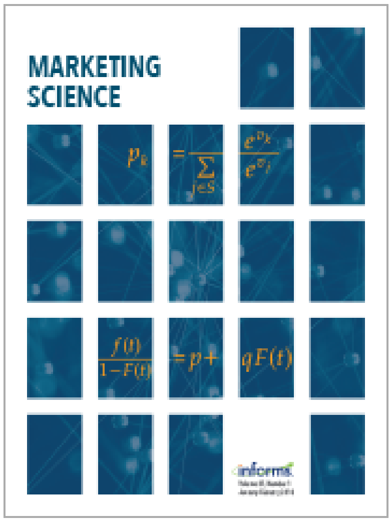

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Durable Products with Multiple Used Goods Markets: Product Upgrade and Retail Pricing Implications

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Used goods markets are currently important transaction channels for durable products. For some durable products, such markets first appeared when retailers started buying back used products from "old" customers and selling them to new ones for a profit (*retail used goods market*). The growth of electronic peer-to-peer (P2P) markets opened up a second, frictionless used goods channel where new customers can buy used products directly from old customers (*P2P used goods market*). Both these markets compete with the original *primary market* where retailers sell unused products procured from the manufacturer. This paper focuses on understanding the role that the sequential emergence of the above two used goods markets plays in shaping the *product upgrade strategy* of the manufacturer and the *pricing strategy* of the primary market retailer in the context of a decentralized, dyadic channel dealing with a renewable set of consumers. Our analysis establishes that frequent product upgrades and rising retail prices in durable product sectors of our interest are due to the emergence of the P2P used goods market and how the market interacts with the retail used goods source in altering the relative powers of the channel partners. Moreover, contrary to popular belief, we show that the initial introduction of the retail used goods channel actually discourages introduction of new versions and restrains the rise in retail prices. We also comment on how the two used goods markets affect the profits of the channel partners. We then provide empirical support for our theoretical result regarding product upgrades using data from the college textbook industry, a durable product that fits our model setup.

Key words: used goods markets; product upgrades; retail pricing; customer buybacks; durable products
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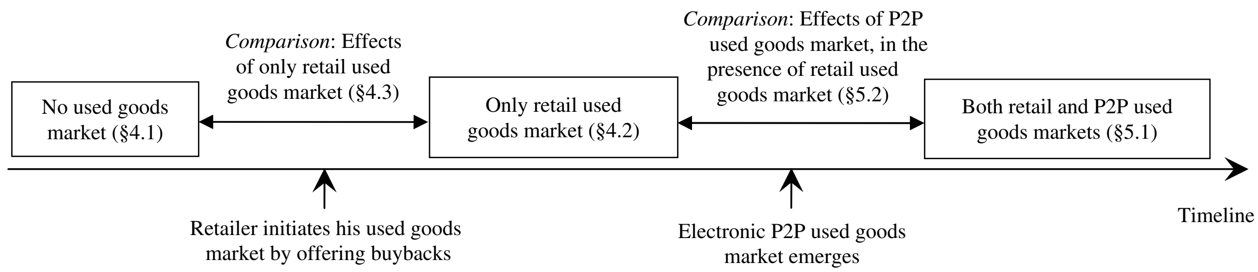
1. Introduction

Electronic peer-to-peer (P2P) markets where consumers buy and sell used products among themselves (e.g., eBay.com, Amazon.com) are rapidly growing in popularity. This phenomenon is particularly relevant for durable products like college textbooks and video games, which have already established retailer-owned used goods markets. Campus bookstores started selling used books bought back from "old" students, in addition to unused ones procured from the publisher, long before P2P markets became popular (U.S. Government Accountability Office (GAO) 2005). Similarly, video game retailers like GameStop have been selling bought-back used games (and unused ones) for quite some time (Kane and Bustillo 2009).[1] A distinctive feature of the above two *durable products* sectors, especially textbooks, is that they have a new set of customers intending to purchase the product in each period.

Interestingly, the retail and P2P *used goods markets* referred to above are quite different in terms of how they operate. The retailer explicitly decides on the price for his used goods by adding a proper margin to the buyback price. In contrast, the P2P market

[1] Thirty percent of college textbook sales (GAO 2005) and about 25% of video game sales (Kane and Bustillo 2009) are through retail used goods markets. Obviously, such markets for textbooks are older than those for video games.

Figure 1 Scenarios Modeled, Analyzed, and Compared in This Paper



is frictionless, and the price is determined primarily by the amount of used goods available for sale there. Customers' valuations for used products from the two markets are also usually different. Our focus is on understanding the effects that successive addition (to the primary market for unused products) of the two used goods markets—first retail and then P2P—has on the *product upgrade strategy* of the manufacturer and the *pricing strategy* for unused products of the primary market retailer, as well as on their profits.

Durable products such as college textbooks and video games have recently generated considerable interest as a result of rising retail prices and frequent releases of new versions. The average retail price for an unused video game has increased 50% in six years—from \$40 in 2002 to \$60 in 2008 (James 2008). As for unused college textbooks, prices have risen at twice the rate of inflation over 1987–2004—6% versus 3% per year. As a result, textbook prices have nearly tripled during that time while the frequency of new edition releases has also increased from every four to five years to every three to four years (GAO 2005). A common belief puts the blame for the above events on retail buybacks (i.e., retail used goods market). The rationale is that manufacturers frequently launch upgraded versions to reduce the value of used products bought back by the retailer. The costs associated with developing new versions, in turn, result in price increases (see, e.g., GAO 2005, Wolk 2006).

The motivation of our research is that although multiple used goods markets have emerged over the years for certain durable goods, and they give rise to novel interactions from supply and demand perspectives, these topics have not been analyzed in the literature. To address this gap, we investigate the following questions in the context of a decentralized, dyadic channel framework:

- What effects does the addition of a retail used goods market as the first source of used goods have on the manufacturer's product upgrade strategy, increase in retail prices for unused products (over time), and profits of the channel partners?
- How does the further addition of a second used goods channel in the form of P2P markets affect the above product upgrade and retail pricing decisions (and also channel profits)?

We analyze and compare three scenarios—no used goods market, only retail used goods market, and both retail and P2P used goods markets—indicated in Figure 1 to answer the preceding questions (the primary market selling unused goods is present in all three scenarios).[2]

An important finding of our paper is that the effects of the second used goods market (P2P) on the channel decisions of our interest are almost opposite to those of the first one (retail). When the retailer initiates the first used goods market by offering buybacks, such an action actually *reduces the incentive* for the manufacturer to frequently upgrade and also *reduces* the extent of increase in retail prices for unused products over time. On the other hand, the emergence of P2P markets as the second source for used goods indeed *encourages* the manufacturer to frequently introduce upgraded versions and also (usually) *amplifies* the temporal increase in retail prices for unused products. The above contrasting effects are quite robust; they hold true irrespective of whether the end customers are myopic or forward looking. Moreover, data from the college textbook industry support our finding about the effect of the introduction of the P2P market on product upgrades. As far as profits are concerned, we establish under which conditions the addition of the retail and (subsequently) the P2P used goods market is detrimental or beneficial for the channel partners.

The underlying intuition behind the above behavior of channel decisions is as follows. If we compare *no* used goods and *only retail* used goods scenarios, any product upgrade is associated with a *wholesale price premium* for the manufacturer in both cases. The premium is actually higher in the latter scenario. However, the manufacturer's *sales volume* of unused

[2] We also briefly analyze a setting where the only source of used goods is the P2P market (see §4.4). We compare the results of §4.4 to those of §4.1 (no used goods) and §5.1 (both used goods markets) to understand the effects of the P2P used goods market individually and those of the retail used goods market in the presence of a P2P one, respectively.

products is much higher in the former because she is the *monopoly* supplier when there are no used goods but has to "compete" with bought-back used products in the presence of a retail used goods market. The volume effect always dominates, so the manufacturer upgrades more frequently in the no used goods scenario. On the other hand, when we compare *only retail* used goods and *both* used goods scenarios, the wholesale price premium for an upgrade is higher in the former case, but the manufacturer's sales volume is higher in the latter scenario. Note that whereas the retailer has sole access to all used goods before emergence of the P2P market, he has to compete with the P2P market for used goods once such a market becomes popular. This competition induces the retailer to increase his purchase quantity of unused products from the manufacturer (i.e., the P2P market partially restores the manufacturer's monopoly position). The volume effect again is stronger; hence the emergence of the P2P market provides a higher impetus for the manufacturer to upgrade. The effects on the temporal retail prices for unused products then follow. The addition of the retail used goods market makes continuation of an existing version more likely, which results in lower temporal increase (compared to the no used goods scenario) as a result of competition from used products, but further addition of the P2P market provides an incentive to upgrade—improved content and associated costs—then amplifies the increase in retail prices over time. To summarize, we show that frequent product upgrades and rising retail prices for certain durable products, as indicated in government and business reports (e.g., GAO 2005), are due to the interaction between the two used goods markets rather than because of the retail used goods market only.

The rest of this paper is organized as follows. In §2 we review the related literature, and in §3 we provide the model framework for the scenario when both used goods markets coexist. Section 4 then establishes the effects of the introduction of the retail used goods market (and also briefly discusses the effects if the first used goods source is the P2P market). Section 5 demonstrates how the subsequent emergence of the P2P market affects channel decisions and profits. In §6 we present two possible model generalizations and the empirical analysis. Last, in §7 we provide our concluding remarks, discuss managerial implications, and suggest future research opportunities.

2. Literature Review

The first stream of literature relevant to us deals with durable products in the marketing and economics domains. Waldman (2003) provides a detailed review of this literature. Of particular interest to us is Levinthal and Purohit (1989); they study the optimal strategy of a monopolist about its existing version of the product (whether to produce it or not) when introducing a new one in the presence of a frictionless used goods market. The monopolist naturally wants to reduce the supply of used products in the market; because there is no vertical channel competition in the Levinthal and Purohit paper, she can do so by buying back from old customers but not reselling the product. In contrast, the retailer in our setup resells bought-back used goods to curtail the sole-supplier power of the manufacturer (and generate revenue), although the manufacturer wants to behave like the monopolist. This incentive asymmetry makes our model more involved. Another distinctive feature of our framework is that the product upgrade is a strategic decision variable for the manufacturer, so the manufacturer needs to consider the associated costs and benefits before making any upgrade decision.

Anderson and Ginsbergh (1994) point out that most of the literature before them assumes homogeneous consumers, so they construct a model with heterogeneous consumer valuations. This heterogeneity allows the monopolist to achieve price discrimination through unused and used products. Subsequently, a large stream of literature (e.g., Desai and Purohit 1998, 1999; Huang et al. 2001; Bhaskaran and Gilbert 2005) was developed based on this idea. Its focus is on comparing leasing and selling of durable goods, albeit under a variety of settings (e.g., horizontal competition or the presence of complementary goods). Note that these papers consider neither vertical channel competition nor issues like product upgrade strategy or interaction between multiple used goods markets. However, they model competition between unused and used goods of the same version and show how a (single) frictionless used goods market, like the P2P one in this paper, affects the price of unused products.

Another stream of literature related to this paper deals with durable products in decentralized settings and aims to develop first-best contracts. In this context, Desai et al. (2004) model a P2P-type used goods market and competing unused and used products of the same version. They do not, however, model the retail used goods market or product upgrade decision. Shulman and Coughlan's (2007) objective is similar to Desai et al. (2004). However, their model incorporates a new set of customers arriving to purchase in each period and a retail used goods market (but not a P2P one). They show that with these two features even complex coordination mechanisms might fail. Evidently, our aim and model setting are quite different. For example, whether to introduce an upgraded version is not a decision in Shulman and Coughlan (2007). Furthermore, our model includes a

P2P used goods market that competes with the retail one in buying and selling used products.

There are two other research streams indirectly related to our research. The first one investigates when, and why, manufacturers should offer to buy back leftover inventory from the retailer (e.g., Padmanabhan and Png 1997, Wang 2004). In this stream, buybacks are offered by the manufacturer to the retailer and not by the retailer to end customers (as in our paper). Consequently, the dynamics involved are quite different. Moreover, the product upgrade issue is not discussed in this stream. A related second stream deals with product upgrade decisions (e.g., Padmanabhan et al. 1997, Kornish 2001). The objective there is to understand how consumer uncertainty about future installed base or product improvements affects upgrade decisions. Our focus—analyzing how used goods markets affect such upgrade decisions—is in comparison quite distinct.

Last, in the operations domain, remanufacturing literature models competition between unused and remanufactured products. Remanufactured products are similar to used ones in the sense that they are valued less by customers. Moreover, remanufacturing might involve product acquisition through customer buybacks. However, models in this literature (e.g., Oraiopoulos et al. 2007 and references therein) do not usually analyze issues like product upgrades, vertical channel competition, or competition between multiple used goods markets.

Our main contribution is that we model the interaction between two behaviorally distinct used goods channels—retail and P2P—for a durable product. In particular, analyzing how the sequential addition of these two channels in the market affects manufacturers' product upgrades and retailers' pricing decisions as well as firm profits sets our paper apart from the existing literature.

3. Model Framework

Our basic model framework involves a decentralized manufacturer-retailer channel selling a durable product to end customers. The distinguishing characteristic of the product in our framework is that there is a new set of customers for it in each period. These customers require the services of the product only for that period, after which its value to them is not significant. However, the product might then be useful for another, new set of customers. As indicated in Bond and Iizuka (2005) and Shulman and Coughlan (2007), college textbooks are classic examples of durable products with such *renewable* customer sets. Thus, unlike customers for many other consumer durables, the customers in our setting *do not* have the opportunity of waiting before buying the product at a later time. Rather, they need to decide whether to buy in that period only.

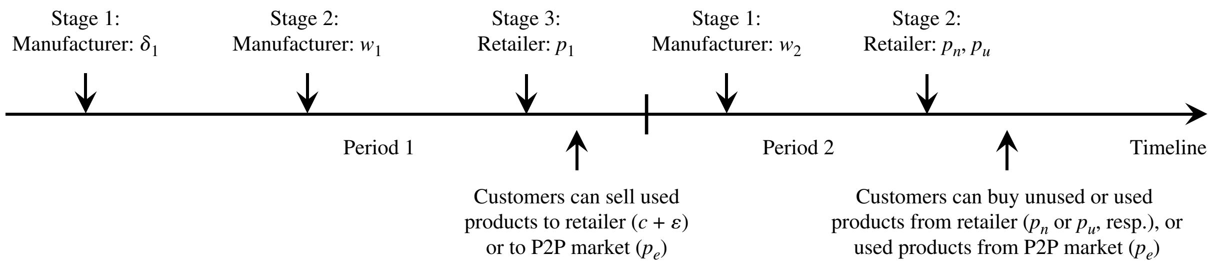
Suppose each consumer needs at most one unit of the product, and consumers' valuation v about the product is heterogeneous. Specifically, it is uniformly distributed on the interval $[0, 1]$; i.e., $v \sim U[0, 1]$. Also, like most of the papers discussed in §2, we focus on a two-period model with rational players (e.g., Desai and Purohit 1998, Desai et al. 2004, Shulman and Coughlan 2007). The sequence of events in our setup is as follows (see also Figure 2).

Period 1. The sequence starts in stage 1 with the manufacturer deciding whether to introduce an upgraded version of the product in period 2.[3] Such upgrade decisions are normally strategic in nature and require significant lead times. For example, edition upgrades of college textbooks often require more than a year's time, and a decision to do so is made years in advance (Friscia 2009, GAO 2005). If a new version is introduced, it increases customers' valuation of the unused products in period 2 by a factor $\delta_1 = 1 + a$, where $a > 0$ represents the degree of *content differentiation* between unused products of the existing version and the upgraded one. However, such a decision involves an investment on the part of the manufacturer, the amount of which depends on the desired degree of upgrade. In stage 2, the manufacturer then determines the unit wholesale price of the existing version w_1, and subsequently, the retailer sets the unit retail price p_1 in stage 3. Note that purchase decisions of customers at the beginning of period 1 depend crucially on whether they *ignore* or *take into account* future payoffs from returning their used products at the end of the period (i.e., whether customers are *myopic* or *forward looking*, respectively). For now assume that the consumers are myopic (we analyze the case of forward-looking customers in §6.1). Consequently, the number of (unused) products of the existing version sold in period 1 is given by $q_1 = 1 - p_1$, and these wind up as used products at the end of the period.

Suppose that used products have a constant residual value of c for all q_1 customers. These customers can return or sell used products in one of the following ways: (i) if *only the retail* used goods market is available, all of them return there at the buyback price $p_b = c + \varepsilon$, $\varepsilon \sim 0$; (ii) if *only the P2P* used goods market is available, all of them sell there at price p_e (we define p_e below); and (iii) if *both* used goods markets are available, suppose that a proportion r of $(1 - p_1)$ customers return to the retailer, and the remaining

[3] Our model setting is a Stackelberg one, with the manufacturer as the leader.

Figure 2 Sequence of Events



customers ($(1-r)(1-p_1)$) sell in the P2P market.[4] Indeed, there are certain customers for whom the convenience and familiarity of retail stores (e.g., college bookstores) make returning there the preferred option, whereas for some tech-savvy customers using P2P markets for selling might be preferable (Deck and Wilson 2006, Shulman and Coughlan 2007).

Period 2. A new set of consumers enters the market in period 2. Their valuation about unused products is $\delta_1 \cdot v$, as described above. However, used products from the retailer are devalued by a factor $\delta_2 (\in [0,1])$ compared to unused ones, where δ_2 measures the degree of *condition differentiation* between used and unused products of the original version. On the other hand, used products from the P2P market are devalued by a factor $\delta_3 (\in [0, \delta_2])$, where δ_3 captures both the condition differentiation between used and unused products and the *disutility* of buying from the electronic P2P market rather than from the retailer (both Chiang et al. 2003 and Forman et al. 2009 discuss the issue of disutility from buying online compared with offline). Customers of period 2, if they want to buy, can do so from one of the following sources: (i) unused products from the retailer at price p_n (the version depends on the manufacturer's decision in period 1), which we denote as the *primary* market;[5] (ii) used products from the retailer (bought back from customers in period 1) at price p_u, if the retailer is selling used products; or (iii) used products from "old" customers in the P2P market paying p_e, if there is a P2P used goods market.

The two used products markets are different in terms of their price-setting behaviors. Specifically, the P2P market is *frictionless*, so the price p_e is set just to clear all the used goods $(1-r)(1-p_1) = q_e$ being sold there (this is the usual assumption in the literature about used goods markets; see, e.g., Desai and Purohit 1998, 1999). In contrast, the retailer optimally *decides* on how many of the used products bought back in the first period ($r(1-p_1)$) to sell in period 2 and at what price, denoted by q_u and p_u, respectively. Following the same procedure as Desai and Purohit (1998, 1999), we can then use a consumer choice model to derive the following period 2 inverse demand functions[6] for the primary, retail used goods, and P2P used goods markets, respectively:

$$\begin{aligned} p_n &= \delta_1(1-q_n) - \delta_2 q_u - \delta_3 q_e, \\ p_u &= \delta_2(1-q_n-q_u) - \delta_3 q_e, \quad \text{and} \\ p_e &= \delta_3(1-q_n-q_u-q_e), \end{aligned} \tag{1}$$

where q_n, $q_u (\leq r(1-p_1))$, and $q_e (= (1-r)(1-p_1))$ are the quantities sold in primary, retail used goods, and P2P used goods markets, respectively, in period 2. Recall that $0 \leq \delta_3 \leq \delta_2 \leq 1 \leq \delta_1$. There are three explicit decisions in period 2—in stage 1 the manufacturer chooses the unit wholesale price w_2 for the primary market unused products; then in stage 2 the retailer simultaneously sets the unit prices for unused and used products, p_n and p_u, respectively. Evidently, $p_n - p_1$ represents the temporal increase (from periods 1 to 2) in retail prices of unused products.

4. Effects of a Single (Retail or P2P) Used Goods Market

As we indicated in §1, for sectors like college textbooks, the retail used goods market was the only source of used goods before P2P markets became popular (Chevalier and Goolsbee 2009, Iizuka 2007). In this section, we study how the emergence of the retailer as the first medium for transacting used goods affects optimal decisions and profits of the channel partners. To do so, we analyze two special cases of the framework discussed in §3; specifically, §§4.1 and 4.2 analyze the scenarios with *no used goods* and *only retail used goods*, respectively. Subsequently, we compare the results from the two sections to establish the effects of a retail used goods market in §4.3. In §4.4, we briefly

[4] Obviously, if no used goods market is available, then consumers cannot return or sell.

[5] Note that we assume that unused products of both original and upgraded versions are not available for sale at the same time. This assumption is reasonable—for example, in the textbook industry, a publisher would typically not sell unused products of the original version once an upgraded version is released (McCully 2009).

[6] The detailed derivations are provided at the beginning of Appendix A.

discuss whether the effects on channel decisions or profits are different if the first (and only) used goods source is the P2P market rather than the retailer.

4.1. No Used Goods Market Scenario

We start by analyzing the "base" case where there is no market for transacting used products (i.e., customers have access only to the primary market for unused products). Note that this model is a special case of the framework in §3, if $\delta_2 = \delta_3 = 0$. The absence of used products means that the two periods in our model are independent, and thus the analysis is separable into two single-period problems. We can analyze this scenario using backward induction in each period.

Suppose that the manufacturer's product upgrade decision (stage 1 of period 1) is given by δ_1. Based on Equation (1), for $\delta_2 = \delta_3 = 0$, inverse demand functions for unused products in periods 1 and 2 are then $p_1 = (1 - q_1)$ and $p_n = \delta_1(1 - q_n)$, respectively. Given δ_1, for each period we first decide on the profit-maximizing retail price for the unused products, as a function of the wholesale price. Substituting that into the manufacturer's profit function, we then determine the optimal wholesale prices w_1^* and w_2^* (and subsequently the overall optimal retail prices p_1^* and p_n^*).[7] The last step of our analysis involves the manufacturer's decision about whether δ_1 should be $1 + a$ (release a new version) or 1 (continue with the existing one) to maximize her total profit over two periods. Suppose that the investment cost function associated with releasing a new version is given by $K(\delta_1^2 - 1)/2$. Such increasing convex cost functions are common in the literature for investments in improvements (e.g., Desai 1997, Gurnani and Erkoc 2008).[8] The manufacturer aims to maximize

$$\Pi_M = \Pi_M^1 + \Pi_M^2 = -K(\delta_1^2 - 1)/2 + w_1^* \cdot q_1^* + w_2^* \cdot q_n^*.$$

The equilibrium decisions and profits for the channel partners in the no used goods scenario are given in Table 1. Note that the threshold value K_0 represents the cost below which the manufacturer will release a new version and above which it will continue with the old one. Note also that all the technical analysis for the paper, unless otherwise stated, is provided in Appendix A.

[7] We assume the manufacturer's marginal variable production cost to be zero. The costs associated with producing textbooks are mostly fixed; the marginal variable cost is indeed quite low (see, e.g., GAO 2005).

[8] Obviously, if no new version is released, then no investment is required.

4.2. Only Retail Used Goods Market Scenario

In this scenario, we assume that the retailer offers to buy back used products from customers who bought the product in period 1; however, there is no P2P market for customers to transact used products among themselves. Because the residual value of used products is c for all customers, a retail buyback price of $c + \epsilon$, $\epsilon \sim 0$, will ensure that all period 1 used products will be returned to the retailer (thus, this is a special case of §3 when $r = 1$ and $\delta_3 = 0$). We again use backward induction to solve this scenario and the equilibrium decisions and profits are again summarized in Table 1.

Note that the threshold cost K_b in Table 1, below which the manufacturer will release a new version of the product, decreases in the customers' valuations of used products δ_2 but increases in the residual value of used products c. When used products are valued less by customers (i.e., low δ_2), the retail used goods market does not significantly affect demand for unused products in period 2. The manufacturer is then effectively a sole supplier and can garner a significant wholesale price premium by releasing an upgraded version (note that as $\delta_2 \to 0$, $K_b \to K_0$). On the other hand, when the residual value of used products c is high, the retailer pays more to buy back used products and so would want to reduce the sales volume of unused products in period 1. Thus in period 2, the manufacturer faces less competition from used products. This increases demand for her unused products and provides her higher benefit from releasing an upgraded product.

4.3. Effects of the Retail Used Goods Market

We now compare the models presented in §§4.1 and 4.2 to understand the role played by a retail used goods market as the first source of used goods in shaping channel decisions and profits. Our initial finding in this context is rather surprising.

Proposition 1 (Retail Used Goods Market Reduces the Frequency of Product Upgrades). *The threshold K values in the only retail used goods and the no used goods scenarios satisfy $K_b \le K_0$. Thus given a cost parameter K, the manufacturer always has a higher incentive to release a new version of the product when there is no used goods market, compared to when a retail used goods market exists. Furthermore, the value of $K_0 - K_b$ decreases in a.*

The presence of a retail used goods market actually *deters* release of a new version. This is in *contrast* to the conventional wisdom that retail buyback offers (i.e., the retail used goods market) are responsible for frequent product upgrades because the manufacturer uses new versions to differentiate and reduce competition from used products (see, e.g., GAO 2005,

Table 1 Equilibrium Decisions and Profits in Models with Myopic Consumers

No used goods market model

Threshold value of K: $K_0 = \frac{1}{4(2+a)}$, below which $\delta_1^* = 1+a$; otherwise, $\delta_1^* = 1$. This structure applies to all other models in the sequel.

Period 1 decisions: $w_1^* = \frac{1}{2}$, $p_1^* = \frac{3}{4}$, and $q_1^* = \frac{1}{4}$.

Period 2 decisions: $w_2^* = \frac{\delta_1^*}{2}$, $p_n^* = \frac{3\delta_1^*}{4}$, and $q_n^* = \frac{1}{4}$.

Profits: $\Pi_M^* = w_1^* q_1^* + w_2^* q_n^* - \frac{K}{2}((\delta_1^*)^2 - 1)$, and $\Pi_R^* = (p_1^* - w_1^*)q_1^* + (p_n^* - w_2^*)q_n^*$.

Only retail used goods market model

Threshold value of K: $K_b = \frac{32(1+a) + 64\delta_2(1+a) - 16\delta_2^2((1-c)^2 - a) - 8\delta_2^3(5+2a-c) + 7\delta_2^4}{32(2+2a+2\delta_2+2\delta_2 a - \delta_2^2)(2+2\delta_2-\delta_2^2)(a+2)}$.

Period 1 decisions: $w_1^* = \frac{16\delta_1^*(1-c) + 4\delta_1^*\delta_2(9-4c) + 4\delta_2^2(5\delta_1^* - 3(1-c)) - 11\delta_2^3}{16(2\delta_1^* - \delta_2^2 + 2\delta_2\delta_1^*)}$, $p_1^* = \frac{15\delta_2\delta_1^* + 4c\delta_1^* + 12\delta_1^* - 8\delta_2^2}{8(2\delta_1^* - \delta_2^2 + 2\delta_2\delta_1^*)}$, and $q_1^* = 1 - p_1^* = \frac{(4+\delta_2-4c)\delta_1^*}{8(2\delta_1^* - \delta_2^2 + 2\delta_2\delta_1^*)}$.

Period 2 decisions: $w_2^* = \frac{\delta_1^* - 2\delta_2(1-p_1^*)}{2}$, $q_u^* = 1 - p_1^*$, $q_n^* = \frac{\delta_1^* - w_2^* - 2\delta_2 q_u^*}{2\delta_1^*}$, $p_n^* = \delta_1^*(1-q_n^*) - \delta_2 q_u^*$, and $p_u^* = \delta_2(1 - q_n^* - q_u^*)$.

Profits: $\Pi_M^* = w_1^* q_1^* + w_2^* q_n^* - \frac{K}{2}((\delta_1^*)^2 - 1)$ and $\Pi_R^* = (p_1^* - w_1^*)q_1^* + (p_n^* - w_2^*)q_n^* + p_u^* q_u^* - cq_1^*$.

Only P2P used goods market model

Threshold value of K: $K_e = \frac{512 - 192\delta_3^2 + 512a - 64\delta_3^2 a - \delta_3^4 + 48\delta_3^3}{32(8+8a-\delta_3^2)(8-\delta_3^2)(a+2)}$.

Period 1 decisions: $w_1^* = \frac{16\delta_3\delta_1^* + 128\delta_1^* - 24\delta_3^2 + \delta_3^3}{32(8\delta_1^* - \delta_3^2)}$, $p_1^* = \frac{24\delta_1^* + 3\delta_3\delta_1^* - 4\delta_3^2}{4(8\delta_1^* - \delta_3^2)}$, and $q_1^* = 1 - p_1^* = \frac{(8-3\delta_3)\delta_1^*}{4(8\delta_1^* - \delta_3^2)}$.

Period 2 decisions: $w_2^* = \frac{\delta_1^*(32\delta_1^* - \delta_3^2 - 8\delta_3)}{8(8\delta_1^* - \delta_3^2)}$, $p_n^* = \frac{3\delta_1^*(32\delta_1^* - \delta_3^2 - 8\delta_3)}{16(8\delta_1^* - \delta_3^2)}$, $p_e^* = \frac{\delta_3(64\delta_1^* + 12\delta_3\delta_1^* - 15\delta_3^2 + 8\delta_3)}{16(8\delta_1^* - \delta_3^2)}$, and $q_n^* = \frac{32\delta_1^* - \delta_3^2 - 8\delta_3}{16(8\delta_1^* - \delta_3^2)}$. [a]

Profits: $\Pi_M^* = w_1^* q_1^* + w_2^* q_n^* - \frac{K}{2}((\delta_1^*)^2 - 1)$, and $\Pi_R^* = (p_1^* - w_1^*)q_1^* + (p_n^* - w_2^*)q_n^*$.

Both used goods markets model

Threshold value of K: $K_{be} = \frac{2(\bar{\Pi}_M(\delta_1 = 1+a) - \bar{\Pi}_M(\delta_1 = 1))}{a(2+a)}$,

where $\bar{\Pi}_M(\delta_1) = \frac{\delta_1[64(\delta_1 + (1-cr)^2) + 32r\delta_2(1-cr+2r\delta_1) - 28r^2\delta_2^2 + 4\delta_3(1-r)(16r\delta_1 + 12cr - 11r\delta_2 - 12) + \delta_3^2(1-r)^2]}{64[8\delta_1 + 8\delta_1 r^2\delta_2 - 4r^2\delta_2^2 - 4\delta_3 r(r-1)(2\delta_1 - \delta_2) - \delta_3^2(1-r)^2]}$.

Period 1 decisions: $w_1^* = \frac{(2r\delta_2 + \delta_3 - \delta_3 r)^2(-22r\delta_2 + 24cr - \delta_3 r - 24 + \delta_3) + 16(\delta_3 r + 1 - r^2\delta_3 + r^2\delta_2)\delta_1^*(8 + 10r\delta_2 - 8cr - \delta_3 r + \delta_3)}{32(8\delta_1^*(\delta_3 r + 1 - r^2\delta_3 + r^2\delta_2) - (2r\delta_2 + \delta_3 - \delta_3 r)^2)}$,

$p_1^* = \frac{\delta_1^*(8 - 6r\delta_2 + 8cr - 16r^2\delta_3 + 16r^2\delta_2 + 8w_1^* + \delta_3 + 15\delta_3 r) - (2r\delta_2 + \delta_3 - \delta_3 r)^2}{16\delta_1^*(-r^2\delta_3 + \delta_3 r + r^2\delta_2 + 1) - (2r\delta_2 + \delta_3 - \delta_3 r)^2}$, and $q_1^* = 1 - p_1^*$.

Period 2 decisions: $w_2^* = \frac{1}{2}(\delta_1^* + p_1^*\delta_3 - rp_1^*\delta_3 - 2r\delta_2 - \delta_3 + r\delta_3 + 2rp_1^*\delta_2)$, $p_n^* = \frac{1}{2}(p_1^*\delta_3 - \delta_3 + r\delta_3 + \delta_1^* - rp_1^*\delta_3 + w_2^*)$, $q_n^* = \frac{\delta_1^* - w_2^* - 2\delta_2 q_u^* - \delta_3 q_e^*}{2\delta_1^*}$,

$p_u^* = \frac{p_n^* - rp_1^*\delta_2 + r\delta_2 - \delta_3 r + \delta_3 - \delta_3 p_1^* + \delta_3 r p_1^* - \delta_1^*(1-p_1^*)(r\delta_2 - \delta_3 r + \delta_3)}{\delta_1^*}$, $q_u^* = r(1-p_1^*)$, and $p_e^* = \frac{p_n^* - rp_1^*\delta_2 + r\delta_2 - \delta_3 r + \delta_3 - \delta_3 p_1^* + \delta_3 r p_1^* - \delta_1^*(1-p_1^*)}{\delta_1^*}$.

Profits: $\Pi_M^* = w_1^* q_1^* + w_2^* q_n^* - \frac{K}{2}((\delta_1^*)^2 - 1)$, and $\Pi_R^* = (p_1^* - w_1^*)q_1^* + (p_n^* - w_2^*)q_n^* + p_u^* q_u^* - crq_1^*$.

Note. The detailed derivations of all the equilibrium decisions and profits are provided in Appendix A.

[a]For $\delta_3 \geq 2c$, we can show that $p_e^* \geq c$; i.e., all customers of period 1 sell their used products in the P2P market. Thus, throughout this paper, we assume $\delta_1 \geq 1 \geq \delta_2 \geq \delta_3 \geq 2c$. The last inequality is a rather mild condition—it means that among all the customers buying from the P2P used goods market, the one with the highest valuation values the product sufficiently higher than the residual value of used products.

Wolk 2006). The underlying reason for the above result is the manufacturer's *monopolistic* position in period 2 of the no used goods scenario. Note that the manufacturer's decision to release a new version depends on whether the extra revenue from doing so (equal to the wholesale price premium for a new version times sales volume) is more than the cost of releasing the new version. Table 1 shows that in the *no* used goods scenario, the manufacturer's period 1 profit remains the same irrespective of whether any new version is released. However, for the *only retail* used goods scenario, release of a new version results in the manufacturer increasing her period 1 wholesale price so as to reduce the supply of used products in period 2. The resulting decrease in the sales of unused products hurts the manufacturer's period 1 profit. In period 2 for both scenarios, release of a new version results in a wholesale price premium. In fact, the premium is *higher* when a retail used goods market exists. However, the manufacturer's monopoly supplier position in the no used goods scenario means that her period 2 sales volume of unused products is *much larger* in that case than in the case when the manufacturer has to "compete" with the retailer's used products. It turns out that the sales volume effect dominates the price premium effect in period 2. Consequently, given a fixed cost of releasing a new version, the manufacturer has a higher incentive to upgrade when there are no used goods. This implies that the *addition of a retail used goods market actually results in less frequent product upgrades*. Obviously, when the degree of upgrade a increases, competition from used products becomes weaker, which leads to a lower deterrent effect of the retail market.

Another interesting issue is how the retail used goods market affects temporal increase in retail prices for unused products, i.e., $p_n^* - p_1^*$.

Proposition 2 (Retail Used Goods Market Reduces Temporal Retail Price Increase for Unused Products). *Relative to when there are no used goods, the presence of used retail goods leads to a lower retail price for unused products in period* 2, *a higher retail price in period* 1, *and thus a lower temporal increase in the retail price for unused products from periods* 1 *to* 2.

A retail used goods market helps end customers by reducing the extent of a hike in retail prices for unused products over time. We proved in Proposition 1 that product upgrades are less likely when the retailer sells used goods. The decrease in the period 2 retail price of the above proposition under that scenario is then due to the competition that unused products face from used goods and also due to the lower wholesale price charged by the manufacturer (less frequent upgrades means less investment cost). On the other hand, the price increase in period 1 is caused by an increase in the wholesale price of period 1 by the manufacturer who, as indicated before, would like to reduce customer demand in period 1 and thus the availability of used products in period 2. Moreover, we can also analytically show that relative to when there are no used goods, the presence of a retail used goods market leads to a lower retail sales volume of unused products in both periods. However, note that the total sales (unused + used) is higher when the retailer sells used goods.

Profits. Both channel members can benefit or lose from the presence of a retail used goods market (compared to the no used goods scenario). When K and δ_2 are large, both members are usually better off. The higher the value of K, the more likely it is that the manufacturer will not release a new version. Thus for large δ_2 (i.e., relatively high value of used goods) and high K, the competition from used goods is high when the retailer sells them. The manufacturer then charges a high wholesale price in period 1 so as to reduce the supply of used products. This higher wholesale price can effectively counterbalance the reduction in sales volume of unused products for her in period 2. Large δ_2 also benefits the retailer because he can sell high-priced used products (i.e., high p_u^*). Low c increases the benefit for the retailer by reducing the acquisition cost of used products.

In Table 2, we summarize the effects of the presence of a retail used goods market on our focal issues—product upgrades and temporal retail prices for unused products.

Table 2 Effects of Addition of a Retail Used Goods Market

	On manufacturer's product upgrade strategy	On temporal retail prices for unused products
Effect of retail used goods market	*Reduces* the frequency of product upgrades	*Reduces* the extent of temporal price increase

4.4. Effects of the P2P Used Goods Market

In some sectors with renewable customer sets (e.g., strollers), used products are not returned to a retailer; consumers carry out transactions among themselves through P2P markets. In this section, we first briefly analyze a setting where in addition to the primary market, consumers can use a frictionless P2P market for buying or selling used products but have no access to the retail used goods market (this is a special case of §3 when $r = 0$ and $\delta_2 = 0$). We then compare the results from this section to those of the no used goods scenario (see §4.1) to demonstrate the effects of a P2P used goods market as the only source of used goods on channel decisions and profits.

In this section, period 1 consumers can sell their used products only in the P2P market (at price p_e), and new customers of period 2 need to choose between buying used products from the P2P market (at price p_e because P2P market is frictionless) or unused ones from the retailer (at price p_n). Note that valuations of customers who buy used products from the P2P market are given by $\delta_3 \cdot v$, where $v \sim U[0, 1]$. Because all other assumptions remain the same, the inverse demand functions of period 2 are as follows: $p_n = \delta_1(1 - q_n)$ and $p_e = \delta_3(1 - q_n - q_e)$, where $q_e = 1 - p_1$. We again use backward induction to derive the equilibrium decisions and profits, which are given in Table 1.

Comparing of the optimal decisions and profits of the P2P only scenario to those of the no used goods model establishes the following.

Proposition 3. *Relative to when there are no used goods, the presence of a P2P used goods market*

(a) *deters release of new versions of the product* (*specifically*, $K_e \le K_0$);

(b) *leads to a lower temporal increase in the retail price of unused products because of a lower unused product retail* *price in period* 2 *and a higher unused product retail price in period* 1; *and*

(c) *results in lower profits for both the manufacturer and the retailer.*

By comparing the effects of the P2P used goods market (Proposition 3) to those of the retail used goods market (see §4.3), we can conclude that their effects on decision variables of our interest are quite similar. *Only one* source of used products reduces frequency of product upgrades and reins in the temporal retail price increase for unused products, *irrespective* of whether the source is the retailer or the P2P market. The primary difference is that the P2P used goods market is harmful for both channel partners, whereas the retail used goods market might result in higher profits for both. However, although each of the two used goods markets individually reduces frequency of product upgrades, they differ in terms of the intensity of their effects.

Proposition 4. *The retail used goods market has a stronger deterrent effect on product upgrades than the P2P used goods market. That is,* $K_b \leq K_e$.

The reason for the above difference is as follows. The addition of the retail used goods market results in the manufacturer losing its monopoly provider status for the retailer *and* end consumers (compared with the no used goods case) because both then have access to used products. On the other hand, when the P2P used goods market is added, the manufacturer competes with that market for satisfying end consumers but is still the monopoly supplier for the retailer. Hence, the adverse effect on the sales volume of unused products for the manufacturer, and consequently the adverse effect on the benefit from product upgrades, is less when the P2P market is added.

5. Interaction Between Retail and P2P Used Goods Markets

As pointed out in §1, although retail used goods market for products like college textbooks was the first source of used goods, development of Internet technologies has resulted in an explosive growth of electronic P2P markets as a *second* used goods channel. In this section, we focus on understanding how the *emergence of a P2P used goods market*, when a retail used goods market is already active, affects the manufacturer's product upgrade and the retailer's pricing strategies as well as their profits. To do so, we next study the model framework discussed in §3, which captures the interaction between the two used goods markets by assuming that they coexist.

5.1. Scenario with Both Used Goods Markets

The sequence of events in the model with both retail and P2P used good markets is described in Figure 2 of §3. Note that consumers are myopic and their valuations are as follows: for unused products in period 1, it is $v \sim U[0, 1]$; for unused products in period 2, it is $\delta_1 \cdot v$; and for used products from the retail and the P2P used goods markets, they are $\delta_2 \cdot v$ and $\delta_3 \cdot v$, respectively. Demand for the product at the beginning of period 1 is $(1 - p_1)$. The model with both used goods markets differs from the only retail used goods model of §4.2 in two aspects: (1) The retailer now faces competition in buying used products from old consumers. Specifically, at the end of period 1, we assume that a proportion r of $(1-p_1)$ consumers returns to the retail used goods market and the remaining return to the P2P used goods market. (2) There is more competition in selling products to new consumers. In the second period, consumers can now buy products, if they want to, from any one of the following three sources: the retail primary market (unused products), the retail used goods market, and the P2P used goods market. Recall from §3 that the inverse demand functions in period 2, when the two used goods markets coexist, are given in Equation (1).

This scenario can also be analyzed using backward induction, first within and then between periods. The equilibrium values are shown in Table 1.

5.2. Effects of the P2P Market in the Presence of the Retail Used Goods Market

To understand the role that P2P markets play as a second source of used goods, we need to compare the results of the only retail used goods model in §4.2 with those of the model incorporating both used goods markets in §5.1. Although we have explicit expressions for threshold K as well as other optimal decisions for the model in §5.1 (refer to Table 1), these expressions (and those for profits) are rather unwieldy for analytical comparison. Thus we resort to an extensive numerical study to compare the two models.[9] Table 3 summarizes our main findings regarding how emergence of the P2P market affects the channel decisions of our interest.

Table 3 reveals that the effects of the second used goods channel (i.e., P2P markets) are significantly different (almost totally opposite) compared to those of the first used goods channel operated by the retailer (as summarized in Tables 2 and 3).

5.2.1. Key Insights.

(1) **Product Upgrades:** Interestingly, in the presence of a retail used goods market, further addition of a

[9] The details of the numerical study are provided in Appendix B.

Table 3 Individual and Joint Effects of Retail and P2P Used Goods Markets for Myopic Consumers

	On manufacturer's product upgrade strategy	On temporal retail prices for unused products
Effect of only retail used goods market	*Reduces* the frequency of product upgrades	*Reduces* the extent of temporal price increase
Effect of P2P market in the presence of retail used goods market	*Increases* the frequency of product upgrades	Mostly *amplifies* the extent of temporal price increase

P2P market always *encourages product upgrades* by the manufacturer ($K_{be} \geq K_b$). This contrasts with the result that a retail used goods market alone deters product upgrades. This suggests that the popularity of the P2P market as a second used goods source is the driver behind the increased frequency of new versions in recent times. The intuition behind this result is as follows.

When we compared *no* used goods and *only retail* used goods models in §4.3, we noted that an upgraded product is associated with a higher wholesale price premium in the second scenario, but the manufacturer's sales volume of unused products is much higher in the first (because she is the "monopoly supplier"). The volume effect dominates, and so the manufacturer has a higher incentive to upgrade when there are no used goods. Comparison between *only retail* used goods and *both* used goods scenarios reveals that an upgrade results in a higher wholesale price premium in the first scenario, but the manufacturer's sales volume is higher in the second case. Note that in the only retail used goods scenario, the retailer has sole access to all the used goods in the market so he does not rely much on the manufacturer's unused products to satisfy customer demand. However, with the emergence of the P2P market, the retailer has to compete with that market for used products. Because of this competition, the retailer can buy and sell *fewer* used goods, and he becomes more dependent on the manufacturer's unused products to generate sales. Consequently, competition between the two used goods markets actually restores some of the monopoly power that the manufacturer enjoyed when there were no used goods and increases her sales volume of unused products. The sales volume effect again dominates the wholesale price premium effect, resulting in the scenario with both used goods market being more conducive for releasing an upgraded version.

As indicated in Appendix B, $K_{be} - K_b$ decreases in δ_3, which is the degree to which customers devalue used products from the P2P market. Thus, the higher the value of δ_3, the weaker the effect of the P2P market in encouraging product upgrades. A higher δ_3 implies stronger competition from used goods in period 2. This reduces the extent of increase in sales of unused products for the manufacturer as a result of the advent of the P2P market and thus reduces her benefit from upgrading.[10]

(2) **Retail Prices:** For unused products, the addition of the first used goods channel (retail) results in a lower rise in retail prices over periods (i.e., a lower $p_n^* - p_1^*$), relative to the no used goods scenario (see §4.3), but further introduction of the P2P used goods market usually reverses the effect. There are two counteracting effects on the retail prices for unused products—any increase in wholesale price puts an upward pressure, whereas the competition from used goods puts a downward pressure. Because emergence of the P2P market results in more frequent upgrades, the associated investment costs induce the manufacturer to charge a higher period 2 wholesale price. This results in *higher period* 2 *retail prices* for unused products (i.e., higher p_n^*) after the P2P market is introduced. More frequent product upgrades also signify that the manufacturer is not much concerned about competition from used products in period 2. She reduces the wholesale price in period 1 so as to increase sales of unused products after the P2P market becomes active. A lower wholesale price means that the *retail price in period* 1 *is also lower* (i.e., lower p_1^*). A lower retail price in period 1 and a higher retail price in period 2 implies that the price increase over two periods is amplified after the introduction of the P2P market as the second used goods source. However, when both δ_2 and δ_3 are high, the competition from the used goods markets is quite strong, which forces the retailer to (substantially) reduce his price for unused products in period 2. Only in that case is the retail price hike from period 1 to period 2 for the scenario with both used goods markets lower than that for the only retail used goods market scenario.

(3) **Profits:** Introduction of the P2P market increases the manufacturer's sales volume of unused products in both periods and allows her to charge a higher wholesale price in period 2, but she charges a lower

[10] We assumed in this paper that consumers value used goods from the retailer more than those from the P2P market (i.e., $\delta_2 \geq \delta_3$). Our analysis, which we do not include in the paper for space considerations, suggests that the insight about the effect of the introduction of the P2P market on product upgrades is valid even if δ_3 is slightly larger than δ_2. However, if δ_3 is considerably larger than δ_2, then the emergence of P2P markets as a second source of used goods might actually further *deter* the frequency of product upgrades (rather than encourage). This is especially true when the retail used goods market is strong (i.e., both the value of δ_2 and the proportion of used goods returned to the retailer, r, are high) or when the P2P market is strong (i.e., both the difference between δ_3 and δ_2 and the proportion of used goods sold in the P2P market, $1 - r$, are high).

wholesale price in period 1 and also incurs more investment costs (because there are more upgrades). Consequently, although the manufacturer usually benefits from the P2P used goods market, there are exceptions to this rule. The retailer also sells more unused products in both periods after the P2P market emerges. Moreover, the effects of the P2P used goods market on the retail prices for unused products are also similar to those on the wholesale prices (except when δ_2 and δ_3 are high). As for used products, the popularity of the P2P used goods market results in the retailer selling less used products but at higher prices. Overall, the emergence of the P2P is usually beneficial for the retailer, but not when the used products are valued highly by the consumers.

A related (but less relevant to this paper) issue is how the effects of the used goods markets would change if their sequence of addition is reversed—first P2P and then retail. As discussed in §4.4, the effects of the P2P market as the first used goods source on product upgrade and retail pricing strategies are the same as those of the retail used goods market (see Table 2). Our numerical study comparing the both used goods markets scenario (see §5.1) to the only P2P used goods market (see §4.4) suggests that the addition of the retailer as the second used goods source amplifies the effects of the P2P used goods market. Specifically, it would further deter introduction of new versions and (usually) would reduce the extent of price increase from periods 1 to 2 even more. This makes sense because the second market now increases the adverse effect on the manufacturer's sales volume, whereas the P2P market only takes away her monopoly supplier power as far as end consumers are concerned, with the retail market she is also no longer the sole supplier for the retailer.

5.2.2. Overall Effects of the Two Used Goods Markets. A natural question is what are the net effects of the two used goods markets (i.e., compared to the no used goods scenario) on relevant channel decisions and profits? To answer this, we compare the results of no used goods scenario (see §4.1) to the scenario where both used goods markets coexist (see §5.1). We know that whereas only retail used goods channel deters product upgrades, further addition of a P2P channel stimulates such upgrade decisions. It turns out that the stimulating effect of the P2P market is not strong enough to counterbalance the (initial) deterring effect of the retail market. Overall, used goods channels result in *reduced* frequency of product upgrades.[11] Furthermore, the both used goods markets scenario mostly results in *lower* retail price increases for unused products from periods 1 to 2 and *lower* profits for both channel partners relative to the no used goods scenario. Used products in general are detrimental for channel partners but beneficial for end customers.

6. Model Generalizations and Empirical Support

In this section, we first discuss two relevant extensions of the framework we have studied: (1) how the results are affected if consumers are forward looking rather than myopic (see §6.1) and (2) what the optimal level is of product upgrade (i.e., optimal a or δ_1) that the manufacturer should undertake, if any (see §6.2). Later, in §6.3, we provide empirical support for our theoretical result regarding a product upgrade strategy using data from the college textbook industry.

6.1. Forward-Looking Consumers

Our analysis until now has assumed that consumers are myopic in that they do not consider their future payoffs while making their initial purchase decisions. However, for products such as college textbooks, consumers can indeed sometimes be forward looking—that is, they take into account possible future payoffs from the product while deciding whether to purchase (Chevalier and Goolsbee 2009, Shulman and Coughlan 2007). Incorporating such behavior in our framework implies that when consumers decide on buying the product at the beginning of period 1, they consider that at the end of period 1, they can get their "expected" payoff from selling the used product either to the retailer or to other new consumers in a P2P market (if either is available) or keep the product for its residual value. The other characteristics of the model remain the same as before. The forward-looking behavior primarily affects the period 1 demand functions. At the beginning of period 1, a forward-looking customer who buys a unit of the unused product of the existing version will generate a utility $v - p_1 + E_u$, where E_u stands for the expected payoff that the customer can obtain from the used product. Thus a customer's indifference point between buying a product in period 1 and not buying is at $v^s = p_1 - E_u$ and the demand function for period 1 is

$$q_1 = 1 - (p_1 - E_u). \tag{2}$$

Note that $E_u = c$ in the no used goods market scenario; $E_u = c + \epsilon$, $\epsilon \sim 0$, in the only retail used goods market scenario; $E_u = p_e$ in the only P2P used goods market scenario; and $E_u = r(c + \epsilon) + (1 - r)p_e$ in the both used goods markets scenario.

We can use the same methodology as in the case of myopic consumers and analytically solve the model with no used goods and the model with only one

[11] Overall, the threshold K values for the four model are related as follows: $K_b \le K_{be} \le K_e \le K_0$.

used goods market (either retail or P2P). Furthermore, by comparing the equilibrium decisions in the model with no used goods and the model with only retail used goods, we can analytically establish the following counterpart of Propositions 1 and 2 for the case of forward-looking consumers (refer to Appendix C for the proof).

Proposition 5. *Relative to the no used goods scenario, the presence of a retail used goods market deters product upgrades and results in a lower temporal increase in retail prices of unused products.*

However, analytically solving the model with both used goods markets is rather cumbersome, so we use a numerical study to derive equilibrium values for that scenario. Keeping in mind the space constraints, we do not provide the details of our analysis here (refer to Appendix C for a detailed analysis and equilibrium values). We only summarize the individual and joint effects of the used goods markets for forward-looking consumers in Table 4.

By comparing Tables 3 and 4, we observe that for forward-looking consumers, the individual and joint effects of the two used goods markets are *consistent* with those for myopic consumers. Specifically, the initial retail used goods source still deters product upgrades and lowers the temporal hike in retail prices for unused products, whereas the subsequent addition of the P2P market still (usually) encourages product upgrades and (usually) amplifies the price increase over periods.

6.2. Endogenous Product Upgrade Quality Decision

Our analysis until §5 assumed that the manufacturer's decision in stage 1 of period 1 involves deciding whether to come up with an upgraded version (i.e., whether δ_1 is 1 or $1+a$). An issue of managerial interest might be that if indeed the decision is to upgrade, to what extent should the "quality" of the new version be an improvement over the existing one? We analyze that issue in this section. The degree of product upgrade δ_1^* is now a decision for the manufacturer in stage 1 of period 1 (all other assumptions remain the same as in §§3–5). The analysis and results derived for all other previous stages of the game remain the same as before.

Table 4 **Individual and Joint Effects of Two Used Goods Markets for Forward-Looking Consumers**

	On manufacturer's product upgrade strategy	On temporal retail price for unused products
Effect of retail used goods market only	*Reduces* the frequency of product upgrades	*Reduces* the extent of temporal price increase
Effect of P2P market in the presence of retail used goods market	Mostly *increases* the frequency of product upgrades	Mostly *amplifies* the extent of temporal price increase

Because of space constraints, we do not go into details of the analysis here (details are provided in Appendix D). However, it turns out that for each of the four models of §§4 and 5, the manufacturer's profit function is well behaved in δ_1, as shown in the following proposition.

Proposition 6. *From the manufacturer's perspective, there is a unique product upgrade level δ_1^* associated with each of the four models.*

For certain parameter values (e.g., high K), the optimal strategy for the manufacturer is not to upgrade the product at all; i.e., $\delta_1^* = 1$. For other cases, it is optimal for the manufacturer to upgrade the product to a certain (unique) level given by δ_1^r, where δ_1^r can be derived from the first-order condition of the manufacturer's profit function with respect to δ_1 for each of the four models (more details about δ_1^r are provided in Appendix D).

Obviously, δ_1^* is a function of model parameters K, c, r, δ_2, and δ_3, whichever is relevant in the corresponding model. Our analysis suggests that δ_1^* decreases in δ_2, δ_3, K, and r and increases in c. It is intuitive that the higher the cost of releasing a new version (high K) or the higher the value of used goods to end consumers (high δ_2 and/or δ_3), the lower the degree of product upgrade. As far as r is concerned, Proposition 4 shows that the retail used goods market has a stronger deterrent effect on product upgrades than does the P2P one. Thus the more the amount of used goods returned to the retailer (i.e., higher r), the less the extent of upgrade for the new version. Finally, a higher residual value of used goods (i.e., higher buyback cost c) induces the retailer to reduce the sales volume of unused products in period 1. This results in less competition for the manufacturer in period 2, which provides her incentive to undertake a higher level of upgrades.

6.3. Empirical Support

In this section, we provide empirical support regarding the analytical insights obtained in §§4 and 5 about frequency of product upgrades, based on data from college textbook industry. As indicated in §3, college textbooks perfectly fit our main modeling assumptions (e.g., renewable customer sets, sequential introduction of retail, and P2P used goods markets).

6.3.1. Data Description. We use data from Monument Information Resources (MIR), the primary source of data for research related to the college textbook industry (e.g., Chevalier and Goolsbee 2009, Iizuka 2007). Our sample includes all textbooks in the fields of business, marketing, management, biology, engineering, and psychology sold during the winter 1995 semester to the winter 2008 semester for a large number of (predominantly) campus textbook retailers.[12] The data set includes information about individual textbook characteristics (e.g., ISBN, title, author, publisher, editions) as well as the total volume of unused and used units sold for each book (per semester). Because every new release is assigned a different ISBN, we create a unique identifier for a particular book by combining the "title-author-publisher" information to track new edition releases.

6.3.2. Measures, Methodology, and Analysis. Our theoretical model predicts a structural change in the release frequency after the introduction of the P2P used goods market—specifically, the frequency of new-edition releases should increase with the emergence of the P2P used book market. The existing literature (e.g., Chevalier and Goolsbee 2009, Iizuka 2007) indicates that the retail used goods market for textbooks has existed since 1995; however, the P2P market for used textbooks emerged only around the early 2000s once Internet-enabled markets like Amazon and eBay started becoming popular (before that time, the used textbook market had relatively insignificant P2P component). Note that Amazon's marketplace, the primary P2P market for used textbooks, opened in November 2000 (refer to Amazon.com's corporate time line at http://phx.corporate-ir.net/phoenix.zhtml?c=176060&p=irol-corporateTimeline). Based on the above observations and our discussion with experts (Friscia 2009), we split our data into two sets—pre-2001 (winter 1995 to fall 2001) and post-2001 (winter 2002 to winter 2008)—and create a dummy variable, *P2P* (which is equal to one for the post-2001 sample and to zero for pre-2001 sample), as a proxy for introduction of the P2P used books market.[13] Given the truncation and censoring present in our event duration data, we use a survival analysis approach to examine the impact of P2P used books market on release frequency of new editions. We estimate the following hazard function for jth edition of the ith book using the Cox proportional-hazards regression model:

$$h_{ij}(t) = h_0(t)\exp\left[\gamma_1 \cdot P2P_{ij(t)} + \gamma_2 \cdot usedBookShare_{i(t-1)} + \sum_{k=1}^{n-1} \eta_k \cdot Discipline_{ik}\right], \quad (3)$$

where $h_{ij}(t)$ is the conditional hazard function at time t, $h_0(t)$ is the baseline hazard, and $P2P$ is a dummy variable as defined above. We also include lagged *usedBookShare* as a control variable in the model because it has been shown to impact the release frequency of textbooks (Iizuka 2007). We calculate the sales share of used books for each book at a given time by dividing the total used units of that book's current edition sold by bookstores (since the introduction of the current edition) divided by the total (new and used) units of that book's current edition sold during the same period. In addition, we control for the unobserved differences across different textbook markets by including dummies (*Discipline*) for each discipline.

Because there are recurrent events in our data set (i.e., a textbook releasing multiple editions), we use robust variance estimation to adjust for correlation among observations from the same textbook (Lin and Wei 1989).[14] The results of the maximum likelihood estimation of the model are shown in Table E.1 in Appendix E. We find the model to be significant (Wald $\chi^2(7) = 122.83;\ p < 0.01$). Our results suggest that the likelihood of a new textbook edition release is 1.20 times greater ($p < 0.01$) in the winter 2002 to winter 2008 time period versus the winter 1995 to fall 2001 time period. Thus consistent with our analytical result, our empirical analysis suggests that publishers are likely to release new editions more frequently after the introduction of the P2P used books market (compared to when such a market did not exist). Also as expected, we find that the hazard rate of new edition release increases as the used book share increases ($\hat{\gamma}_2 = 6.19;\ p < 0.01$). To assess the goodness of fit, we also conducted a likelihood ratio test, which suggests that including the P2P variable in the model improves the fit ($\chi^2(1) = 3.45;\ p < 0.064$).

6.3.3. Additional Tests. To test the robustness of the results, we also use 2000 (i.e., pre-2000 and post-2000) and 2002 (i.e., pre-2002 and post-2002) as cutoff times for creating the *P2P* dummy variable (as a proxy for emergence of the P2P used books market). Results show that the hazard ratio for the P2P dummy is less than one if we use a cutoff lower than 2001, whereas the hazard ratio is greater than one if we use a cutoff higher than 2001 (hazard ratio is 0.34, 1.20, and 3.01 for 2000, 2001, and 2002 as cutoffs, respectively). This

[12] The number of retailers in our data set for 2007 is around 1,800. The majority of the 1,800 are on-campus stores, although there are also a few off-campus (physical) stores.

[13] We allowed one year for Amazon's marketplace to gain traction. We also test different cutoffs (2000 and 2002) as proxies for emergence of the P2P used books market. The results, as reported later, provide support to our hypothesis.

[14] As an alternative, we introduced textbook level frailty (i.e., a latent random effect with mean equal to one and variance equal to θ) in the model and estimated a shared-frailty survival model to account for within-textbook correlation and unobserved heterogeneity. We find that the results are similar; however, the likelihood-ratio test suggests that frailty effect is not significant in our data ($\theta = 1.13\text{e}{-07};\ p = 0.50$).

is consistent with our exploratory regression results[15] and supports our assumption that 2001 is an appropriate cutoff.

In addition, we also conducted nonparametric tests that provide similar results. The log-rank test for equality of survivor functions (i.e., pre-2001 versus post-2001) is rejected ($\chi^2(1) = 13.56$). The Peto-Peto test, which does not assume proportionality of hazard function and is also not affected by the differences in censoring patterns across groups (Peto and Peto 1972), is also rejected ($\chi^2(1) = 14.17$), suggesting that survivor functions across our subsamples differ. Finally, we also tested a parametric survival model with baseline hazard modeled as a Weibull distribution and found consistent results.[16]

7. Conclusions, Implications, and Future Research Opportunities

Multiple used goods markets, an offline (for-profit) one operated by retailers and an online (frictionless) P2P one, are now important transaction channels for many durable products. Because these two markets compete with each other for buying used products from old customers, and also compete between themselves and with the primary market (a retailer selling unused products procured from the manufacturer) to satisfy demand from new customers, they give rise to interesting competitive issues on both supply and demand sides. In this paper, we analyze these issues using a dyadic channel framework facing renewable consumer sets. Motivated by textbook and video game industries, we specifically focused on studying the effects of the sequential addition of the two used goods markets—first retail and then P2P—on the manufacturer's product upgrade strategy, the retailer's pricing strategy for unused products, and their profits.

Surprisingly, our analysis indicates that the addition of the first used goods market in the form of the retailer results in less frequent product upgrades and a relatively lower retail price increase over time for unused products (compared to when there are no used goods).[17] However, the subsequent emergence of the second used goods market (i.e., P2P) actually increases the frequency of product upgrades and results in a (mostly) higher level of retail price increase over time. We interpret these results as follows. When there are no used goods, both channel partners benefit from an upgrade because improved content and no competition from used products allow them to charge higher prices. However, when the retailer starts to operate a used goods market, his sole access to this supply source reduces the amount of unused products he orders from the manufacturer. This reduces the benefit for the manufacturer of releasing an upgraded version and thus weakens her incentive to do so. When a second P2P used goods market comes into existence and competes with the retailer for buying used products, the retailer has an incentive to acquire more unused products from the manufacturer to offset the competition in the used goods market. This in turn increases the manufacturer's benefit from product upgrades. The above results are valid regardless of whether customers are myopic or forward looking in terms of their purchase decisions. Moreover, we provide empirical support about the effect of the P2P used goods market on product upgrades by using data from the textbook industry. Finally, we note that the sequential addition of the two used goods markets can be either beneficial or detrimental (profitwise) to both channel members.

In the durable product literature, issues concerning competition between the primary market and a P2P-type used goods market have been studied before. What is missing is the analysis of the interaction between the two sources of used goods and its impact on product upgrade strategy, which, we believe, is a novel addition to the literature. In this context, our study brings to light a number of important implications of multiple used goods markets for certain durable products. First, it shows that the recent spate of product upgrades and rising retail prices for textbooks and video games are due to the growing popularity of the P2P used goods markets and perhaps should not be attributed (as has been done in the practitioner literature) to retail buybacks of used products. Second, as more P2P-type used goods markets emerge, they will make it more difficult for retailers to acquire used products and will probably increase the frequency of product upgrades by the manufacturer.[18]

[15] We conducted an ordinary least-squares regression analysis (not included in the paper because of space constraints) to examine the relationship between *Release Gap* (i.e., the number of semesters between two consecutive editions of a book) and *Time*. We find support for a quadratic relationship with a changing trend in the release gap around semester 15 (i.e., winter 2002). The details of the analysis are available from the authors on request. We also compare two samples—pre-2001 (winter 1995 to fall 2001) and post-2001 (winter 2002 to winter 2008)—and find that *Release Gap* has decreased to 4.82 semesters in the post-2001 sample versus 5.64 semesters in the pre-2001 time period ($t = 5.24$, $p < 0.01$).

[16] However, we note that there might be other macroeconomic factors, in addition to the emergence of the P2P market that may have affected the frequency of new edition releases in the post-2001 time period. Future research should explore the impact of such factors on the hazard rate of new-edition releases before and after 2001.

[17] We showed that this is true even if the first used goods source is the P2P market, although the effect is weaker.

[18] Note that if the disutility of buying online decreases significantly over time, it might restrain, or even reduce, the frequency of such upgrades.

However, whether such P2P markets are beneficial for the manufacturer and whether they would increase or decrease retail prices depend on a number of factors (e.g., how customers will value used products in the future, how much disutility of buying online will decrease over time). Third, if indeed technologies like e-books and video games, with codes that unlock extra content, that can only be used once become popular (GAO 2005, Kane and Bustillo 2009), they would really "kill" the used goods market (i.e., it will be like our no used goods model). Such a scenario would result in new upgrades being released more frequently and customers paying higher prices. Moreover, such a scenario would also be more profitable for the manufacturer; thus it is not surprising that they are actively pursuing such technologies. Last, for durable products for which P2P is the first used goods source (e.g., strollers), such a used goods market would actually reduce both the frequency of new releases and the extent of rise in retail prices over time. In fact, if retailers also start taking back such used products and reselling them (stricter environmental regulations might force them to do so), new releases would become more infrequent and the price increase over time would also reduce.

Our model setting assumed an exogenous segmentation of consumers who return used goods to the retail store or exchange them in P2P markets. An extension to our model would be to endogenize the consumers' decisions as a function of the prices in the two markets. Also, although it is increasingly common to see retail stores selling used products (as a competitive necessity), another extension would be to endogenize whether to do so as a decision for the retailer. Finally, our model assumes a renewable set of consumers. A nonrenewable market, a typical assumption in the durable product literature, would bring forth additional issues not considered in this paper. For instance, demand in the first period might be potentially hurt because some consumers may prefer to buy the new version in the second period. Incentives are then needed to promote early sales. For example, companies such as TechForward offer a guaranteed buyback program, providing insurance against future product upgrades. We hope that this work will spur a stream of research regarding the important and ever-increasing role that multiple used products channels play in the durable goods industry, which will serve to provide guidance to marketing managers.

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Appendix A. Technical Proofs[19]

Derivation of Period 2 Inverse Demand Functions of Equation (1). The derivation of the demand functions follows Chiang et al. (2003). A customer has four different options—not buying any product, buying a used product from the P2P used goods market, buying a used product from the retail used goods market, and buying an unused product from the primary market. Thus we need to derive six indifference points for these options, which are as follows. Based on utility theory, a customer who is indifferent between buying a used product from the P2P market and not buying is at $v^e = p_e/\delta_3$. If a customer's valuation is above v^e, then he or she will buy; otherwise, he or she will not. Similarly, the indifference point for a customer between buying a used product from the retail market and not buying is at $v^u = p_u/\delta_2$, the indifference point between buying an unused product and not buying is at $v^n = p_n/\delta_1$, the indifference point between buying a used product from the P2P market and an unused one is at $v^{en} = (p_n - p_e)/(\delta_1 - \delta_3)$, the indifference point between buying a used product from the retail used goods market and an unused one is at $v^{un} = (p_n - p_u)/(\delta_1 - \delta_2)$, and finally the indifference point between buying a used product from the P2P market and a used one from the retail used goods market is at $v^{eu} = (p_u - p_e)/(\delta_2 - \delta_3)$. One can verify that the retailer will set prices such that $v^e \le v^u \le v^{eu}$ and $v^u \le v^n \le v^{un}$. This gives rise to the following demand functions:

$$q_n = 1 - \frac{p_n - p_u}{\delta_1 - \delta_2},$$
$$q_u = \frac{p_n - p_u}{\delta_1 - \delta_2} - \frac{p_u - p_e}{\delta_2 - \delta_3}, \quad \text{and}$$
$$q_e = \frac{p_u - p_e}{\delta_2 - \delta_3} - \frac{p_e}{\delta_3}.$$

The inverse demand functions of (1) can then be derived from the above expressions. □

Analysis of the Scenario with No Used Goods Market. In the model without any used products, given δ_1, it is easy to show that the equilibrium decisions for the channel partners in period 2 are $w_2^* = \delta_1/2$, and $p_n^* = 3\delta_1/4$ (so $q_n^* = 1 - p_n^*/\delta_1 = 1/4$), and in period 1 they are $w_1^* = 1/2$ and $p_1^* = 3/4$ (so $q_1^* = 1 - p_1^* = 1/4$). This leads to the manufacturer's total profit in stage 1 of period 1 being $\Pi_M = -(K/2)(\delta_1^2 - 1) + w_1^* \cdot q_1^* + w_2^* \cdot q_n^* = -(K/2)(\delta_1^2 - 1) + (1 + \delta_1)/8$.

[19] To accommodate space constraints, for some results we will only provide a sketch of the proofs. A detailed analysis of these results is available from the authors upon request.

If $\delta_1 = 1$, her profit is $\Pi_M(\delta_1 = 1) = 1/4$, and if $\delta_1 = 1+a$, her profit is $\Pi_M(\delta_1 = 1+a) = -(K/2)(2a+a^2)+(2+a)/8$. Clearly, $\Pi_M(\delta_1 = 1+a)$ decreases in K linearly, and the manufacturer prefers $\delta_1 = 1+a$ over $\delta_1 = 1$ if $K < K_0$, prefers $\delta_1 = 1$ over $\delta_1 = 1+a$ if $K > K_0$, and is indifferent between the two if $K = K_0$, where K_0 satisfies $\Pi_M(\delta_1 = 1) = \Pi_M(\delta_1 = 1+a)$; i.e., $K_0 = 1/(4(2+a))$. The equilibrium profit for the retailer can be derived by substituting the relevant expressions. All equilibrium decisions and profits are presented in Table 1. □

Analysis of the Scenario with Only Retail Used Goods Market. To establish the equilibrium decisions and profits of Table 1, we work backward starting from stage 2 of period 2.

In stage 2 *of period* 2, the retailer sets (p_n, p_u) to maximize his profit in period 2. Mathematically, it is equivalent for the retailer to choose his best (q_n, q_u) to maximize period 2 profit

$$\Pi_R^2 = (p_n - w_2)q_n + p_u q_u - cI_r, \quad \text{subject to} \quad q_u \le I_r, \quad \text{and} \quad q_u, q_n \ge 0, \tag{A1}$$

where $I_r = (1-p_1)$ is the amount of used goods returned to the retailer, $p_n = \delta_1(1-q_n) - \delta_2 q_u$ and $p_u = \delta_2(1-q_n-q_u)$. Π_R^2 is jointly concave in (q_u, q_n). Thus there is a unique global optimal (q_u^*, q_n^*). Solving first for q_n^* for a given q_u gives us $q_n^* = [(\delta_1 - w_2 - 2\delta_2 q_u)/(2\delta_1)]^+$. We next solve for q_u^* under the constraint $0 \le q_u \le I_r$. Consider two cases: (a) $I_r \le 1/2$ and (b) $I_r \ge 1/2$.

(a) $I_r \le 1/2$. The optimal q_u^* depends on the value of w_2 and I_r. There are two cases. (i) For $I_r \le (\delta_1 - w_2)/(2\delta_2)$, or equivalently, $w_2 \le \delta_1 - 2I_r\delta_2$, because $q_u \le I_r \le (\delta_1 - w_2)/(2\delta_2)$, we always have $q_n^* = (\delta_1 - w_2 - 2\delta_2 q_u)/(2\delta_1)$. Substituting it into Π_R^2 yields a concave function of q_u with the unconstrained global maximizer $q_u = w_2/(2(\delta_1 - \delta_2)) \ge 0$. Hence $q_u^* = \min(I_r, w_2/(2(\delta_1-\delta_2)))$. (ii) For $I_r \ge (\delta_1 - w_2)/(2\delta_2)$, or $w_2 \ge \delta_1 - 2I_r\delta_2$, the retailer has two choices for q_u: (1) If $q_u \le (\delta_1 - w_2)/(2\delta_2)$, then $q_n^* = (\delta_1 - w_2 - 2\delta_2 q_u)/(2\delta_1)$ and $q_u^* = \min((\delta_1 - w_2)/(2\delta_2), w_2/(2(\delta_1-\delta_2))) = (\delta_1 - w_2)/(2\delta_2)$. The last equality stems from the fact that $w_2 \ge \delta_1 - 2I_r\delta_2 \ge \delta_1 - \delta_2$. (2) If $(\delta_1 - w_2)/(2\delta_2) \le q_u \le I_r$, $q_n^* = 0$, which leads to the retailer's period 2 profit function being concave in q_u with an unconstrained optimal $q_u = 1/2 \ge I_r$. Hence $q_u^* = I_r$. Because choice (1) is a boundary solution of choice (2), we have $q_u^* = I_r$ when $w_2 \ge \delta_1 - 2I_r\delta_2$. Combining the analysis in cases (i) and (ii), we conclude

$q_n^* = (\delta_1 - w_2 - 2\delta_2 q_u^*)/(2\delta_1)$ and $q_u^* = w_2/(2(\delta_1 - \delta_2))$ for $w_2 \le 2I_r(\delta_1 - \delta_2)$.

$q_n^* = (\delta_1 - w_2 - 2\delta_2 q_u^*)/(2\delta_1)$ and $q_u^* = I_r$ for $2I_r(\delta_1-\delta_2) \le w_2 \le \delta_1 - 2I_r\delta_2$.

$q_n^* = 0$ and $q_u^* = I_r$ for $w_2 \ge \delta_1 - 2I_r\delta_2$.

(b) $I_r \ge 1/2$. Following the analysis procedure we used in case (a) above, we solve for (q_n^*, q_u^*): $q_n^* = (\delta_1 - w_2 - 2\delta_2 q_u^*)/(2\delta_1)$ and $q_u^* = w_2/(2(\delta_1-\delta_2))$ for $w_2 \le \delta_1 - \delta_2$, and $q_n^* = 0$ and $q_u^* = 1/2$ otherwise.

In stage 1 *of period* 2, we consider the manufacturer's best wholesale price, w_2, to maximize her profit in the second period, $\Pi_M^2 = w_2 q_n^*$. Again, two cases are studied with respect to I_r.

(a) $I_r \le 1/2$. Consider three choices as follows: (1) If $w_2 \le 2I_r(\delta_1 - \delta_2)$, $\Pi_M^2 = w_2(\delta_1 - w_2 - 2\delta_2 q_u^*)/(2\delta_1)$, where $q_u^* = w_2/(2(\delta_1-\delta_2))$. The profit function is concave in w_2 with the unconstrained optimal $w_2 = (\delta_1 - \delta_2)/2$. Hence $w_2^* = 2I_r(\delta_1-\delta_2)$ if $I_r \le 1/4$, and $w_2^* = (\delta_1-\delta_2)/2$ if $I_r \ge 1/4$. (2) If $2I_r(\delta_1 - \delta_2) \le w_2 \le \delta_1 - 2I_r\delta_2$, $\Pi_M^2 = w_2(\delta_1 - w_2 - 2\delta_2 I_r)/(2\delta_1)$, which is again concave in w_2 with the unconstrained optimal $w_2 = (\delta_1 - 2I_r\delta_2)/2$. Thus $w_2^* = 2I_r(\delta_1-\delta_2)$ if $I_r \ge \delta_1/(4\delta_1 - 2\delta_2)$, and $w_2^* = (\delta_1 - 2I_r\delta_2)/2$ if $I_r \le \delta_1/(4\delta_1 - 2\delta_2)$. (3) If $w_2 \ge \delta_1 - 2I_r\delta_2$, $\Pi_M^2 = 0$ because $q_n^* = 0$. Clearly, (3) is not optimal for the manufacturer. By comparing (1) and (2), we have $w_2^* = (\delta_1 - 2I_r\delta_2)/2$ if $I_r \le \bar{I}_r$, and $w_2^* = (\delta_1-\delta_2)/2$ if $I_r \ge \bar{I}_r$, where $\bar{I}_r$ makes the manufacturer indifferent between choices (1) and (2) at $w_2 = (\delta_1-\delta_2)/2$ and $w_2 = (\delta_1 - 2I_r\delta_2)/2$, respectively. Accordingly, one can easily solve for $\bar{I}_r = (\delta_1 - \sqrt{\delta_1(\delta_1-\delta_2)})/(2\delta_2) \in (1/4, \delta_1/(4\delta_1 - 2\delta_2))$.

(b) $I_r \ge 1/2$. Based on the retailer's best reaction functions in stage 2 of period 2, it is evident that it is not optimal for the manufacturer to choose $w_2 \ge \delta_1 - \delta_2$ because she will get a zero profit. Hence the manufacturer will set a w_2 so that $w_2 \le \delta_1 - \delta_2$, for which we have $q_n^* = (\delta_1 - w_2 - 2\delta_2 q_u^*)/(2\delta_1)$, where $q_u^* = w_2/(2(\delta_1-\delta_2))$. Accordingly, $\Pi_M^2 = w_2 q_n^*$ is concave in w_2 with the constrained optimal $w_2^* = (\delta_1-\delta_2)/2$.

Combining cases (a) and (b), we conclude that $w_2^* = (\delta_1 - 2I_r\delta_2)/2$, $q_u^* = I_r$, and $q_n^* = (\delta_1 - w_2 - 2\delta_2 q_u^*)/(2\delta_1)$ for $I_r \le \bar{I}_r$, and $w_2^* = (\delta_1-\delta_2)/2$, $q_u^* = 1/4$, and $q_n^* = 1/4$ for $I_r \ge \bar{I}_r$. Accordingly, we can calculate p_n^* and p_u^*.

In stage 3 *of period* 1, the retailer needs to set p_1 to maximize $\Pi_R = (p_1 - w_1)(1-p_1) + (p_n^* - w_2^*)q_n^* + p_u^* q_u^* - c(1-p_1)$. He has two choices for p_1. (1) If p_1 is set such that $I_r = (1-p_1) \le \bar{I}_r$, substituting the corresponding best reaction functions in period 2 into Π_R and simplifying yields a concave function in p_1 with the unconstrained optimal $p_1 = (4c\delta_1 + 4\delta_1 - 2\delta_2^2 + 5\delta_1\delta_2 + 4\delta_1 w_1)/(2(4\delta_1\delta_2 + 4\delta_1 - \delta_2^2))$. Hence

$$p_1^* = \max\left(1 - \bar{I}_r, \frac{4c\delta_1 + 4\delta_1 - 2\delta_2^2 + 5\delta_1\delta_2 + 4\delta_1 w_1}{2(4\delta_1\delta_2 + 4\delta_1 - \delta_2^2)}\right).$$

Thus $p_1^* = 1 - \bar{I}_r$ if

$$w_1 \le \frac{3\delta_1\delta_2 + 4\delta_1 - 4c\delta_1 - 2\bar{I}_r(4\delta_1\delta_2 + 4\delta_1 - \delta_2^2)}{4\delta_1},$$

and

$$p_1^* = \frac{4c\delta_1 + 4\delta_1 - 2\delta_2^2 + 5\delta_1\delta_2 + 4\delta_1 w_1}{2(4\delta_1\delta_2 + 4\delta_1 - \delta_2^2)}$$

otherwise. (2) If p_1 is set such that $I_r = (1-p_1) \ge \bar{I}_r$, substituting the corresponding best reaction functions in period 2 into Π_R and simplifying yields a concave function in p_1 with the unconstrained optimal $p_1 = (1+c+w_1)/2$. Hence $p_1^* = 1 - \bar{I}_r$ if $w_1 \ge 1 - c - 2\bar{I}_r$, and $p_1^* = (1+c+w_1)/2$ otherwise. Comparing choices (1) and (2), we have

$p_1^* = (1+c+w_1)/2$, $q_u^* = 1/4$, $q_n^* = 1/4$, and $w_2^* = (\delta_1-\delta_2)/2$ for $w_1 \le 1 - c - 2\bar{I}_r$;

$p_1^* = 1 - \bar{I}_r$, $q_u^* = 1/4$, $q_n^* = 1/4$, and $w_2^* = (\delta_1-\delta_2)/2$ for $w_1 \le (3\delta_1\delta_2 + 4\delta_1 - 4c\delta_1 - 2\bar{I}_r(4\delta_1\delta_2 + 4\delta_1 - \delta_2^2))/(4\delta_1)$; and

$p_1^* = (4c\delta_1 + 4\delta_1 - 2\delta_2^2 + 5\delta_1\delta_2 + 4\delta_1 w_1)/(2(4\delta_1\delta_2 + 4\delta_1 - \delta_2^2))$, $q_u^* = I_r^* = 1 - p_1^*$, $q_n^* = (\delta_1 - w_2^* - 2\delta_2 q_u^*)/(2\delta_1)$, and $w_2^* = (\delta_1 - 2I_r\delta_2)/2$ for $w_1 \ge (3\delta_1\delta_2 + 4\delta_1 - 4c\delta_1 - 2\bar{I}_r(4\delta_1\delta_2 + 4\delta_1 - \delta_2^2))/(4\delta_1)$.

In stage 2 *of period* 1, the manufacturer chooses her optimal w_1 to maximize $\Pi_M = \Pi_M^1 + \Pi_M^2 = -K(\delta_1^2 - 1)/2 +$

$w_1 \cdot q_1^* + w_2^* \cdot q_n^*$. Based on the analysis above, the manufacturer has three choices for w_1. (1) If $w_1 \le 1 - c - 2\bar{I}_r$, substituting the corresponding best decision variables in the subsequent stages into Π_M gives a concave function in w_1 with the unconstrained optimal $w_1 = (1-c)/2$, which is greater than $1 - c - 2\bar{I}_r$ because $\bar{I}_r > 1/4$. Hence $w_1^* = 1 - c - 2\bar{I}_r$. (2) If $1 - c - 2\bar{I}_r \le w_1 \le (3\delta_1\delta_2 + 4\delta_1 - 4c\delta_1 - 2\bar{I}_r(4\delta_1\delta_2 + 4\delta_1 - \delta_2^2))/(4\delta_1)$, substituting the corresponding best decision variables in the subsequent stages into Π_M results with a linear and increasing function in w_1. Thus $w_1^* = (3\delta_1\delta_2 + 4\delta_1 - 4c\delta_1 - 2\bar{I}_r(4\delta_1\delta_2 + 4\delta_1 - \delta_2^2))/(4\delta_1)$. (3) If $w_1 \ge (3\delta_1\delta_2 + 4\delta_1 - 4c\delta_1 - 2\bar{I}_r(4\delta_1\delta_2 + 4\delta_1 - \delta_2^2))/(4\delta_1)$, substituting the subsequent decision variables into Π_M leads to a concave function in w_1 with the unconstrained optimal

$$w_1 = \frac{16\delta_1 - 16c\delta_1 + 36\delta_2\delta_1 - 16c\delta_1\delta_2 - 12\delta_2^2 - 11\delta_2^3 + 20\delta_1\delta_2^2 + 12c\delta_2^2}{16(2\delta_2\delta_1 + 2\delta_1 - \delta_2^2)}.$$

This unconstrained optimal w_1 satisfies the constraint; thus

$$w_1^* = \frac{16\delta_1 - 16c\delta_1 + 36\delta_2\delta_1 - 16c\delta_1\delta_2 - 12\delta_2^2 - 11\delta_2^3 + 20\delta_1\delta_2^2 + 12c\delta_2^2}{16(2\delta_2\delta_1 + 2\delta_1 - \delta_2^2)}.$$

We note that w_1^* in choice (1) is on the boundary of choice (2), and w_1^* in choice (2) is on the boundary of choice (3). Hence, choice (3) is always optimal for the manufacturer, and

$$w_1^* = \frac{16\delta_1 - 16c\delta_1 + 36\delta_2\delta_1 - 16c\delta_1\delta_2 - 12\delta_2^2 - 11\delta_2^3 + 20\delta_1\delta_2^2 + 12c\delta_2^2}{16(2\delta_2\delta_1 + 2\delta_1 - \delta_2^2)},$$

$p_1^* = (4c\delta_1 + 4\delta_1 - 2\delta_2^2 + 5\delta_1\delta_2 + 4\delta_1 w_1^*)/(2(4\delta_1\delta_2 + 4\delta_1 - \delta_2^2))$, $q_u^* = I_r^* = 1 - p_1^*$, $q_n^* = (\delta_1 - w_2^* - 2\delta_2 q_u^*)/(2\delta_1)$, and $w_2^* = (\delta_1 - 2I_r^*\delta_2)/2$. Next, we are ready to solve for the manufacturer's equilibrium product upgrade strategy in stage 1 of period 1.

In stage 1 *of period* 1, the manufacturer's profit is

$$\Pi_M = -\frac{K}{2}(\delta_1^2 - 1) + w_1^* \cdot q_1^* + w_2^* \cdot q_n^* - \frac{K}{2}(\delta_1^2 - 1),$$
$$+ \frac{\delta_1(16\delta_2\delta_1 + 16\delta_1 - 7\delta_2^2 - 8c\delta_2 + 8\delta_2 - 32c + 16c^2 + 16)}{64(2\delta_2\delta_1 + 2\delta_1 - \delta_2^2)}.$$

Now the manufacturer needs to compare $\Pi_M(\delta_1 = 1 + a)$ and $\Pi_M(\delta_1 = 1)$ to determine the equilibrium value of δ_1. Clearly, $\Pi_M(\delta_1 = 1 + a)$ decreases linearly in K, and the manufacturer prefers $\delta_1 = 1 + a$ over $\delta_1 = 1$ if $K < K_b$, prefers $\delta_1 = 1$ over $\delta_1 = 1 + a$ if $K > K_b$, and is indifferent between the two if $K = K_b$, where K_b satisfies $\Pi_M(\delta_1 = 1) = \Pi_M(\delta_1 = 1 + a)$; i.e.,

$$K_b = \frac{32(1+a) + 64\delta_2(1+a) - 16\delta_2^2((1-c)^2 - a) - 8\delta_2^3(5 + 2a - c) + 7\delta_2^4}{32(2 + 2a + 2\delta_2 + 2\delta_2 a - \delta_2^2)(2 + 2\delta_2 - \delta_2^2)(a+2)}.$$

□

Proof of Proposition 1. Based on Table 1,

$$K_0 - K_b = \frac{\delta_2^2(4c - \delta_2 - 4)^2}{32(2\delta_2 + 2\delta_2 a - \delta_2^2 + 2 + 2a)(2 + 2\delta_2 - \delta_2^2)(a+2)} \ge 0.$$

It is also straightforward to show that $K_0 - K_b$ decreases in a. □

Proof of Proposition 2. Recall that the equilibrium decisions in the models with and without a retail used goods market are displayed in Table 1. Let δ_1^* be the equilibrium product strategy in the model with a retail used goods market. We use a superscript "0" for equilibrium values in the base model without any used goods and "b" for equilibrium values in the retail used goods market scenario. For the difference in the equilibrium values of p_1^*, we have $p_1^0 - p_1^b = -(3\delta_2\delta_1^* - 2\delta_2^2 + 4c\delta_1^*)/(8(2\delta_2\delta_1^*\delta_2^2 + 2\delta_1^*))$, and it can be shown to be negative. Thus, $p_1^0 \le p_1^b$. For the difference in p_n^*, we have

$$p_n^0 - p_n^b \ge \frac{\delta_1^*\delta_2(4 + \delta_2 - 4c)}{16(2\delta_2\delta_1^* - \delta_2^2 + 2\delta_1^*)} \ge 0,$$

where the first inequality is due to $\delta_1^0 \ge \delta_1^b$ by Proposition 1. □

Analysis of the Scenario with Only P2P Used Goods Market. The procedure for the derivation of the equilibrium decisions and profits in the P2P-only model is similar to that of the retail used goods market model in §4.1. Thus the details are omitted here. The equilibrium decisions and profits are presented in Table 1.

Proof of Proposition 3. The differences between equilibrium decisions in the base and P2P models can be established in the same way as those in the proofs of Propositions 1 and 2. Thus the details are omitted here. In this proof, we only discuss the differences in equilibrium profits for the channel partners. We can prove that both players perform better in the base model, as long as we can show that their profits are higher in the base model than those at the optimal product strategy level in the P2P model. Let δ_1^* be the optimal product strategy in the P2P model. For the manufacturer's profit, we have $\Pi_M^*(base) - \Pi_M^*(\text{P2P}) \ge (\delta_3(48\delta_1^* - 8\delta_3 - 9\delta_3\delta_1^*))/(64(8\delta_1^* - \delta_3^2)) \ge 0$. For the retailer's profit, we have

$$\Pi_R^*(base) - \Pi_R^*(\text{P2P})$$
$$\ge \frac{\delta_3(768(\delta_1^*)^2 - 192\delta_3\delta_1^* + 16\delta_3^3 - 144\delta_3(\delta_1^*)^2 + 9\delta_1^*\delta_3^3 - 48\delta_1^*\delta_3^2)}{256(8\delta_1^* - \delta_3^2)^2} \ge 0.$$

Therefore, both channel players are better off under the base case relative to the P2P model. □

Proof of Proposition 4. Recall that K_b and K_e are given in Table 1. From the expressions there, we have

$$\frac{\partial(K_e - K_b)}{\partial c}$$
$$= -\frac{\delta_2^2(4 + \delta_2 - 4c)}{4(2\delta_2 + 2\delta_2 a - \delta_2^2 + 2 + 2a)(2 + 2\delta_2 - \delta_2^2)(a+2)} \le 0.$$

Thus $K_e - K_b$ decreases in c. Because $c \le \delta_3/2$, we need to show that the difference at $c = \delta_3/2$ is positive, which can be expressed in the following format:

$$K_e - K_b$$
$$= \frac{-2f_1(\delta_2^2\delta_3^2 - 4\delta_3\delta_2^2 + 4\delta_2^2 + 16\delta_2 + 8\delta_3 - 5\delta_3^2\delta_2 - 3\delta_3^2 + \delta_3^3\delta_2) + f_2 \cdot a}{16((8 + 8a - \delta_3^2)(8 - \delta_3^2)(a+2)(2\delta_2 + 2\delta_2 a - \delta_2^2 + 2 + 2a)(2 + 2\delta_2 - \delta_2^2))},$$

where $f_1 = 2\delta_2^2\delta_3^2 - 4\delta_3\delta_2^2 - 4\delta_2^2 - 16\delta_2 + 16\delta_3\delta_2 + 8\delta_3 - \delta_3^2\delta_2 - 3\delta_3^2 - \delta_3^3\delta_2$ and

$$f_2 = 25\delta_3^4\delta_2^2 + 4\delta_3^2\delta_2^4 - 32\delta_3^2\delta_2^3 + 32\delta_3^3\delta_2^3 - 112\delta_3^3\delta_2^2 - 192\delta_3^3\delta_2$$
$$+ 36\delta_3^4\delta_2 + 256\delta_3^2\delta_2 + 128\delta_3\delta_2^3 - 512\delta_2^2 - 256\delta_2^3 + 512\delta_3\delta_2^2$$
$$+ 18\delta_3^4 - 96\delta_3^3 - 32\delta_2^4 - 9\delta_3^4\delta_2^3 + 128\delta_3^2.$$

To show that $K_e - K_b \geq 0$, it is sufficient to show that $f_1 \leq 0$ and $f_2 \leq 0$. Because f_1 decreases in δ_2 and it is negative when $\delta_2 \to \delta_3$ from above, it is always negative. Note that we have $\partial(f_2)^3/\partial^3\delta_3 \leq 0$. Thus $\partial(f_2)^2/\partial^2\delta_3$ decreases in δ_3. Because $\partial(f_2)^2/\partial^2\delta_3(\delta_3=0) \geq 0$ and $\partial(f_2)^2/\partial^2\delta_3(\delta_3=\delta_2)$ is either positive or negative, we conclude that $\partial(f_2)^2/\partial^2\delta_3$ is always positive or it is first positive and then negative when δ_3 increases. We also know that $(\partial f_2/\partial\delta_3)(\delta_3=0) \geq 0$ and $(\partial f_2/\partial \delta_3)\cdot(\delta_3=\delta_2) \geq 0$. Hence $\partial f_2/\partial\delta_3 \geq 0$ and f_2 increases in δ_3 with $f_2(\delta_3=\delta_2)=\delta_2^2(3-\delta_2)(9\delta_2^4-34\delta_2^3+6\delta_2^2+96\delta_2-128) \leq 0$. Therefore, both $f_1 \leq 0$ and $f_2 \leq 0$, and thus $K_e - K_b \geq 0$. □

Analysis of the Scenario with Both Used Goods Markets. The analysis procedure for deriving equilibrium decisions and profits in this case is analogous to that of the model with only retail used goods market. We only provide a sketch of the proof here.

In stage 2 *of period* 2, the retailer sets (q_n, q_u) to maximize $\Pi_R^2=(p_n-w_2)q_n+p_uq_u-cI_r'$, subject to $q_u \leq I_r'$ and $q_u, q_n \geq 0$, where $I_r'=r(1-p_1)$, $p_n=\delta_1(1-q_n)-\delta_2q_u-\delta_3q_e$, $p_u=\delta_2(1-q_n-q_u)-\delta_3q_e$, and $q_e=(1-r)(1-p_1)$. Π_R^2 is jointly concave in (q_u, q_n) and the optimal values are given in the following two cases: (a) For $I_r' \leq 1/2-\delta_3q_e/(2\delta_2)$, $q_n^*=(\delta_1-w_2-2\delta_2q_u^*-\delta_3q_e)/(2\delta_1)$, and $q_u^*=w_2/(2(\delta_1-\delta_2))-\delta_3q_e/(2\delta_2)$ for $w_2 \leq 2I_r'(\delta_1-\delta_2)+((\delta_1-\delta_2)\delta_3q_e)/\delta_2$; and $q_n^*=(\delta_1-w_2-2\delta_2q_u^*-\delta_3q_e)/(2\delta_1)$ and $q_u^*=I_r'$ for $2I_r'(\delta_1-\delta_2)+((\delta_1-\delta_2)\delta_3q_e)/\delta_2 \leq w_2 \leq \delta_1-2I_r'\delta_2-\delta_3q_e$; and $q_n^*=0$ and $q_u^*=I_r'$ otherwise. (b) For $I_r' \geq 1/2-\delta_3q_e/(2\delta_2)$, $q_n^*=(\delta_1-w_2-2\delta_2q_u^*-\delta_3q_e)/(2\delta_1)$, and $q_u^*=w_2/(2(\delta_1-\delta_2))-\delta_3q_e/(2\delta_2)$ for $w_2 \leq \delta_1-\delta_2$; and $q_n^*=0$ and $q_u^*=1/2-\delta_3q_e/(2\delta_2)$ otherwise.

In stage 1 *of period* 2, the manufacturer sets w_2 to maximize $\Pi_M^2=w_2q_n^*$. We can derive $w_2^*=(\delta_1-2I_r'\delta_2-\delta_3q_e)/2$, $q_u^*=I_r'$, and $q_n^*=(\delta_1-w_2-2\delta_2q_u^*-\delta_3q_e)/2\delta_1$ for $I_r' \leq \bar{I}_r'$; and $w_2^*=(\delta_1-\delta_2)/2$, $q_u^*=1/4-\delta_3q_e/(2\delta_2)$ and $q_n^*=1/4$ otherwise, where $\bar{I}_r'=(\delta_1-\sqrt{\delta_1(\delta_1-\delta_2)})/(2\delta_2)-\delta_3q_e/(2\delta_2) \in (1/4-\delta_3q_e/(2\delta_2), \delta_1/(4\delta_1-2\delta_2)-\delta_3q_e/(2\delta_2))$.

In stage 3 *of period* 1, the retailer needs to set p_1 to maximize $\Pi_R=(p_1-w_1)(1-p_1)+(p_n^*-w_2^*)q_n^*+p_u^*q_u^*-cr(1-p_1)$. The retailer has two choices on p_1: (1) p_1 is set such that $I_r'=r(1-p_1) \leq \bar{I}_r'$ (which is equivalent to $p_1 \geq 1-(\delta_1-\sqrt{\delta_1(\delta_1-\delta_2)})/(2\delta_2r+(1-r)\delta_3)$) and (2) p_1 is set such that $I_r'=r(1-p_1) \geq \bar{I}_r'$ (which is equivalent to $p_1 \leq 1-(\delta_1-\sqrt{\delta_1(\delta_1-\delta_2)})/(2\delta_2r+(1-r)\delta_3)$). Let w_{11} be the unique solution to $1-(\delta_1-\sqrt{\delta_1(\delta_1-\delta_2)})/(2\delta_2r+(1-r)\delta_3)=p_{11}$, where

$$p_{11}=\big(\delta_1(8-6r\delta_2+8cr-16r^2\delta_3+16r^2\delta_2+8w_1+\delta_3+15\delta_3r)-(2r\delta_2+\delta_3-\delta_3r)^2\big)\cdot\big(16\delta_1(-r^2\delta_3+\delta_3r+r^2\delta_2+1)-(2r\delta_2+\delta_3-\delta_3r)^2\big)^{-1}$$

and

$$w_{12}=1-cr-2\frac{\delta_1-\sqrt{\delta_1(\delta_1-\delta_2)}}{2\delta_2r+(1-r)\delta_3}.$$

Analyzing and comparing options (1) and (2) results with the optimal p_1 in stage 3 of period 1,

When $w_{11} \leq w_{12}$, there exists a unique $\bar{w}_1 \in (w_{11}, w_{12})$ that makes the retailer indifferent between choosing $p_1^*=p_{11}$ and $p_1^*=(1+cr+w_1)/2$. Note that $\bar{w}_1$ is a function of model parameters and δ_1 only. For $w_1 \leq \bar{w}_1$, $p_1^*=(1+cr+w_1)/2$, $I_r' \geq \bar{I}_r'$, $w_2^*=(\delta_1-\delta_2)/2$, $q_u^*=1/4-\delta_1q_e^*/(2\delta_2)$, and $q_n^*=1/4$; and for $w_1 \geq \bar{w}_1$, $p_1^*=p_{11}$, $I_r'=\bar{I}_r'$, $w_2^*=(\delta_1-2I_r'\delta_2-\delta_3q_e^*)/2$, $q_u^*=I_r'$, $q_e^*=(1-r)(1-p_1^*)$, and $q_n^*=(\delta_1-w_2^*-2\delta_2q_u^*-\delta_3q_e^*)/(2\delta_1)$.

When $w_{11} \geq w_{12}$, for $w_1 \leq w_{12}$, $p_1^*=(1+cr+w_1)/2$, $I_r' \geq \bar{I}_r'$, $w_2^*=(\delta_1-\delta_2)/2$, $q_u^*=1/4-\delta_1q_e^*/(2\delta_2)$, and $q_n^*=1/4$; for $w_{12} \leq w_1 \leq w_{11}$, $p_1^*=1-(\delta_1-\sqrt{\delta_1(\delta_1-\delta_2)})/(2\delta_2r+(1-r)\delta_3)$, $w_2^*=(\delta_1-\delta_2)/2$, $q_u^*=1/4-\delta_1q_e^*/2\delta_2$, and $q_n^*=1/4$; and for $w_1 \geq w_{11}$, $p_1^*=p_{11}$, $I_r'=\bar{I}_r'$, $w_2^*=(\delta_1-2I_r'\delta_2-\delta_3q_e^*)/2$, $q_u^*=I_r'$, $q_e^*=(1-r)(1-p_1^*)$, and $q_n^*=(\delta_1-w_2^*-2\delta_2q_u^*-\delta_3q_e^*)/2\delta_1$.

In stage 2 *of period* 1, the manufacturer chooses w_1 to maximize $\Pi_M=-K(\delta_1^2-1)/2+w_1\cdot q_1^*+w_2^*\cdot q_n^*$. Analyzing cases when $w_{11} \leq w_{12}$ and when $w_{11} \geq w_{12}$ generates the best reaction functions of all decisions but δ_1,

$$w_1^* = \big((2r\delta_2+\delta_3-\delta_3r)^2(-22r\delta_2+24cr-\delta_3r-24+\delta_3)+16(\delta_3r+1-r^2\delta_3+r^2\delta_2)\delta_1(8+10r\delta_2-8cr-\delta_3r+\delta_3)\big)\cdot\big(32(8\delta_1(\delta_3r+1-r^2\delta_3+r^2\delta_2)-(2r\delta_2+\delta_3-\delta_3r)^2)\big)^{-1},$$

$p_1^*=p_{11}(w_1=w_1^*)$, $I_r'=\bar{I}_r'$, $w_2^*=(\delta_1-2I_r'\delta_2-\delta_3q_e^*)/2$, $q_u^*=I_r'$, $q_e^*=(1-r)(1-p_1^*)$, and $q_n^*=(\delta_1-w_2^*-2\delta_2q_u^*-\delta_3q_e^*)/(2\delta_1)$.

In stage 1 *of period* 1, the manufacturer's total profit over two periods becomes $\Pi_M=K/2(\delta_1^2-1)+w_1^*(1-p_1^*)+w_2^*q_n^*$. Substituting w_1^* and the subsequent decisions into Π_M, the manufacturer needs to compare her profit at $\delta=1+a$ and at $\delta_1=1$. Note that $\Pi_M(\delta_1=1+a)$ is a linear increasing function of K and $\Pi_M(\delta_1=1)$ is independent of K. Thus there exists a unique value of K, denoted by K_{be}, such that $\Pi_M(\delta_1=1+a)=\Pi_M(\delta_1=1)$ for $K=K_{be}$, $\Pi_M(\delta_1=1+a) > \Pi_M(\delta_1=1)$ for $K < K_{be}$, and $\Pi_M(\delta_1=1+a) < \Pi_M(\delta_1=1)$ for $K > K_{be}$. Thus K_{be} is the indifference point for the manufacturer to choose $\delta_1^*=1+a$ or $\delta_1^*=1$, and it has the form of $K_{be}=(2(\bar{\Pi}_M(\delta_1=1+a)-\bar{\Pi}_M(\delta_1=1)))/(a(2+a))$, where $\bar{\Pi}_M=w_1^*(1-p_1^*)+w_2^*q_n^*$. Substituting w_1^* and the subsequent decisions into this expression, we have

$$\bar{\Pi}_M = \big(\delta_1(64(\delta_1+(1-cr)^2)+32r\delta_2(1-cr+2r\delta_1)-28r^2\delta_2^2+4\delta_3(1-r)(16r\delta_1+12cr-11r\delta_2-12)+\delta_3^2(1-r)^2)\big)\cdot\big(64(8\delta_1+8\delta_1r^2\delta_2-4r^2\delta_2^2-4\delta_3r(r-1)\cdot(2\delta_1-\delta_2)-\delta_3^2(1-r)^2)\big)^{-1}. \quad \square$$

Appendix B. Numerical Study to Compare the Retail Used Goods Market Model and the Model with Both Used Goods Markets

In §5.1, the large number of model parameters involved (i.e., a, δ_2, δ_3, c, and r) makes examining the property of K_{be} rather cumbersome. Thus we resort to a numerical study and compute values of K_{be}. Our parameter set are as follows: $a \in \{0.1, 0.3, 0.5, 0.7, 1.0\}$, $\delta_3 \in \{0.009, 0.150, 0.450, 0.750, 0.900\}$, $\delta_2 \in \{0.01, 0.20, 0.50, 0.80, 0.99\}$ because $\delta_2 \geq \delta_3$ and $r \in \{0.01, 0.20, 0.50, 0.80, 0.99\}$. For the residual value of used products c typically it is much lower than the highest valuation of consumers who are interested in buying these used products. Based on the assumption $c \leq \delta_3/2$, we consider c as a proportion of δ_3, where the proportion takes values $\{0.1, 0.2, 0.3, 0.4, 0.5\}$. Thus, given $\delta_3 \leq \delta_2$, there are 1,875 cases in our numerical study for K_{be}.

Based on K_b and K_{be} expressions from Table 1, Table B.1 shows some illustrative examples for the difference between

Table B.1 **Illustrative Examples of $K_{be} - K_b$ Assuming $c = (0.5)(0.009) = 0.0045$**

	$a = 0.1$				$a = 0.5$			
	$r = 0.2$		$r = 0.8$		$r = 0.2$		$r = 0.8$	
	$\delta_2 = 0.2$	$\delta_2 = 0.8$	$\delta_2 = 0.2$	$\delta_2 = 0.8$	$\delta_2 = 0.2$	$\delta_2 = 0.8$	$\delta_2 = 0.2$	$\delta_2 = 0.8$
$\delta_3 = 0.009$	0.0016	0.0207	0.0005	0.0051	0.0010	0.0121	0.0003	0.0028
$\delta_3 = 0.150$	0.0012	0.0197	0.0004	0.0050	0.0007	0.0115	0.0002	0.0028
$\delta_3 = 0.450$	—	0.0175	—	0.0049	—	0.0102	—	0.0028
$\delta_3 = 0.750$	—	0.0153	—	0.0048	—	0.0089	—	0.0027

Table B.2 **Illustrative Examples of the Effects of Introduction of a P2P Market into a Retail Used Goods Market Model on Prices and Profits Assuming $a = 0.5$, $\delta_2 = 0.8$, $r = 0.8$, and $c = 0.0045$**

	K						
	0.0600	0.0700	0.0800	0.0900	0.1000	0.1100	0.1200
Increase in retail price of unused products							
$\delta_3 = 0.009$	0.0294	0.0294	0.0294	0.0287	0.0287	0.0287	0.0287
$\delta_3 = 0.150$	0.0221	0.0221	0.0221	0.0213	0.0213	0.0213	0.0213
$\delta_3 = 0.450$	0.0074	0.0074	0.0074	0.0062	0.0062	0.0062	0.0062
$\delta_3 = 0.750$	−0.0062	−0.0062	−0.0062	−0.0078	−0.0078	−0.0078	−0.0078
Manufacturer's profit							
$\delta_3 = 0.009$	0.0087	0.0087	0.0087	0.0069	0.0069	0.0069	0.0069
$\delta_3 = 0.150$	0.0051	0.0051	0.0051	0.0033	0.0033	0.0033	0.0033
$\delta_3 = 0.450$	−0.0022	−0.0022	−0.0022	−0.0040	−0.0040	−0.0040	−0.0040
$\delta_3 = 0.750$	−0.0091	−0.0091	−0.0091	−0.0108	−0.0108	−0.0108	−0.0108
Retailer's profit							
$\delta_3 = 0.009$	0.0036	0.0036	0.0036	0.0020	0.0020	0.0020	0.0020
$\delta_3 = 0.150$	0.0018	0.0018	0.0018	0.0002	0.0002	0.0002	0.0002
$\delta_3 = 0.450$	−0.0019	−0.0019	−0.0019	−0.0034	−0.0034	−0.0034	−0.0034
$\delta_3 = 0.750$	−0.0053	−0.0053	−0.0053	−0.0068	−0.0068	−0.0068	−0.0068

K_{be} and K_b. Table B.1 suggests that $K_{be} \geq K_b$. This inequality holds for all 1,875 parameter combinations considered in this study. Thus one can conclude that emergence of the P2P used goods market as a second source of used goods (i.e., in a setting where a retail used goods market already exists) stimulates new version releases. Note also from the following table that $(K_{be} - K_b)$ decreases in δ_3 (we observed this throughout our numerical experiments).

Table B.2 presents the difference in the equilibrium temporal price increase of unused products over two periods (i.e., $(p_n^* - p_1^*)$) in models with and without a P2P market. Here, we assume $K \in [0.06, 0.12]$, where the upper bound $K = 0.12$ is based on the threshold value K_0 in the base model above which there will be no new version releases. From this table, one can observe that the price increase is higher under the model with both used goods markets than under the retail used goods market model except when δ_3 (and accordingly δ_2) is relatively large. Furthermore, the difference between price increase decreases in δ_3. That means that when the P2P market becomes stronger, its effect on increasing the price increase over time is reduced compared with the case when there is no such a market. Finally, Table B.2 also gives some examples on the difference in channel members' profits in the model with both used goods markets and the retail used goods market model. From this table, we observe that the difference in profits for both channel members decreases in δ_3, and the introduction of a P2P market into the retail used goods market model can benefit both the manufacturer and the retailer when δ_3 is very small.

Appendix C. Forward-Looking Consumers

In this appendix, we solve for equilibrium solutions in all four models with forward-looking consumers. The analysis process is the same as that in the myopic consumers case in §§4 and 5, except that the demand function in period 1 is now modified to take into account the future payoffs. Note that in all models considered, the manufacturer's product upgrade strategy follows a threshold policy. That is, when the cost of product upgrade K is below a certain level, she would release a new version; i.e., $\delta_1^* = 1 + a$. Otherwise, she would keep the existing version; i.e., $\delta_1^* = 1$. Except for the model with both used goods markets, we can derive the equilibrium decisions and profits for the other three models; these values are summarized in Table C.1 without giving a detailed analysis. For the both used goods model, the full analysis is cumbersome, so a numerical analysis is required to solve the last two stages of the game.

Taking the same values for model parameters as those in the myopic consumers case, we conduct a numerical study to compare all four models with forward-looking consumers. For space consideration, we do not present the numbers here and the observations are summarized in Table 4.

Table C.1 Equilibrium Decisions and Profits in Models with Forward-Looking Consumers

No used goods market model

Threshold value of K: $K_0 = \dfrac{1}{4(2+a)}$.

Period 1 decisions: $w_1^* = \frac{1}{2}(1+c)$, $p_1^* = \frac{3}{4}(1+c)$, and $q_1^* = \frac{1}{4}(1+c)$.

Period 2 decisions: $w_2^* = \dfrac{\delta_1^*}{2}$, $p_n^* = \dfrac{3\delta_1^*}{4}$, and $q_n^* = \dfrac{1}{4}$.

Profits: $\Pi_M^* = w_1^* q_1^* + w_2^* q_n^* - \dfrac{K}{2}((\delta_1^*)^2 - 1)$ and $\Pi_R^* = (p_1^* - w_1^*)q_1^* + (p_n^* - w_2^*)q_n^*$.

Only retail used goods market model

Threshold value of K: $K_b = \dfrac{-64\delta_2 - 32 + 16\delta_2^2 - 64\delta_2 a - 32a - 16\delta_2^2 a + 40\delta_2^3 - 7\delta_2^4 + 16\delta_2^3 a}{32((2\delta_2 + 2\delta_2 a + 2 + 2a - \delta_2^2)(-2\delta_2 - 2 + \delta_2^2)(a+2))}$.

Period 1 decisions: $w_1^* = \dfrac{36\delta_2\delta_1^* - 11\delta_2^3 + 20\delta_1^*\delta_2^2 + 16\delta_1^* - 12\delta_2^2}{16(2\delta_2\delta_1^* + 2\delta_1^* - \delta_2^2)}$, $p_1^* = \dfrac{(8\delta_2 c\delta_1^* + 5\delta_2\delta_1^* + 8c\delta_1^* + 4w_1^*\delta_1^* - 2\delta_2^2 + 4\delta_1^* - 2c\delta_2^2)}{2(4\delta_2\delta_1^* + 4\delta_1^* - \delta_2^2)}$, and $q_1^* = 1 - (p_1^* - c)$.

Period 2 decisions: $w_2^* = \dfrac{\delta_1^*}{2} - \delta_2 c - \delta_2 + p_1^*\delta_2$, $p_n^* = \dfrac{1}{2}(\delta_1^* + w_2^*)$, $p_u^* = \dfrac{(p_n^* - c\delta_1^* + \delta_2 c - \delta_1^* + \delta_2 + p_1^*\delta_1^* - p_1^*\delta_2)\delta_2}{\delta_1^*}$, $q_n^* = 1 - \dfrac{p_n^* - pu^*}{\delta_1^* - \delta_2}$ and $q_u^* = 1 - p_1^*$.

Profits: $\Pi_M^* = w_1^* q_1^* + w_2^* q_n^* - \dfrac{K}{2}((\delta_1^*)^2 - 1)$ and $\Pi_R^* = (p_1^* - w_1^*)q_1^* + (p_n^* - w_2^*)q_n^* + p_u^* q_u^* - cq_1^*$.

Only P2P used goods market model

Threshold value of K: $K_e = \dfrac{2(\hat{\Pi}_M(\delta_1 = 1+a) - \hat{\Pi}_M(\delta_1 = 1))}{a(2+a)}$, where

$$\hat{\Pi}_M = ((1+\delta_3)(81\delta_3^8 - 270\delta_3^7\delta_1 - \delta_3^6\delta_1(432 + 109\delta_1) + \delta_3^5\delta_1^2(524\delta_1 + 1{,}116) - \delta_3^4\delta_1^2(244\delta_1 - 700\delta_1^2 + 864) - \delta_3^3\delta_1^3(1{,}208\delta_1 + 256\delta_1^2 - 1{,}536) - \delta_3^2\delta_1^3(768 - 60\delta_1 + 768\delta_1^2)$$
$$+\delta_3\delta_1^4(704 + 768\delta_1) + 256\delta_1^4(\delta_1 + 1))) \cdot (16((\delta_1 + \delta_3\delta_1 - \delta_3^2)(-7\delta_3^2 + 8\delta_1 + 8\delta_3\delta_1)(-3\delta_3^2 + 4\delta_1 + 4\delta_3\delta_1)^2))^{-1}.$$

Period 1 decisions: $w_1^* = \dfrac{(-135\delta_3^6 + 481\delta_1^*\delta_3^5 - 570\delta_3^4(\delta_1^*)^2 + 504\delta_3^4\delta_1^* - 1{,}194\delta_3^3(\delta_1^*)^2 + 224\delta_3^3(\delta_1^*)^3 + 704\delta_3^2(\delta_1^*)^3 - 624\delta_3^2(\delta_1^*)^2 + 736\delta_3(\delta_1^*)^3 + 256(\delta_1^*)^3)(1+\delta_3)}{4((-7\delta_3^2 + 8\delta_1^* + 8\delta_3\delta_1^*)(-3\delta_3^2 + 4\delta_1^* + 4\delta_3\delta_1^*)^2)}$

$p_1^* = \dfrac{15\delta_3\delta_1^* + 8\delta_1^* - 6w_1^*\delta_3^2 + 8w_1^*\delta_1^* + 8w_1^*\delta_3\delta_1^* - 7\delta_3^2 + 7\delta_3^2\delta_1^* - 7\delta_3^3}{16\delta_3\delta_1^* - 13\delta_3^2 + 16\delta_1^*}$, $p_e^* = \dfrac{(p_n^* - \delta_1^* + \delta_3 + p_1^*\delta_1^* - p_1^*\delta_3)\delta_3}{(\delta_1^* + \delta_3\delta_1^* - \delta_3^2)}$, and $q_1^* = 1 - (p_1^* - p_e^*)$.

Period 2 decisions: $w_2^* = \dfrac{(\delta_1^* + \delta_3\delta_1^* - \delta_3^2 + p_1\delta_3 - \delta_3)}{2(1+\delta_3)}$, $p_n^* = \dfrac{(w_2^* + w_2^*\delta_3 + \delta_1^* + \delta_3\delta_1^* - \delta_3^2 - \delta_3 + p_1^*\delta_3)}{2(1+\delta_3)}$, and $q_n^* = \dfrac{(\delta_1^* + \delta_3\delta_1^* - \delta_3 p_n^* - \delta_3 + p_1^*\delta_3 - p_n^* - \delta_3^2)}{(\delta_1^* + \delta_3\delta_1^* - \delta_3^2)}$.

Profits: $\Pi_M^* = w_1^* q_1^* + w_2^* q_n^* - \dfrac{K}{2}((\delta_1^*)^2 - 1)$, and $\Pi_R^* = (p_1^* - w_1^*)q_1^* + (p_n^* - w_2^*)q_n^*$.

Both used goods markets model

The model involves a two-period problem with five stages. Because it cannot be solved analytically, a numerical search is conducted to solve for the optimal w_1^* and δ_1^* in the first two stages of the game. Details are provided in this appendix.

Proof of Proposition 5. Recall from Table C.1 that

$$K_b = \frac{32 + 32a + 64\delta_2 + 16\delta_2^2 a - 40\delta_2^3 - 16\delta_2^2 + 7\delta_2^4 + 64\delta_2 a - 16\delta_2^3 a}{32(-\delta_2^2 + 2 + 2a + 2\delta_2 + 2\delta_2 a)(2 + 2\delta_2 - \delta_2^2)(2+a)}$$

and $K_0 = 1/(4(2+a))$. Hence

$$K_0 - K_b = \frac{\delta_2^2(\delta_2 + 4)^2}{32(-\delta_2^2 + 2 + 2a + 2\delta_2 + 2\delta_2 a)(2 + 2\delta_2 - \delta_2^2)(2+a)},$$

which can be shown to be nonnegative, and so $\delta_1^0 \geq \delta_1^b$.

Recall again from Table C.1 that $p_1^0 = (3+3c)/4$ and $p_n^0 = 3\delta_1^0/4$, where δ_1^0 is the manufacturer's optimal product upgrade strategy in the scenario with no used goods. Hence $p_n^0 - p_1^0 = (3\delta_1^0 - (3+3c))/4$. From Table C.1,

$$p_1^b = \frac{16\delta_2 c\delta_1^b + 15\delta_2\delta_1^b + 16c\delta_1^b + 12\delta_1^b - 8\delta_2^2 - 8c\delta_2^2}{8(2\delta_2\delta_1^b + 2\delta_1^b - \delta_2^2)}$$

and

$$p_n^b = \frac{(24\delta_2\delta_1^b + 24\delta_1^b - 13\delta_2^2 - 4\delta_2)\delta_1^b}{8(2\delta_2\delta_1^b + 2\delta_1^b - \delta_2^2)},$$

where δ_1^b is the manufacturer's optimal product upgrade strategy in the scenario with retail used goods. Hence

$$\begin{aligned} p_n^b - p_1^b &= (24\delta_2(\delta_1^b)^2 + 24(\delta_1^b)^2 + 16\delta_2^2 + 16c\delta_2^2 - 13\delta_1^b\delta_2^2 \\ &\quad - 34\delta_2\delta_1^b - 32\delta_2 c\delta_1^b - 32c\delta_1^b - 24\delta_1^b) \\ &\quad \cdot (16(2\delta_2\delta_1^b + 2\delta_1^b - \delta_2^2))^{-1}. \end{aligned}$$

It is shown that $\delta_1^0 \geq \delta_1^b$, and further, $p_n^0 - p_1^0 = (3\delta_1^0 - (3+3c))/4 \geq (3\delta_1^b - (3+3c))/4$. Next, we would like to show that $(3\delta_1^b - (3+3c))/4 \geq p_n^b - p_1^b$, which can be rewritten as

$$\begin{aligned} &\frac{3\delta_1^b - (3+3c)}{4} - (p_n^b - p_1^b) \\ &\quad = \frac{\delta_1^b\delta_2^2 + 10\delta_2\delta_1^b + 8\delta_2 c\delta_1^b + 8c\delta_1^b - 4\delta_2^2 - 4c\delta_2^2}{16(2\delta_2\delta_1^b + 2\delta_1^b - \delta_2^2)} \geq 0 \end{aligned}$$

and $(p_n^0 - p_1^0) \geq (p_n^b - p_1^b)$. □

Appendix D. Endogenous Product Upgrade Quality

Proof of Proposition 6. In the scenario without any used goods, based on the analysis in §4.1, one can easily derive the optimal value of product upgrade: $\delta_1^* = \max(1/8K, 1)$. In all other three scenarios, the manufacturer sets δ_1 to maximize $\Pi_M^i = -(K/2)(\delta_1^2 - 2) + \hat{\Pi}_M^i$, where $\hat{\Pi}_M^i = w_1(1 - p_1^*) + w_2^* q_n^*$ and $i \in \{b, e, be\}$ represents three different models. Substituting w_1^*, p_1^*, w_2^*, and q_n^* from Table 1 into the corresponding model, we can show that $\partial\hat{\Pi}_M^i/(\partial\delta_1)$ is concave in δ_1, and thus $\partial\Pi_M^i/(\partial\delta_1)$ is concave in δ_1. This implies that there are only two real solutions to $\partial\Pi_M^i/(\partial\delta_1) = 0$. We denote the left root by $\delta_1^l(i)$ and the right root by $\delta_1^r(i)$. The concavity of $\partial\Pi_M^i/(\partial\delta_1)$ also implies that the manufacturer's profit function either (1) first decreases and then increases and then decreases again in $\delta_1 \geq 1$ (when $1 \leq \delta_1^l(i) \leq \delta_1^r(i)$), (2) first increases and then decreases in $\delta_1 \geq 1$ (when $\delta_1^l(i) \leq 1 \leq \delta_1^r(i)$), or (3) always decreases in $\delta_1 \geq 1$ (when $\delta_1^l(i) \leq \delta_1^r(i) \leq 1$). Let $\bar{\delta}_1(i) = \max(1, \delta_1^r(i))$. We can summarize δ_1^* as follows: $\delta_1^* = \bar{\delta}_1(i)$ if $\Pi_M(\delta_1 = \bar{\delta}_1(i)) \geq \Pi(\delta_1 = 1)$, and $\delta_1^* = 1$ otherwise. Indeed, the optimal δ_1^* in the scenario with no used goods can be presented in the same format where $\bar{\delta}_1(i) = \max(1, \delta_1^r(0))$ and $\delta_1^r(0) = 1/8K$. □

Appendix E. Supporting Details for the Empirical Analysis

Table E.1 Survival Analysis (Cox Model) Results

Independent variables	
P2P (post-2001 = 1; pre-2001 = 0)	1.20 (0.08)**
usedBookShare (lagged)	6.19 (1.27)**
Discipline dummies	Yes
Observations	1,634
Clusters (unique books)	380
Number of failures	493
Wald $\chi^2(7)$	122.83**
Log pseudo-likelihood	−3,289.85
AIC score	6,593.71

Note. Robust standard errors are in parentheses.
*Significant at 5%; **significant at 1%.

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