or coupon	64	5.91%
Number of Responses	**1083**	

19. When purchasing product B from the same retailer, does the experience of purchasing and using product A bring additional value to product B? If so, to what extent? [Single choice]

Options	Count	Proportion
Extremely low additional value	58	5.36%
Relatively low additional value	75	6.93%
Not sure	346	31.95%
Relatively high additional value	465	42.94%
Extremely high additional value	139	12.83%
Number of Responses	**1083**	

Appendix E

Interviews with Retail Industry Practitioners

Dear interviewee, we are the research team led by Prof. Gang Li from School of Management at Xi'an Jiaotong University. We are currently studying the secondhand channels and platforms in the retail industry, as well as consumers' repeat purchases. We are interested in conducting direct interviews with managers and practitioners within the retail industry to strengthen our research. We hereby kindly request you to join this interview, which will take approximately ten minutes. We assure you that the information, data, and content you provide will be used only for academic research purposes. It will be recorded in a statistical format (including the interviewee's name and position) for publication in academic papers. Additionally, we guarantee the confidentiality of the information and data and will not disclose it to any third parties. Thank you for your support.

E.1 Profiles of the interviewees

The profiles of the interviewees are as follows:

1. Huan Zhou, head of business improvement department of paipai. Paipai is one of the top three secondhand platforms in China and is affiliated to JD.com - China's second largest e-commerce platform. Huan owns extensive experience in resale business.

2. Shasha Zhou, general manager of Henan bangcheng auto service Co., Ltd. Shasha worked in automotive retail industry for over 20 years. Her company has been providing secondhand automotive services for nearly 19 years. She owns extensive experience in secondhand automotive business.

3. Xiaotian Zhuang, senior director of logistics technology and data intelligence department of JD.com. Xiaotian has served in both academic communities and industries for over 15 years, and he used to be a research scientist in Amazon.com. He has extensive practical and research experience in the fields of e-commerce, secondhand market, and large-scale logistic services.

4. Changsheng Liu, board chairman of forty-nine union. The forty-nine union is an emerging internet-based new retail enterprise. Changsheng worked in retail industry for over 20 years and he was originally the supply chain director of an e-commerce company. He owns extensive experience in retail industry.

5. Shujun Yan, project manager. Shujun worked in a multinational corporation for over 20 years, and she has participated in multiple resale programs.

E.2 Transcripts of interviews

E.2.1 Interview with Huan Zhou

Q1: What category of products has the largest market scale in paipai's businesses? Can we say that high-value products are more likely to reach secondhand transactions?

Huan Zhou: High-value 3C products have relatively high circulation value.

Q2: How does paipai cooperate with business-side?

Huan Zhou: Retailers and third-party sellers enter paipai using a B2C mode (similar to Taobao). Paipai has its own quality control regulations.

Q3: How does paipai collaborate with consumer-side?

Huan Zhou: Platforms like goofish serve as intermediaries in C2C mode, connecting supply and demand of secondhand products with information exchange between buyers and sellers. Paipai functions in C2B mode to empower secondhand products collected from consumer-side (i.e., selecting eligible secondhand products, refurbishing, quality inspection, setting recycling price, etc.). Buyers and sellers do not directly share information and transact.

Q4: Do you think secondhand channel affects the sales of new product channel, and will it have negative or positive effects?

Huan Zhou: Secondhand recycling channel can stimulate consumers to trade-in for new items, and increase new product sales. Secondhand recycling channel has iterations with new product selling channel. For example, this week Apple releases iPhone 14, while paipai focuses on the recycling of previous generation products, creating a complementary relationship with new products.

Q5: If the brands or retailers expand into secondhand business, are they more likely to cooperate with paipai or establish their own secondhand platforms?

Huan Zhou: Apple's self-operated secondhand channel has limited coverage and offers relatively low rebates to consumers. Paipai has a broader coverage than a single retailer.

Q6: Do you think repeat purchases or loyal consumers are important in secondhand business?

Huan Zhou: There is communities of consumers in second-hand business who are interested in a certain type of product. For example, consumers favor photography and video products change their gear frequently. Secondhand books have collectible value and secondhand watches may have premiums higher than new ones. Young consumers favor secondhand smartphones to experience the latest models at low expenses. They have a low preference over new and old products and are willing to make an attempt.

E.2.2 Interview with Shasha Zhou

Q1: What are your views on secondhand channels or secondhand platforms?

Shasha Zhou: 4S stores have been involved in secondhand business since 2003. Due to the needs of consumer repurchase and replacement, the used car market has gradually developed with specific certifications for used cars and trustworthy used car businesses. The used car industry is becoming more standardized and expanding in scale. In the past, consumers had doubts about used cars, such as its accident history. However, the market is becoming more transparent and informative, and professional certification organizations are making consumers increasingly trust used cars.

Q2: Do you think secondhand channel affects the sales of new product channel, and will it have negative or positive effects?

Shasha Zhou: The positive impact is greater. Consumer recognition of brands leads to repurchase or replacement, which promotes new car sales. Consumers can upgrade their car models by transacting through secondhand purchases.

Q3: If 4S stores expand into secondhand business, are they more likely to cooperate with resale platforms or establish their own secondhand platforms?

Shasha Zhou: 4S stores collaborate with multiple secondhand channels, including auction platforms and platforms like guazi. The returned used cars during trade-ins cover multiple brands. 4S stores classify used cars that meet quality requirements as certified used cars and trustworthy used cars, and sell them in store. 4S stores resell used cars that do not meet quality requirements through wholesale or auction.

Q4: If brands or retailers expand into secondhand business, is it provide consumers participating in secondhand transactions with certain subsidies on new product prices to achieve repeat sales?

Shasha Zhou: 4S stores have a complete trade-in policy. The subsidy varies depending on the manufacturer. A car worth 100,000 is subsidized by around 1,000 yuan, and a car worth 300,000 is subsidized by roughly 3,000 to 5,000 yuan.

Q5: Do you think repeat purchases or loyal consumers are important in secondhand business?

Shasha Zhou: Very important. 25% of repeat consumers can generate 75% of profits.

E.2.3 Interview with Xiaotian Zhuang

Q1: What are your views on secondhand channels or secondhand platforms?

Xiaotian Zhuang: Secondhand resale is a popular trend. Firms are catering to the trend of consumers' desire for participating in secondhand transactions. However, the ways whereby firms benefit from C2C resale markets remain unclear.

Q2: Do you think repeat purchases or loyal consumers are important in secondhand business? Do repeat purchases add value to the product?

Xiaotian Zhuang: Repeat buyers are very important. The product value increments exist in repeat purchases. By facilitating consumers to resell their used products, we can entice them to repeatedly purchase new products from us.

E.2.4 Interview with Changsheng Liu

Q1: Do you think secondhand channel affects the sales of new product channel, and will it have negative or positive effects?

Changsheng Liu: Firms are balancing the impacts brought about by secondhand channel. On one hand, we are afraid of secondhand channel's cannibalization of new-product demand by competing with the incumbents. On the other hand, we are attracted by the potential opportunity that secondhand channel can expand the market by generating extra values to consumers from reselling.

Q2: If the brands or retailers expand into secondhand business, are they more likely to cooperate with third-party secondhand platforms or establish their own secondhand platforms?

Changsheng Liu: It depends on brand recognition. For major brands, establishing their own platforms is better. For retailers without strong appeal, it is better to cooperate with third parties.

Q3: If brands or retailers expand into secondhand business, is it provide consumers participating in secondhand transactions with certain subsidies on new product prices to achieve repeat sales?

Changsheng Liu: This is common in the electrical and automotive industries.

Q4: Do you think repeat purchases or loyal consumers are important in secondhand business?

Changsheng Liu: Very important. The cost of serving returned consumers is one-tenth of attracting new consumers, and the repeat purchase rate is a very important indicator.

E.2.5 Interview with Shujun Yan

Q1: Do you think secondhand channel affects the sales of new product channel, and will it have negative or positive effects?

Shujun Yan: The positive effect is greater. Secondhand products can be better utilized through the reselling channel. Consumers who resell secondhand products are likely to purchase new products.

Q2: If the brands or retailers expand into secondhand business, are they more likely to cooperate with third-party secondhand platforms or establish their own secondhand platforms?

Shujun Yan: Brands and retailers are more likely to cooperate with third-party platforms, since they have a large consumer base, fast turnover, and platform guarantees. Building their own secondhand platforms will take time.

Q3: If brands or retailers expand into secondhand business, is it provide consumers participating in secondhand transactions with certain subsidies on new product prices to achieve repeat sales?

Shujun Yan: It is possible. Price subsidies can promote product selling.

Q4: Do you think repeat purchases or loyal consumers are important in secondhand business?

Shujun Yan: Very important. The repurchase rate in my industry is 90%. Consumers' attention is limited. It is better to first cultivate loyal consumers before developing new ones, creating a positive cycle.