Published online ahead of print May 22, 2013

MARKETING SCIENCE
Articles in Advance, pp. 1–22
ISSN 0732-2399 (print) | ISSN 1526-548X (online)

http://dx.doi.org/10.1287/mksc.2013.0784

Returns Policies Between Channel Partners for Durable Products

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Many durable products with relatively short selling seasons have been using returns policies between manufacturers and retailers as the contractual protocol for some time. Recently, these sectors have witnessed the growing popularity of peer-to-peer Web-based used goods markets as important transaction channels between buyers and sellers. Given that these two issues are critically linked from both supply and demand perspectives, in this paper we study the role that consumer valuation of used products plays in shaping a manufacturer's incentive to offer a returns policy option to a retailer when used goods might be devalued compared to new ones as a result of physical deterioration (or obsolescence). We do so through a two-period dyadic channel framework where the retailer faces uncertain demand for a durable product from a renewable set of customers who are impatient but forward looking. The manufacturer, on the other hand, needs to decide whether or not to offer a returns contract to the retailer. We first characterize the necessary and sufficient condition under which a returns contract is the equilibrium strategy as well as the corresponding channel decisions. Further analysis of this condition reveals that a higher consumer valuation of used products increases the likelihood of a returns contract being the equilibrium strategy. This result seems to be robust except when the potential demands for the two periods are quite deterministic and uncorrelated. However, it contradicts the burgeoning managerial trend to replace returns contracts with price-only ones in sectors where used goods are valued relatively highly by the consumers. We also discuss how used goods markets affect the equilibrium channel decisions as well as how demand uncertainty and logistics costs associated with returns influence the equilibrium contracting strategy.

Key words: returns policy; used goods; stochastic demand; decentralized channel; demand correlation
History: Received: September 5, 2010; accepted: February 25, 2013; Eric Bradlow and then Preyas Desai served as the editor-in-chief and Richard Staelin served as associate editor for this article. Published online in *Articles in Advance*.

1. Introduction

Returns policy has been an integral part of contractual obligations between channel partners in a number of durable goods sectors for almost 80 years. With this policy, the retailer pays a per-unit wholesale price to purchase a product but receives financial restitution from the manufacturer in the form of a per-unit return price for any unsold products that are returned at the end of the selling season.[1] This policy has now become a salient mechanism in many durable products sectors for manufacturers to provide assurance to retailers who are dealing with demand uncertainty and short selling seasons (Padmanabhan and Png 1995). For example, a returns policy is in vogue for products such as fashion apparel and accessories, video games, books, and toys (Marvel and Wang 2007, Padmanabhan and Png 1995). As of late, however, many of these sectors are experiencing an increase in the rate of returns. For mass market paperbacks, adult trade hardbound books, and adult trade paperbacks, return rates run at about 50%, 37.5%, and 21.9%, respectively (refer to Marvel and Wang 2007 for more details). Such high rates of return are also associated with significant logistics costs for the channel partners (Neary 2008, Padmanabhan and Png 1995). Concerned by the substantial expenses incurred during the returning process, many firms have started questioning the value of a returns policy contract (Cachon and Terwiesch 2009). This is evident from the publisher HarperCollins doing away with its returns policy in one of its new divisions (Rich 2008), as well as by the action of some other publishers who have stopped doing deals with mass-market book retailers

[1] Our focus is on *intrachannel* returns policies offered by manufacturers to retailers, not on extrachannel returns policies offered by retailers to their end customers. For the latter type of returns policies, refer to Shulman et al. (2011). So, throughout this paper, the term "returns policy" refers to intrachannel policies, unless otherwise stated.

such as Costco because of their stringent returns policy requirements (*Economist* 2011).

Another turn of events that has affected the retail industry is the growth of used goods markets. E-commerce has been a boon for new products because it allows a whole new segment of individual buyers and sellers to transact among themselves with relative ease (i.e., peer-to-peer (P2P) markets), but its impact on the sales of used products has been extraordinary (Ghose et al. 2006, Rapson and Schiraldi 2012). Some of the most well-known e-commerce sites are P2P used goods marketplaces (e.g., eBay, Amazon.com marketplace, Craigslist.org, Taobao.com). In 2008, nearly \$60 billion of goods were transacted on eBay, a large majority of them being used goods (Rapson and Schiraldi 2012); the subsequent financial crisis has made this sector even more popular (Nakata 2010). More importantly, although such markets initially dealt mainly in used books (McAfee 2007, Varian 2005), the types of products being transacted nowadays are much more extensive. Used fashion apparel/accessories and toy sectors have become especially active as is evident by the growth of e-tailers such as Milan Station, Brands Off, 99dresses, and Threadflip (*Jing Daily* 2012, Nakata 2010). An estimated 23% of Amazon's sales come from used goods (Varian 2005), approximately 45% of the books on sale at Amazon in October 2012 were used ones (data collected from Amazon.com website in October 2012), and about 25% of video games sales are now through used goods markets (Kane and Bustillo 2009).

Intuitively speaking, the two phenomena—returns policy and the used goods market—are interconnected. Returns policy affects the order quantity of new items from the retailer, which in turn influences the sales volume. The volume of new goods sold determines the size of the supply source for the used goods market, and their loss in perceived value from consumers' perspective—either as a result of physical deterioration from usage (e.g., for books, toys) or as a result of obsolescence (e.g., for fashion apparel)—affects the price in that market. The impact of used goods markets on the demand for new products and the frequency of new product releases has been discussed before; see, e.g., Ghose et al. (2006) and Yin et al. (2010). It is noteworthy that, to the best of our knowledge, literature is silent about *how used goods markets affect the manufacturers' incentive to offer a returns policy option to retailers*. The primary motivation of this paper is to address this gap in the literature.

Specifically, we explore the following issues in the context of a decentralized, dyadic (manufacturer–retailer) channel framework:

- What role does a P2P used goods market play in determining a manufacturer's incentive to offer a returns policy contract? Moreover, how does such a market affect the equilibrium decisions of the two channel partners?
- How do the following factors shape the above incentive in the presence of a P2P used goods market: (i) level of demand uncertainty, (ii) costs of handling returns, (iii) whether new and used goods are sold concurrently or not, and (iv) degree of demand correlation across periods?

To answer these questions, we develop a two-period model that captures the basic features of a durable product with a short selling season. Potential demand for the product arises from a new set of customers in each period who need to use the product in that period only,[2] and the number of such customers in each set is random. Initially, we assume that the potential demands for the two periods are perfectly correlated and that there is only one type of product in each period—new products from the retailer in the first period and used goods from the P2P market in the second period. At the beginning of the first period (before uncertainty is realized), the manufacturer decides on her contracting strategy with the retailer—price-only or returns. Keeping the contract offered in mind, the retailer then chooses his order quantity. Subsequently, the demand uncertainty is realized. The retailer then announces his price for the new goods in period 1, which determines his sales in period 1 as well as the amount he needs to return to the manufacturer (if a returns policy is offered). In period 2, there is only a P2P market selling used goods that might have lost some of its value to consumers as a result of physical deterioration or obsolescence. The supply source of the P2P market is the first-period retail sales and the price in that market is set based on a clearing mechanism. Note that the two periods in our setting interact: while deciding on whether or not to buy in period 1, customers take into account the price that they can get by selling their used products in period 2's P2P market (i.e., customers are forward looking). Any leftover new goods at the end of period 1 are disposed of either by the manufacturer (for a returns contract) or by the retailer (for a price-only contract). There is a logistics cost associated with returns for both channel partners. We analyze the resulting game to characterize the necessary and sufficient condition that defines the equilibrium contracting strategy and decisions for the channel partners.

One of the most important findings of our analysis is that the *higher consumer valuation of used goods in the P2P market increases the manufacturer's incentive*

[2] This assumption makes sense for the types of products we have in mind, such as fashion apparel and accessories, toys, video games, and books.

to offer a returns policy contract to the retailer. The underlying reason is that the higher the consumer valuation of used goods in period 2, the more the period 1 customers benefit by selling their used products in the P2P market. Consequently, these customers are then willing to pay a price premium for buying new products and/or willing to buy more of them. A returns contract enables the manufacturer to better exploit this situation more so than a price-only contract would. Specifically, the manufacturer can charge a higher wholesale price under a returns contract, and the extent of this price premium increases in the consumer valuation of used goods.[3] The difference in retail order quantities between a returns contract and a price-only contract also increases as the used goods become more valuable from the consumer's perspective. Consequently, a P2P market selling used goods highly valued by consumers creates the potential for both margin and volume gains for the manufacturer by offering a returns option. Although this gain comes at a cost (return price + logistics costs) for the manufacturer, overall, her benefits more than counterbalance the losses.

The above-mentioned result appears to be quite robust. Specifically, the effect of the used goods market remains valid even if the potential demands for the two periods are imperfectly correlated. The primary impact of this imperfection is that as the degree of correlation decreases, the manufacturer is comparatively less able to utilize a returns contract to extract the benefits that period 1 consumers can obtain from a P2P market selling high-valuation used goods, especially when the demand uncertainty of each period is also relatively low.[4] The insight about the effect of the used goods market generally holds true even if we allow the retailer to also sell new goods in period 2, where it competes with the P2P used goods market. The retailer in that case determines the new goods prices for both periods as well as the amount to return at the end of period 2 (for a returns contract). The main implication of a returns contract in this framework is that, in addition to better positioning the manufacturer to extract part of the consumer benefits, such a contract helps the manufacturer manage the cannibalization effect of high-valuation used goods in a more effective fashion.

We further demonstrate that demand uncertainty has a nonmonotone effect on the likelihood of a returns contract—*medium levels of demand uncertainty make returns contracts most likely*, whereas very high or low levels of uncertainty provide significant incentives for the manufacturer to offer a price-only contract. This is because the increase in the retail order quantity stemming from a returns contract is nonmonotone in the randomness of demand. As expected, higher returns logistics costs for channel partners always discourage a returns option.

The rest of this paper is organized as follows. In §2 we review the related literature. Section 3 presents our basic model framework. The model is analyzed for equilibrium characterization in §4, and in §5 we establish how the used goods market, demand uncertainty, and returns logistics costs affect the incentives and decisions of the channel partners. Section 6 presents the two robustness checks of the basic model (i.e., imperfect correlation and second retail sales opportunity). Finally, §7 provides managerial implications, concluding remarks, and suggestions for future research.

2. Review of Related Literature

Although, to our knowledge, the research questions in this paper have not been addressed before, the extant literature nevertheless has tackled other fundamental issues related to our work. This can be divided primarily into two streams: (i) papers dealing with characterizing the optimal returns policy between channel partners but where used goods markets do not play any role and (ii) papers on durable products that consider the effects of used goods markets but without any channel returns option.

The first stream of literature started with the seminal paper by Pasternack (1985), who established that a properly designed returns policy can achieve channel coordination even in a multiretailer environment. Subsequently, an extensive body of research addressing various facets of returns policy emerged in marketing, economics, and operations management literature. Rather than providing an exhaustive review, we focus here on some representative examples. The returns contract has been analyzed in a variety of settings, including when there is competition either at the retail level (Padmanabhan and Png 1997, Wang 2004) or at the manufacturer level (Bandyopadhyay and Paul 2010), when there is information asymmetry in the channel (Arya and Mittendorf 2004, Sarvary and Padmanabhan 2001), when retail price is endogenous (Emmons and Gilbert 1998, Granot and Yin 2005, Kandel 1996, Song et al. 2008), when there is threat of retail markdowns (Marvel and Wang 2007), and when there is valuation uncertainty (Marvel and Peck 1995). Although the issues addressed are different, the common themes connecting these papers are their single-period settings and the uncertainty in retail demand. The fundamental insight of this stream is that a returns contract enables the manufacturer to induce larger retail orders

[3] Throughout the paper, we use "greater/smaller," "higher/lower," and "increasing/decreasing" in the weak sense.

[4] Consequently, the effect of the used goods market might not be valid only when the potential demands for the two periods are relatively deterministic and are independent of each other.

Table 1 Representative Papers Dealing with Durable Products

	Deterministic demand	Uncertain demand
Centralized channel	Desai and Purohit (1998, 1999), Tilson et al. (2009)	Ferguson and Koenigsberg (2007)
Decentralized channel	Desai et al. (2004), Shulman and Coughlan (2007), Yin et al. (2010)	Current study

by sharing demand risk through an assured (and relatively high) salvage value in case of overstocking. We augment this literature by incorporating in our model a growing phenomenon in many durable products sectors—used goods markets—and we show that such markets can significantly affect the incentive to offer a returns option. Note that there is another stream of literature dealing with returns policy, but it focuses on such an arrangement between the retailer and end customers. We do not go into the details of that literature stream, but we refer readers to Shulman et al. (2010, 2011) for reviews.

The second stream of literature consists of papers dealing with durable products in the marketing/economics domain. They are relevant because of the presence of a used goods market that competes with new products sold by retailers; moreover, most of them also use a two-period framework with a clearance market for the used products in the second period such as in this paper. This stream can be further subdivided based on whether the channel structure is centralized or decentralized and whether or not there is any uncertainty in retail demand. Representative papers in each of these categories are presented in Table 1 (refer to Yin et al. 2010 for a more detailed review).[5] Papers in the centralized–deterministic cell mainly focus on comparing the leasing and selling of durable goods under various setups. Those in the decentralized–deterministic cell develop channel coordinating contracts, and those in the centralized–uncertain cell propose optimal inventory management strategies. The goal of our paper, as well as our decentralized–uncertain demand framework, differentiates us from this literature stream.

Our main contribution is that we model the interaction between used goods markets and returns policy contracts in the context of a nondeterministic, decentralized channel. In particular, our analysis of how such markets affect the manufacturer's incentive to offer such a contract as well as their associated channel decisions sets our paper apart from the existing literature.

[5] There are also some papers in marketing (e.g., Bhaskaran and Gilbert 2005, Desai and Purohit 1999) and in operations management (e.g., Ferguson and Toktay 2006, Ferrer and Swaminathan 2006) that address the issue of horizontal competition in the context of durable products. However, the focus of our paper is on vertical competition.

3. Model Framework

We develop a stylized model of one manufacturer selling to one retailer to capture the basic features of the examples in §1. Like most of the literature on durable goods (e.g., Desai et al. 2004, Shulman and Coughlan 2007), we assume that the selling season lasts for two periods. The two most important characteristics of our model are that it considers the manufacturer's decision about whether or not to offer a returns option to the retailer and the P2P used goods market for end customers.

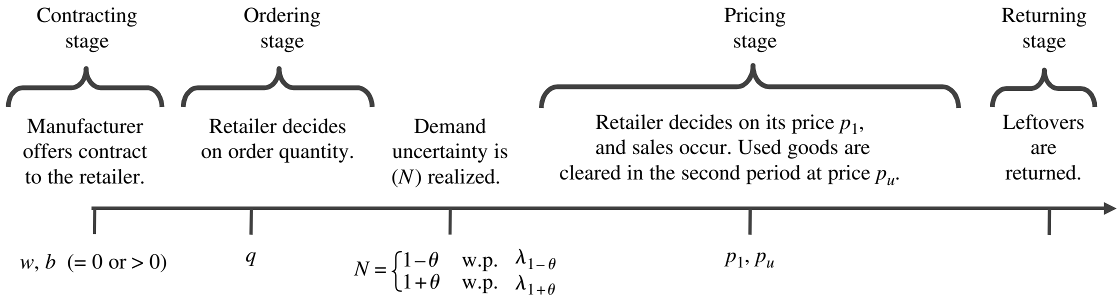
Suppose that there is a renewable set of a random number of potential customers, denoted by N, interested in buying at most one unit of the product in each period (as in Shulman and Coughlan 2007). While the product is durable, the customers entering the market require it specifically for that period only.[6] For tractability reasons, we assume that N can be either high $(1+\theta)$ or low $(1-\theta)$ with probability $\lambda_{1+\theta}$ and $\lambda_{1-\theta}$, respectively, where $\lambda_{1+\theta}+\lambda_{1-\theta}=1$. Clearly, $\theta \in (0,1)$ measures the *degree of uncertainty* in the retailer's market potential—the higher the value of θ, the greater the uncertainty. Moreover, potential customers' valuation of the product per period in its new condition, v, is heterogeneous and follows a uniform distribution between 0 and 1 (i.e., $v \sim \mathrm{U}[0,1]$). The sequence of events in our Stackelberg model is shown in Figure 1 and is also described below.

1. *Contracting Stage*: Our model setting starts with the manufacturer (leader) deciding on her contract variables at time 0. Specifically, she decides on a unit wholesale price, w, with or without a returns option. If a returns option is offered, she also sets the return price, b $(b>0)$, at which rate the retailer (follower) will be compensated for returning any unsold inventory. Thus, in our context, $b=0$ defines a no-returns, price-only contract. Note that most of our discussion will focus on *full-credit* returns policy whereby the retailer's compensation per unit returned includes the full wholesale price as well as any logistics cost associated with returns he incurs.

2. *Ordering Stage*: A distinctive feature of many of the durable products of our interest (e.g., fashion apparel, toys, and even textbooks) is that they are nowadays produced offshore in low-cost countries, making their supply delivery times relatively long. Consequently, the retailers often have only one opportunity to place an order with the manufacturer for the short selling season (refer to Cachon and Terwiesch 2009 for more details). Based on this idea, we assume that the retailer can place only one order. Specifically, given the above-mentioned contract, the retailer

[6] Thus, the customers cannot decide to wait and buy in the next period; i.e., they are impatient. We briefly discuss the implications of customer patience in §7.

Figure 1 **Timeline of Events**



decides on how many new units of the product, q, to order from the manufacturer at time 0.

After the order is fulfilled, uncertainty about demand potential N is realized ($1+\theta$ or $1-\theta$). It is natural to think that demand potentials for the two periods are positively correlated (refer to Cachon and Kok 2007 and references therein). For now, suppose that they have a perfect, positive correlation. So once N realizes, this denotes the number of potential customers in each period. We discuss the implications of imperfectly correlated demand potentials in §6.1.

3. *Pricing and Returning Stages*: Knowing the realization of N and the amount of inventory q available to him for sale, the retailer decides on his pricing policy so as to maximize his revenue (as in Padmanabhan and Png 1997). For high-end products such as fashion apparel/accessories and toys, the retailer may not want to sell new items of a particular model when the used goods market for that model has become popular in order to protect brand image (Aurora 2011, Padmanabhan and Png 1995). Keeping this in mind, we initially assume that the retailer sells only new goods in period 1, and only used goods are transacted in a P2P market (e.g., eBay, Threadflip) in period 2. However, for products such as textbooks and games, indeed, both types of products can be sold simultaneously. We analyze such a framework in §6.2, whereby the retailer sells new items in both periods 1 and 2 and there is a P2P used goods market in period 2.

At the beginning of period 1, the retailer announces the price of new products for period 1, p_1, which also determines the price for the P2P used goods market, p_u. However, N ($=1+\theta$ or $1-\theta$) potential customers in period 1 know that there is a P2P used goods market available to them in period 2 for selling their used products and can anticipate the equilibrium price in that market, p_u. Suppose that all the customers who buy in period 1 sell their used products in the P2P market in period 2.[7] Potential customers in period 1 thus take the anticipated equilibrium *resale value of the used products* into account while deciding on whether or not to buy. If the net utility $v-(p_1-p_u)$ is positive, they buy the product; otherwise, they leave the market. Given our setting, the demand for (or sales of) new products in period 1 is then given by $x_1 = N(1-(p_1-p_u))$. Any leftover new goods at the end of period 1 (i.e., $(q-x_1)^+$) are disposed of by the retailer (for a price-only contract) or returned to the manufacturer, who then disposes of them (for a returns contract). In the latter case, the manufacturer and the retailer incur a per-unit cost of c_m and c_r, respectively, for returns-associated logistics activities. For expositional simplicity, suppose that the disposal cost (or salvage value) is negligible. Any customer who does not buy in period 1 leaves the market.

In period 2, an entirely new set of N ($=1+\theta$ or $1-\theta$, as in period 1) customers enters the market. These customers can buy only used products from a *P2P used goods market*. The supply source of the P2P market is the customers who bought the product in period 1, i.e., x_1. Period 2 consumers' valuations of these used products are given by δv, where $0 \le \delta \le 1$. Thus, $1-\delta$ is the loss in value of used products from the perspective of end consumers. This loss might be as a result of deterioration in the condition of the products (for products such as toys or books) and/or their relative obsolescence (for products such as fashion apparel) (refer to Ray et al. 2005 and Yin et al. 2010 for more discussion).[8] In other words, the higher the value of δ, the more consumers in period 2 value the used goods. This factor δ will be the parameter of primary interest in this paper. For example, books and DVDs do not lose their much of their value with use, implying that δ for such products is relatively high. On the other hand, toys might lose a substantial portion of their value because of usage. For a fashion product, in addition to usage,

[7] This implies that all customers who buy in period 1 have negligible valuations for used products in period 2. For renewable customer sets, we feel this to be a reasonable assumption, and it also provides analytical tractability. The implications of this assumption compared with the alternative scenario whereby used goods have certain remaining valuations for period 1 customers is that our setting results in a higher amount of used goods and, hence, a lower used goods price in the P2P market.

[8] In our setting, there is only vertical product differentiation in the form of new and used goods.

Table 2 Parameters and Decision Variables

Symbol	Definition
i	Time period; $i = 1$ or 2.
N	Potential market size for each period; $N = 1+\theta$ or $1-\theta$.
θ	Degree of uncertainty, where $\theta \in (0, 1)$.
λ_N	Probability that the demand state is N.
ρ	Degree of correlation between demands of two periods; $\rho \in [0, 1]$.
δ	Discount factor for used goods in period 2, where $\delta \in [0, 1]$.
m	Marginal production cost for the manufacturer.
c_m	Manufacturer's unit cost for returns-associated logistics activities.
c_r	Retailer's unit cost for returns-associated logistics activities.
w	Manufacturer's unit wholesale price.
b	Manufacturer's return price for each unit returned.
$\hat{b}$	Net benefit that the retailer earns for each unit returned, where $\hat{b} = (b - c_r)^+$.
p_i	Retailer's selling price of new goods in period i.
p_u	Clearance price of used goods in P2P market of period 2.
q	Retailer's order quantity.
x_i	Retailer's demand or sales of new goods in period i.
x_u	Demand for (= supply of) used goods in period 2.
Π_M	Manufacturer's profit function.
Π_R	Retailer's profit function.

the loss in value might depend on whether that particular style is still popular in the market or if it has become obsolete. Moreover, based on what is well known in practitioner literature (e.g., McAfee 2007), we assume that the P2P used goods market is characterized by a market-clearing price (p_u). Given customers' valuations of used products in period 2, we can determine the volume of sales of such products in the P2P market, say, x_u. Because the price for used goods is market clearing, supply and demand must match in the P2P market, i.e., $x_u = x_1$, which yields $p_u = (\delta/(1+\delta))p_1$. Note that the two periods in this model interact through p_u. Our key notations are summarized in Table 2.

4. Model Analysis

In this section, we first develop the equilibrium decisions for both channel partners under price-only and returns contracts. We subsequently analyze those decisions to establish the equilibrium contracting strategy as well as determine how the used goods market (in terms of δ) and uncertainty in market potential (in terms of θ) affect the equilibrium decisions and contracting strategy. Given the framework defined in the previous section, we can formulate the expected profit functions Π_M and Π_R for the manufacturer and the retailer, respectively. These expressions would depend crucially on the type of contract in place among the channel partners. If the contract is a returns one, then the expected profit functions of the channel partners would be given by (subscripts M and R denote the manufacturer and the retailer, respectively)

$$\Pi_M = (w-m)q - \sum_{N\in\{1+\theta,1-\theta\}} \lambda_N (b+c_m)(q-x_1)^+ \quad \text{and} \tag{1}$$

$$\Pi_R = -wq + \sum_{N\in\{1+\theta,1-\theta\}} \lambda_N \{p_1x_1 + (b-c_r)^+(q-x_1)\}, \tag{2}$$

where m is the marginal production cost for the manufacturer and $(\bullet)^+ = \max(0, \bullet)$. Otherwise, if the contract is a price-only one, then the profit functions would be

$$\Pi_M = (w-m)q \quad \text{and}$$
$$\Pi_R = -wq + \sum_{N\in\{1+\theta,\,1-\theta\}} \lambda_N \{p_1x_1\}. \tag{3}$$

Note that in both contracts, the selling amount of new goods is constrained by q; i.e., $x_1 \le q$. In this section, we analyze the above profit functions to answer some of our research questions. For expositional simplicity, suppose that $m = 0$ and that the two demand states are equally likely; i.e., $\lambda_N = \frac{1}{2}$ for $N \in \{1+\theta, 1-\theta\}$. We next determine the equilibrium decisions and profits of the channel partners using backward induction (note that for the price-only contract, $b = c_r = c_m = 0$).

1. *Returning Stage*: With a returns contract in place, the retailer will return any remaining units to the manufacturer at the end of period 1 if the return price b is greater than his logistics costs c_r, i.e., if $b \ge c_r$. If $b < c_r$, then he will dispose of the remaining units. However, the number of remaining units at the end of period 1 depends on the pricing decision as discussed next.

2. *Pricing Stage*: Given the contract terms (b, w) and the ordering decision q at time 0, the retailer observes the realization of N and decides on the optimal price for the first period p_1. Because the uncertainty is resolved before the pricing decision is made, the retailer's price optimization problem can be equivalently expressed in terms of period 1 sales quantity, x_1, as follows:

$$\Pi_R(q) = -wq + \max_{0\le x_1\le q} \{p_1x_1 + (b-c_r)^+(q-x_1)\}, \tag{4}$$

where p_1 is the implied price that results in sales of x_1 units in period 1. Using the inverse demand function, we can express p_1 in terms of x_1 as follows:[9]

$$p_1 = (1+\delta)\left(1 - \frac{x_1}{N}\right). \tag{5}$$

In the retailer's profit maximization problem, he is also effectively determining the optimal number of units to be returned $(q - x_1)$ by trading off the benefits of selling at the rate of p_1 against the benefits

[9] Our direct demand function is $x_1 = N - (N/(1+\delta))p_1$, whereas in Padmanabhan and Png (1997), it is $x_1 = N - p_1$. Note that in the latter paper, uncertainty appears only in the demand intercept; in our case, both the intercept and slope of the demand function are random. Moreover, only our slope is affected by the used goods market (in Padmanabhan and Png 1997, $\delta = 0$).

of returning at the rate of $(b-c_r)^+$. For expositional convenience, in what follows, we let $\hat{b}=(b-c_r)^+$ represent the net amount earned by the retailer for each returned unit.

Substituting (5) in (4), the retailer's profit becomes concave in x_1. Analysis of the profit function reveals the following optimal state-dependent sales quantity x_1^* for period 1:[10]

$$(x_1^* \mid \hat{b}, q, N) = \min\left[\frac{N}{2}\left(1-\frac{\hat{b}}{1+\delta}\right), q\right]. \qquad (6)$$

If the order quantity q is relatively low ($q \le N/2(1-\hat{b}/(1+\delta))$), then the retailer sells all q units in period 1 and does not return anything; otherwise, he sells x_1^* units and returns $(q-x_1^*)$ units.

3. *Ordering Stage*: For a given returns contract (i.e., w and $\hat{b}$), and knowing his optimal sales strategy from the previous stage, the retailer determines the optimal order quantity $q^*(w,\hat{b})$ before observing the demand state. Suppose that during the contracting stage, the manufacturer decides between either of the two contracts: $b=0$ (a price-only contract) and $\hat{b}=w$ (a full-credit returns contract).[11] The optimal order quantities under the two contracts in that case are as follows:

$$q^*(w, b=0) = \begin{cases} \dfrac{(1+\delta-2w)(1+\theta)}{2(1+\delta)} & \text{if } w \le \dfrac{\theta(1+\delta)}{1+\theta}, \\[2ex] \dfrac{(1+\delta-w)(1-\theta^2)}{2(1+\delta)} & \text{otherwise;} \end{cases}$$

$$\text{and} \quad q^*(w, \hat{b}=w) = \frac{(1+\delta-w)(1+\theta)}{2(1+\delta)}.$$

Higher return prices (i.e., higher $\hat{b}=w$) provide a higher "salvage" value for any remaining inventory for the retailer, but they also increase the wholesale price charged to him. Consequently, the retailer's optimal order quantity actually decreases in $\hat{b}$ for a returns contract. Note, however, that a returns contract, in contrast to a price-only one, still allows the manufacturer to increase the retailer's order quantity (for a given w and $\hat{b}$).

4. *Contracting Stage*: At this stage, the manufacturer decides whether to offer a price-only contract or to offer a full-credit returns one, keeping in mind the retailer's best response function in terms of pricing and ordering decisions as discussed previously. We can determine the equilibrium contracting parameters, retail prices, and order quantities for both types of contracts, as shown in Table 3.

[10] The derivation for x_1^* as well as proofs for all the propositions in the paper are provided in the appendix.

[11] Note that a full-credit returns option can indeed be the equilibrium strategy under certain cases and is the standard in a number of durable goods sectors (refer to Bandyopadhyay and Paul 2010, Padmanabhan and Png 1997).

Comparison of the above two contracts then establishes the following equilibrium contracting strategy for the manufacturer.

Proposition 1. *In equilibrium, the manufacturer offers a full-credit returns contract to the retailer if and only if $c_r + c_m \le \bar{c}(\delta,\theta)$; otherwise, she offers a price-only contract, where $\bar{c}(\delta,\theta)$ is as shown below*:

$$\bar{c}(\delta,\theta) = \begin{cases} \dfrac{(1+\delta)(1-\sqrt{1-\theta^2})}{\theta} & \text{if } \theta < \dfrac{1}{2}, \\[2ex] \dfrac{(1+\delta)(2-\sqrt{2(1+\theta)})}{2\theta} & \text{if } \theta \ge \dfrac{1}{2}. \end{cases}$$

A closer examination of Table 3 and Proposition 1 reveals some interesting issues.

- A comparison of the unit total returns logistics costs for the channel partners, $c_r + c_m$, against the threshold value, $\bar{c}(\delta,\theta)$, is necessary and sufficient for determining the manufacturer's equilibrium contracting strategy. A threshold-type optimal policy implies that *higher returns logistics costs—higher c_m and/or c_r—make a returns contract less likely*, which is intuitive. Moreover, the threshold $\bar{c}(\delta,\theta)$ is nonnegative for all $\theta \in (0,1)$ and $\delta \in [0,1]$. So if the channel partners can reduce their returns logistics costs to negligible levels, either through technology investments or through process changes (e.g., no physical returns; rather, the retailer disposes of the leftovers even for a returns contract), it is always optimal for the manufacturer to provide the returns option to the retailer.
- There are two different price-only contracts in equilibrium depending on the value of θ. Lower levels of demand uncertainty (i.e., lower θ) are associated with higher wholesale prices but smaller retail orders. On the other hand, when θ is high, the retailer bears significant risk in the end customer market, and this makes him wary of overstocking. His order quantity in that case is thus more responsive to any increase in wholesale price. While designing the returns contract, the manufacturer uses the higher wholesale price (i.e., the one associated with lower θ) as the base price and adds a markup to it to, e.g., recover a portion of the total return logistics costs $c_r + c_m$. Since the manufacturer's risk of receiving a return increases in θ, the markup also increases in θ.
- As regards the retailer's equilibrium order quantity under a returns contract, we already mentioned that there are two counteracting effects acting on it. The higher wholesale price under such a contract induces the retailer to reduce his order quantity compared with a price-only one; on the other hand, the returns option incentivizes him to increase the order quantity. Because a high level of θ results in a relatively low wholesale price under a price-only contract (as shown in the above bullet point), the wholesale price premium under a returns contract looms large. The order quantity under a returns contract in that

Table 3 Equilibrium Contracts, Retail Orders, and Retail Prices

If $c_r + c_m > \bar{c}(\delta, \theta)$:	If $c_r + c_m \le \bar{c}(\delta, \theta)$:
$w^* = \begin{cases} \frac{1}{2}(1+\delta) & \theta < \frac{1}{2}, \\ \frac{1}{4}(1+\delta) & \theta \ge \frac{1}{2} \end{cases}$	$w^* = \frac{1}{2}(1+\delta) + \frac{1}{2}\theta(c_r + c_m)$ $b^* = w^* + c_r = \frac{1}{2}(1+\delta) + \frac{1}{2}\theta(c_r + c_m) + c_r$
$q^* = \begin{cases} \frac{1}{4}(1+\theta)(1-\theta) & \theta < \frac{1}{2}, \\ \frac{1}{4}(1+\theta) & \theta \ge \frac{1}{2} \end{cases}$	$q^* = \frac{1}{4}(1+\theta)\left(1 - \frac{\theta(c_r + c_m)}{1+\delta}\right)$
$p_1^* = \begin{cases} \frac{1+\delta}{4}(3+\theta) & \theta < \frac{1}{2} \text{ and } N = 1+\theta, \\ \frac{1+\delta}{4}(3-\theta) & \theta < \frac{1}{2} \text{ and } N = 1-\theta, \\ \frac{3}{4}(1+\delta) & \theta \ge \frac{1}{2} \text{ and } N = 1+\theta, \\ \frac{1}{2}(1+\delta) & \theta \ge \frac{1}{2} \text{ and } N = 1-\theta \end{cases}$	$p_1^* = \begin{cases} \frac{3}{4}(1+\delta) + \frac{1}{4}\theta(c_r + c_m) & N = 1+\theta, \\ \frac{3}{4}(1+\delta) + \frac{1}{4}\theta(c_r + c_m) & N = 1-\theta \end{cases}$

Notes. $p_u^* = (\delta/(1+\delta))p_1^*$ and $x_1^* = N(1 - p_1^*/(1+\delta))$. The profits can be deduced by substituting the equilibrium values in the corresponding profit functions of (1)–(3).

case is indeed smaller than that under a price-only setting. On the other hand, when θ is relatively low, the difference in wholesale prices between the two contracts is relatively smaller, and the effect of the returns option incentive is then stronger; q^* is then higher under a returns contract.

- Finally, as regards equilibrium retail prices, a returns contract allows the retailer to return and receive a relatively high salvage value in the case of low demand, thus enabling him to charge the same (relatively high) price to end customers irrespective of the demand realization. This benefit, however, is not available in the price-only setting; in that case, the retailer's price depends on demand realization. He is able to charge a premium price when he has only a low amount of inventory to sell, but the demand realization is high (i.e., $\theta < \frac{1}{2}$ and $N = 1+\theta$). In contrast, he needs to set a low price when the opposite is true (i.e., $\theta \ge \frac{1}{2}$ and $N = 1-\theta$).

Whereas the above discussion brings out some salient features of the two equilibrium contracts, one of the main objectives of this paper is to understand how the manufacturer's incentive to offer a returns option is impacted by the consumer valuation of the products being sold in the used goods market. For this, we need to analyze the behavior of the returns-optimal region, i.e., $c_r + c_m \le \bar{c}(\delta, \theta)$, with respect to δ. We conduct this analysis below.

5. Effects of the Used Goods Market

In this section, we first discuss the effects of the loss in valuation of the used goods on the equilibrium decisions (provided in Table 3), and we subsequently discuss its effect on the equilibrium contacting strategy.

5.1. On Equilibrium Decisions

The following proposition establishes the effects of δ on the equilibrium channel decisions.

Proposition 2. *A higher customer valuation of used goods* (*i.e., a higher value of* δ) *affects equilibrium channel decisions as follows*:

—If a price-only contract is the equilibrium, a higher value of δ increases the manufacturer's wholesale price w^* and the retail price p_1^*, but it has no impact on the retailer's order quantity q^*.

—If a full-credit returns contract is the equilibrium, a higher value of δ increases the manufacturer's wholesale and return prices as well as the retailer's price and order quantity.

We explain the rationale behind this result by starting with the price-only contract. If the used goods do not lose much of their consumer valuation as a result of condition deterioration or obsolescence, this enables period 1 customers to receive higher prices for their used products (p_u^*) in the P2P market. As a result, they are willing to pay more for new products in period 1. The retailer can then charge a higher price. In fact, the retailer extracts the whole benefit from the customers; thus, the *net price* (i.e., $p_1^* - p_u^*$) paid by the customers actually does not change with δ. Consequently, the retailer's price increases in δ, but his order quantity does not. However, the retailer is not the sole beneficiary of the above-mentioned effect—the manufacturer extracts some of the retail price premium, which results in the wholesale price also increasing δ.

The above reasoning can explain the effects of δ on w^* and p_1^* even for a returns contract, but the presence of the returns logistics costs (c_r and/or c_m) in this case adds a new wrinkle. Note that although the two channel partners bear some of this cost, they also pass some of it on to the customers in the form of higher retail price p_1^*. Obviously, this passed-through cost has a detrimental effect on consumers' net utility from buying a new product. This cost also interacts with the benefit that they obtain from the used goods market. Specifically, the retailer can no longer extract the whole benefit that the customers obtain from higher valued used goods. However, the higher valuation still has a positive effect because it is better able to dampen the detrimental effect of the returns logistics costs and induce more customers to be willing to buy the product. Consequently, the retail order quantity q^* actually increases in δ for a returns contract.

5.2. On Optimal Contracting Strategy

Now we are ready to analyze the effects of δ on the manufacturer's optimal contracting strategy. Specifically, we study whether higher values of δ make it more or less likely for the manufacturer to offer a returns option to the retailer.

Recall that Proposition 1 identifies $c_r + c_m \le \bar{c}(\delta, \theta)$ as the necessary and sufficient condition for a returns contract to be the equilibrium. So to understand the effect of δ on the manufacturer's incentive to offer such a contract, we analyze how this condition behaves with respect to δ.

Proposition 3. *In the condition for a full-credit returns policy to be the equilibrium, $c_r + c_m \le \bar{c}(\delta, \theta)$, the threshold $\bar{c}(\delta, \theta)$ must increase in δ. Thus, an increase in δ makes the condition more likely to hold true, which implies that a higher customer valuation of used goods encourages the manufacturer to offer a returns contract to the retailer.*

The above result has important managerial implications. As discussed in §1, there is a growing concern about returns contracts, and in some sectors they are being rescinded in favor of price-only contracts. Manufacturers should take note, though, that, fueled by better design, products are becoming more durable and their level of deterioration from usage has been reduced. On the other hand, because of the increasing price sensitivity and environmental consciousness of customers, customer acceptance of used goods markets is gaining in strength. The end result is that customers are no longer devaluing used goods significantly (i.e., δ is becoming higher). Proposition 3 suggests that, in that case, it might make more sense for manufacturers to stick with the strategy of providing retailers with the option to return any excess inventory. In fact, manufacturers of certain short lifecycle durable products for which used goods markets are picking up steam should think about bringing their products under the returns policy regime.

To understand the underlying rationale behind the result in Proposition 3, we focus on the difference in manufacturer's profit under the two contracts (i.e., $\Pi_M(\text{returns}) - \Pi_M(\text{price-only})$) and analyze how this difference behaves with respect to δ. The manufacturer's profit function in our model consists of the following:

$$\text{wholesale price} \times \text{retail order quantity}$$
$$- \text{returns volume (if any)} \times \text{returns price},$$

where the second term is only for the returns contract case. We start by understanding the behavior of the difference when the degree of demand uncertainty (i.e., θ) is low.

When θ is low, the manufacturer takes advantage of this to charge a high wholesale price in the price-only contract setting. This results in a relatively low order quantity from the retailer. For a returns contract, the manufacturer can charge a wholesale price even higher than in the price-only case. In addition, by reducing the retailer's overstocking risk through a high return price, it can even induce a higher order quantity. Indeed, the amount of *excess order quantity* induced by the returns option increases in δ, as does the *wholesale price premium* the manufacturer can charge on that excess quantity. The primary detriment of the returns contract is that because the returns price increases in δ, the total returns cost for the manufacturer increases in δ. However, returns happen only when the demand turns out to be low (i.e., $N = 1 - \theta$), and the return price is paid only for the returned amount, whereas price and order quantity gains accrue irrespective of the demand state. Consequently, the latter gains are higher than the losses stemming from returns. Ceteris paribus, a higher δ makes it more beneficial for the manufacturer to offer a returns contract.

When θ is high, keeping in mind the higher level of retail demand uncertainty, the manufacturer charges a low wholesale price under a price-only contract. This induces a relatively high order quantity from the retailer. However, under a full-credit returns policy, the retailer is effectively risk-free. Thus, the manufacturer can charge a significantly higher wholesale price in this case compared with the price-only one, and this price premium increases in δ. This higher price results in the retail order quantity being lower under a returns contract compared with that under a price-only one. However, the loss in order quantity actually decreases in δ. So as δ increases, the manufacturer once again gains in terms of both margin and volume when offering a returns option. Although the losses stemming from a high returns price are also increasing in δ, as discussed in the previous paragraph, they are incurred less frequently than the gains. So even for the high θ case, a P2P market that sells more valuable used goods provides a greater incentive for the manufacturer to offer a returns policy option to the retailer.

Note that the incentive to offer a returns contract is also impacted by factors other than δ. One of them, the costs of handling returns, was discussed in §4. We now shed light on how the level of demand uncertainty θ affects the manufacturer's equilibrium contracting strategy.

5.2.1. Effect of θ. To understand the manufacturer's incentive, we again study the difference between her profits under the two contracts as θ changes. It turns out that as θ increases, the difference in the wholesale prices between returns and price-only contracts also increases. On the other hand, the difference between order quantities under the two contracts is nonmonotone: it increases for low values of θ ($\theta < \frac{1}{2}$) and then decreases in θ. Moreover, the impact of order quantity seems to be more than that of wholesale price. Consequently, we have the following proposition about the effect of θ on $\bar{c}(\delta, \theta)$, i.e., the effect of demand uncertainty on the likelihood of a returns contract.

Proposition 4. *The threshold $\bar{c}(\delta, \theta)$ of Proposition 1 is nonmonotone in θ—it increases for low values of θ and then decreases. Thus, a returns contract is most likely for medium values of demand potential uncertainty (θ) and relatively less likely for extreme values of θ.*

6. Robustness Check of Analytical Insights

The results of the previous section regarding the effects of the P2P used goods market are obtained under two main assumptions: (i) the demands for the two periods have a perfect, positive correlation, and (ii) the retailer does not sell any new goods in period 2, so there is no direct competition between new retail goods and used goods from the P2P market. Although these assumptions are reasonable for some of the durable products we have in mind, and they provide analytical tractability, in this section we relax them, one at a time, to study the robustness of insights about the effects of the used goods market obtained under the assumptions mentioned above.

6.1. General (Nonnegative) Correlation

The model framework in this case remains the same as in §3 (including the full-credit returns policy) except that the potential demands between the two periods can have any degree of nonnegative correlation. Specifically, suppose ρ represents the degree of correlation between the demand potentials, where $\rho \in [0, 1]$ (obviously, $\rho = 1$ until §5), and N_i is the market potential for period $i = 1, 2$, where

$$(N_1, N_2) = \begin{cases} (1-\theta, 1-\theta) & \text{w.p. } (1+\rho)/4, \\ (1+\theta, 1-\theta) & \text{w.p. } (1-\rho)/4, \\ (1-\theta, 1+\theta) & \text{w.p. } (1-\rho)/4, \\ (1+\theta, 1+\theta) & \text{w.p. } (1+\rho)/4. \end{cases}$$

It is important to point out that forward-looking customers in period 1 make their purchasing decisions before N_2 is realized. So they need to compute second-period resale values of their purchases (that affect their period 1 purchase decisions) by forming expectations about the state-contingent p_u values in the used goods P2P market. These expectations should be consistent with the used goods prices in equilibrium.

We can proceed with the analysis following the same technique as outlined in §§4 and 5, although the expressions are now much more involved. For example, the state-dependent inverse demand function under imperfect correlation is given by

$$p_1 = (1+\delta)\left[1 - \frac{1+\delta\mu_{N_1}}{1+\delta}\frac{x_1}{N_1}\right], \quad \text{where}$$

$$\mu_{N_1} = \begin{cases} \dfrac{1+\theta\rho}{1+\theta} & \text{if } N_1 = 1-\theta, \\[2ex] \dfrac{1-\theta\rho}{1-\theta} & \text{if } N_1 = 1+\theta. \end{cases}$$

Note that $\mu_{N_1} = 1$ for any $N_1 \in \{1-\theta, 1+\theta\}$ when $\rho = 1$, which results in the p_1 expression in Equation (5). We are able to analytically characterize all four stages outlined in §3 and establish the following proposition (counterparts of Table 3 and Propositions 1 and 3).[12]

Proposition 5. (i) *In equilibrium, the manufacturer offers a full-credit returns contract to the retailer if and only if $c_r + c_m \le \tilde{c}(\delta, \theta, \rho)$, where $\tilde{c}(\delta, \theta, \rho)$ is as shown below*:

$$\tilde{c}(\delta,\theta,\rho) = \begin{cases} \tilde{c}_1 = \dfrac{(1+\delta)}{\theta(1+\rho\delta)}\left[(1+\delta) - \sqrt{(1+\delta)^2 - \theta^2(1+\rho\delta)^2}\right] \\[2ex] \qquad \textit{if } \theta < \theta_1 = \dfrac{(1+\delta)}{2(1+\rho\delta)}, \\[2ex] \tilde{c}_2 = \dfrac{(1+\delta)}{2\theta(1+\rho\delta)}\left[2(1+\delta) - \sqrt{2(1+\delta)(1+\delta+\theta+\rho\delta\theta)}\right] \\[2ex] \qquad \textit{if } \theta_1 \le \theta \le \bar{\theta} = \dfrac{3(1+\delta)}{(\delta+4\rho\delta+5)}. \end{cases}$$

[12] As discussed in the appendix, we assume $\theta \in (0, \bar{\theta})$ for $\rho \in [0, 1)$ to rule out cases that require inventory rationing and result in complicated expressions (for $\rho = 1$, $\theta \in (0, 1)$). It is not a very restrictive assumption since $\bar{\theta} \ge 0.6$.

Table 4 Equilibrium Contracts and Retail Orders for General ρ

If $c_r + c_m > \tilde{c}(\delta, \theta, \rho)$:	If $c_r + c_m \le \tilde{c}(\delta, \theta, \rho)$:
$w^* = \begin{cases} \frac{1}{2}(1+\delta) & \theta < \theta_1, \\ \frac{1}{4}(1+\delta) & \theta_1 \le \theta \le \bar{\theta} \end{cases}$	$w^* = \frac{1}{2}(1+\delta) + \frac{1}{2}\theta(c_r + c_m)\frac{1+\rho\delta}{1+\delta}$ $b^* = w^* + c_r = \frac{1}{2}(1+\delta) + \frac{1}{2}\theta(c_r + c_m)\frac{1+\rho\delta}{1+\delta} + c_r$
$q^* = \begin{cases} \frac{1}{4}(1-\theta^2) & \theta < \theta_1, \\ \frac{1}{4}\frac{(1-\theta^2)(1+\delta)}{(1+\delta)-\theta(1+\rho\delta)} & \theta_1 \le \theta \le \bar{\theta} \end{cases}$	$q^* = \frac{1}{4}(1-\theta^2)\frac{(1+\delta)^2 - \theta(c_r + c_m)(1+\rho\delta)}{(1+\delta)^2 - \theta(1+\delta)(1+\rho\delta)}$

Note. p_1^*, p_u^*, and x_1^* and the equilibrium profits can be deduced from these expressions.

(ii) *The equilibrium values for both contracts and their corresponding equilibrium retail order quantities are provided in Table* 4.

(iii) *Analysis of* $\tilde{c}(\delta, \theta, \rho)$ *shows that* $\tilde{c}_2$ *is always increasing in* δ, *and* $\tilde{c}_1$ *is also increasing in* δ *for* $\rho \ge \rho_1 = (1-\sqrt{1-\theta^2})/\theta^2$. *If* $\rho < \rho_1$, $\tilde{c}_1$ *can be nonmonotone. That is, a higher customer valuation of used goods encourages a returns contract unless the demand potential uncertainty and demand correlation are both low.*

Note that all the above expressions reduce to the corresponding ones in §§4 and 5 when we substitute $\rho = 1$. Clearly, the optimal contracting strategy is still a threshold-type policy similar to that in §4. More importantly, the effect of the consumer valuation in the used goods market (δ) on the equilibrium contracting strategy, discussed in §5, still remains valid, except for low θ and low ρ scenarios. The underlying reason for high values of θ is actually quite similar to what was discussed in §5. However, a closer look at low θ values reveals that although the difference in wholesale prices between the two contracts (returns − price-only) still increases in δ, the rate of this increase is quite slow when the demand potentials are relatively independent (i.e., low ρ). On the other hand, the difference in order quantities increases in δ for high values of ρ, but it may actually decrease for low values of ρ. So for low values of ρ and θ, which represent the least risky conditions for the retailer, the manufacturer does not gain much from wholesale prices as δ increases and can actually lose in terms of retail order quantity. Consequently, we note that the positive impact of a more valuable used goods market on the likelihood of a returns contract prevails in all conditions except for low θ and low ρ scenarios, in which case the effect might be reversed. As regards the effect of demand potential uncertainty (i.e., θ) on the optimal contracting strategy, it is also quite similar to Proposition 4—a returns contract is most likely for medium values of θ and is relatively less likely for extreme values of θ. Finally, since ρ also affects overall demand uncertainty in a manner similar to θ—specifically, lower values of ρ represent lower uncertainties—the effect of ρ on the optimal contracting strategy is quite similar to that of θ.

6.2. Retail Sales of New Goods in Period 2

Until now, we assumed that the retailer sells new goods only in period 1 and in period 2 it is only the P2P used goods market where transactions take place. Now suppose that the retailer is willing to sell new goods in both periods (the P2P used goods market still operates only in period 2). In this case, new and used goods directly compete in period 2, and there is possible cannibalization of retail demand by the P2P market. If a returns contract is offered by the manufacturer, returns take place at the end of period 2. Everything else remains the same as in §3, including the fact that the demand potentials in the two periods have a perfect, positive correlation (i.e., $N_1 = N_2 = N$).

Among the four decision-making stages outlined in §3, it is the pricing stage that is most affected. In period 1, only new products from the retailer are for sale in the market at price p_1 for $N(= 1+\theta$ or $1-\theta)$ forward-looking customers. The demand (or sales) of new products in period 1 is still $x_1 = N(1-(p_1 - p_u))$. Any leftover new goods at the end of period 1 (i.e., $q - x_1$) are carried over by the retailer for possible sale in period 2. Any customer who does not buy in period 1 leaves the market. In period 2, an entirely new set of N (same value as in period 1) potential customers enters the market. These customers have the choice of buying either new or used products. We use a consumer choice model that captures the competition between new and used products to derive their sales, x_2 and x_u, respectively, in period 2, where[13] $x_2 = N(1-(p_2-p_u)/(1-\delta))$ and $x_u = N((p_2 - p_u)/(1-\delta) - p_u/\delta)$. Clearly, a higher δ increases the cannibalization effect of the P2P market. Recall that the price for used goods is market clearing;

[13] Refer to the appendix for the derivation and validity of these expressions for extreme values of δ.

p_u is then based on $x_u = x_1$, i.e., $p_u = \delta(1-(x_1+x_2)/N)$. Thus, period 2 involves sales of x_2 new goods at price p_2 by the retailer and sales of x_u $(= x_1)$ used goods at price p_u in the P2P market. The retailer trades off the revenue from selling versus returning while deciding on how much to return (in case of a returns contract) and takes into account the inventory on hand at the end of period 1 and the competition between new and used goods while deciding on the price in period 2. As regards the retailer setting the period 1 price, he has to consider all possible demand scenarios in period 2, as well as the order quantity and the returns price. The analysis of the returning stage remains unaltered compared to §4. In the pricing stage, we now optimize the following dynamic problem (for a given order quantity and contract parameters):

$$\Pi_R = -wq + \max_{0\le x_1\le q}\left\{p_1x_1 + \max_{0\le x_2\le (q-x_1)}\{p_2x_2 + (b-c_r)^+(q-x_1-x_2)\}\right\}.$$

Analysis of the above problem results in the following optimal selling strategy for the retailer.

Proposition 6. *The optimal sales quantities for the two periods are*

$$(x_1^*, x_2^* \mid \hat{b}, q, N) = \begin{cases} (q,0) & \text{if } 0\le \hat{b} < b_1 \text{ and } 0\le q\le q_{11},\\ \left(\dfrac{N\delta+2q(1-\delta)}{2(2-\delta)}, \dfrac{2q-N\delta}{2(2-\delta)}\right) & \text{if } 0\le \hat{b}<b_1 \text{ and } q_{11}<q\le q_{12},\\ \left(\dfrac{2N(1-\hat{b}+\hat{b}\delta)}{4+4\delta-3\delta^2}, \dfrac{N}{2}(1-\hat{b})-\dfrac{\delta}{2}x_1^*\right) & \text{if } 0\le\hat{b}<b_1 \text{ and } q_{12}<q,\\ (q,0) & \text{if } b_1\le\hat{b}<b_2 \text{ and } 0\le q\le q_{21},\\ \left(\dfrac{2N(1-\hat{b}+\hat{b}\delta)}{4+4\delta-3\delta^2}, \dfrac{N}{2}(1-\hat{b})-\dfrac{\delta}{2}x_1^*\right) & \text{if } b_1\le\hat{b}<b_2 \text{ and } q_{21}<q,\\ \left(\min\left(q, \dfrac{N(1-\hat{b})}{\delta}\right), 0\right) & \text{if } b_2\le\hat{b}<b_3,\\ \left(\min\left(q, \dfrac{N(1+\delta-\hat{b})}{2(1+\delta)}\right), 0\right) & \text{if } b_3\le\hat{b}. \end{cases}$$

The expressions for b_i, $i = \{1,2,3\}$, q_{11}, q_{12}, and q_{21} are provided in the appendix.

Clearly, if the order quantity is low, the retailer sells the whole amount in period 1. As the order quantity increases, it becomes more likely for him to also sell in period 2. On the other hand, when the returns price is low, the retailer sells in both periods; if it is high, then he may sell only in period 1 and return the remaining products at the end of period 2 without selling them in that period.

We subsequently analyze the ordering and contracting stages. Even though the optimal order quantities and contract parameters for the price-only contract can still be analytically determined, the equilibrium characterization of full-credit returns contracts and a comparison of the two contracts are quite cumbersome. Therefore, we focus on the two limiting cases, $\delta = 0$ (used goods have no value) and $\delta = 1$ (used goods are valued the same as new goods).

Proposition 7. (i) *In equilibrium, the manufacturer offers a full-credit returns contract to the retailer if and only if $c_r + c_m \le \hat{c}(\delta = i, \theta)$, $i = \{0,1\}$; otherwise, she offers a price-only contract, where*

$$\hat{c}(\delta=0,\theta) = \begin{cases} (1-\sqrt{1-\theta^2})/\theta & \text{if } \theta<0.5,\\ (2-\sqrt{2(1+\theta)})/(2\theta) & \text{if } \theta\ge 0.5, \end{cases} \tag{7}$$

and

$$\hat{c}(\delta=1,\theta) = \begin{cases} \dfrac{2(1-\sqrt{1-\theta^2})}{\theta} & \text{if } \theta<0.507,\\ \dfrac{2}{\theta}\left(1-\dfrac{\sqrt{2((3\theta-1)\sqrt{10(1-\theta)(3-\theta)}+9(1-\theta^2)-12(1-\theta)^2)}}{10\sqrt{1+\theta}}\right) & \text{if } 0.507\le\theta\le 0.554,\\ \dfrac{2-\sqrt{2(1+\theta)}}{\theta} & \text{if } \theta\ge 0.554. \end{cases} \tag{8}$$

(ii) *The equilibrium values for both contracts as well as the corresponding equilibrium retail order quantities are provided in Table 5.*

(iii) *$\hat{c}(\delta=1,\theta)\ge\hat{c}(\delta=0,\theta)$, i.e., it is more likely for the manufacturer to offer a returns contract for a P2P market selling used goods with higher consumer valuation.*

When $\delta = 0$, there is effectively no interaction between the two periods. We can then envisage the model in this section to be equivalent to a repeated version of the framework in §§3–5. Specifically, the equilibrium values for both types of contracts in Table 5 are the same as those in Table 3; the equilibrium retail prices for both periods (and for both

Table 5 Equilibrium Contracts and Retail Orders for Two-Period Retail Sales

	If $c_r + c_m > \hat{c}(\delta = 0, \theta)$:	If $c_r + c_m \leq \hat{c}(\delta = 0, \theta)$:
$\delta = 0$	$w^* = \begin{cases} \frac{1}{2} & \theta < \frac{1}{2}, \\ \frac{1}{4} & \theta \geq \frac{1}{2} \end{cases}$	$w^* = \frac{1}{2} + \frac{1}{2}\theta(c_r + c_m)$ $b^* = w^* + c_r = \frac{1}{2} + \frac{1}{2}\theta(c_r + c_m) + c_r$
	$q^* = \begin{cases} \frac{1}{2}(1+\theta)(1-\theta) & \theta < \frac{1}{2}, \\ \frac{1}{2}(1+\theta) & \theta \geq \frac{1}{2} \end{cases}$	$q^* = \frac{1}{2}(1+\theta)(1 - \theta(c_r + c_m))$
	If $c_r + c_m > \hat{c}(\delta = 1, \theta)$:	If $c_r + c_m \leq \hat{c}(\delta = 1, \theta)$:
$\delta = 1$	$w^* = \begin{cases} 1 & \theta < 0.507, \\ 1 - \frac{1-\theta}{1+\theta} - \frac{1}{10}\sqrt{10\frac{1-\theta}{1+\theta}\left(1 + 2\frac{1-\theta}{1+\theta}\right)} & 0.507 \leq \theta \leq 0.554, \\ \frac{1}{2} & 0.554 \leq \theta \end{cases}$	$w^* = 1 + \frac{1}{2}\theta(c_r + c_m)$ $b^* = w^* + c_r = 1 + \frac{1}{2}\theta(c_r + c_m) + c_r$
	$q^* = \begin{cases} \frac{1}{4}(1+\theta)(1-\theta) & \theta < 0.507, \\ \frac{1+\theta}{2} - \frac{1+\theta}{2}\left(1 - \frac{1-\theta}{1+\theta} - \frac{1}{10}\sqrt{10\frac{1-\theta}{1+\theta}\left(1 + 2\frac{1-\theta}{1+\theta}\right)}\right) & 0.507 \leq \theta \leq 0.554, \\ \frac{1}{4}(1+\theta) & 0.554 \leq \theta \end{cases}$	$q^* = \frac{1}{4}(1+\theta)\left(1 - \frac{\theta(c_r + c_m)}{2}\right)$

Note. p_1^*, p_u^*, and x_1^* and the equilibrium profits can be deduced from these expressions.

contracts) in this section are also the same as p_1^* in Table 3. The only difference is that the equilibrium order quantity is now twice as large (to satisfy new goods demands for two periods) as is the number of returns. Indeed, the number of leftovers in each period remains the same as before, but because all leftovers are now returned only at the end of period 2, the total return amount doubles. Consequently, the threshold returns logistics cost below which a returns contract is the equilibrium strategy remains unaltered compared to §4.

However, as δ increases, the two periods start interacting because both the cannibalization effect of the used goods market on the demand for new goods in period 2 and the p_u effect on the purchase decisions of forward-looking customers in period 1 come into play. As in §5, a returns contract still allows the manufacturer to better extract the consumer benefits obtained from selling at a higher price than a price-only one would when used goods are valued more (i.e., for higher values of δ). In addition, such a contract now helps the manufacturer to more effectively counteract the detrimental effect of demand cannibalization associated with higher δ by allowing the retailer to return. Consequently, based on the limiting values, our main insight from §5—a higher customer valuation of used goods encourages the manufacturer to offer a returns contract—still remains valid. Our numerical analysis for other values of $0 < \delta < 1$ also, in general, confirms this insight, except when the demand uncertainty level is quite low.[14] In actuality, even when $\delta = 1$ for both low and high values of θ, the threshold values in this section are similar to those of §4 because the retailer sells only in period 1 even though he is allowed to sell in both periods. When the wholesale price is high, θ is low, and so the retailer buys only a low quantity of new goods that are all sold in period 1. When θ is high, a low wholesale price induces the retailer to buy more in period 1, which raises the possibility of heightened competition from the used goods market in period 2. So it makes more sense for him to return (at the end of period 2) any leftover new goods from period 1 rather than sell them in period 2. Only for medium values of θ do we note the cannibalization-reducing effect of a returns contract in period 2. Indeed, this effect makes a returns contract now even more desirable than in §5 as evidenced by $\hat{c}(\delta = i, \theta) \geq \bar{c}(\delta = i, \theta)$, $i = \{0, 1\}$.

7. Managerial Implications and Concluding Remarks

A returns policy is a popular contracting arrangement between channel partners for a number of short life-cycle durable products such as books, video games,

[14] Because of a lack of space, the details of the numerical experiments are not included here, but they are available from the authors upon request.

fashion apparel, and toys. These durable products have also seen the emergence of P2P used goods markets as important channels for transactions in recent times. Returns policy affects sales of new products and hence the supply and price in the used goods market. This gives rise to an interesting interaction between returns policy and used goods markets from both the supply and demand perspectives. In this paper, we use a two-period, dyadic channel selling a durable product with a short selling season and facing demand uncertainty and forward-looking customer behavior to model the above interaction. We analytically derive the *necessary and sufficient condition* that drives the manufacturer's optimal contracting strategy. We also provide closed-form expressions for the associated equilibrium decisions for both channel partners. Our work bridges two disparate streams of existing literature: one related to returns contracts that focuses on perishable products in an uncertain demand environment and the other that deals with durable products in a deterministic, price-only contract setup.

Our analysis establishes that *the more customers value used goods in the P2P market, the more likely it is that the manufacturer would offer a returns policy option to the retailer*. Specifically, such a higher-valued used goods market enables the manufacturer to charge higher wholesale prices under a returns contract versus a price-only one by taking better advantage of consumers' willingness to pay higher prices for new goods. It also makes it more likely that the retailer's order quantity will be higher under a returns contract because he is effectively risk-free under such a contract. Consequently, higher consumer valuation for used goods provides the manufacturer with the potential for significant gains in terms of revenue by offering a returns contract (more than the cost increase she has to bear by offering such a contract). This result seems to be rather robust and remains generally valid irrespective of whether the demands for the two periods are perfectly or imperfectly correlated and whether the retailer can sell new goods in one period or both.[15] We also demonstrate that, in general, *medium* levels of demand uncertainties, *medium* levels of demand correlation, and *low* returns logistics costs make it more likely that a returns contract is the equilibrium outcome for the channel. Building on our analysis, we summarize the conditions under which each type of contract is the most likely equilibrium strategy in Table 6.

Table 6 **Conditions for the Most Likely Equilibrium Contracting Strategy for the Manufacturer**

Returns contract	Price-only contract
• High customer valuation of used goods	• Low customer valuation of used goods
• Medium levels of (positive) demand correlation	• Highly correlated or relatively independent demands
• Medium levels of demand uncertainty	• Very high or very low levels of demand uncertainty
• Low returns logistics costs	• High returns logistics costs

Our study also brings to light a number of important managerial implications in the context of a returns policy contract for certain durable products. First and foremost, managers need to be careful about replacing such contracts with price-only ones. This caveat is especially relevant for products that consumers do not devalue much because of their used condition. In our setting, such devaluation can come from two sources: physical deterioration as a result of usage and relative obsolescence of the product style. Concerns about sustainable development and government regulations have seen a renewed emphasis on designing more durable (i.e., less likely to deteriorate) products in a number of sectors, e.g., toys. Also, the Internet has made P2P used goods markets accessible to a much larger segment of buyers and sellers, and an increasing price sensitivity of customers is accelerating the adoption of such markets. Given that these indications suggest that used goods are not going to lose much of their consumer valuation (compared with new products) in the future, it may make more sense for managers to hold on to their returns policy contracts. Rather, it might be time that, for certain durable products for which price-only contracts have been the norm until now, manufacturers start thinking about providing retailers with the option of returning excess inventory. Obviously, if it turns out (e.g., because of certain exogenous conditions) that used goods are of very little value to consumers[16] or if the fashion quotient of the product is so high that used goods become almost obsolete, price-only contracts should be the way to go. Second, if improved handling technologies or process improvements can reduce returns logistics costs for channel partners, a returns policy would then become a more attractive proposition. On the other hand, if heavy items are involved or if fuel price increase results from the handling costs being high, a returns policy should not be offered. Third, managers should also think about customizing their returns policies depending on the demand characteristics of the product. For example, such policies should not be offered for products of highly uncertain and/or correlated demands (e.g., a very popular fashion accessory or a quite rare book).

[15] The only exception seems to be when the demand uncertainty and demand correlations are both low.

[16] For example, there are reports that soon-to-be-released Xbox 720 will not allow used games (Dyer 2012).

Returns policies should be geared toward "regular" products in the growth stage of life cycle (medium levels of demand correlation and uncertainty) and relatively valuable used goods markets.

Note that we focused on a full-credit returns policy in this paper; our numerical analysis suggests that allowing the manufacturer to offer a partial-credit policy would make a returns contract even more attractive from her viewpoint. Also, we assumed that customers are impatient, which makes sense in our context. However, analyzing a durable product model that deals with optimal contracting strategy when customers can decide to wait and buy a product (e.g., an automobile) in the presence of a used goods market would be interesting. Our intuition is that such customer patience would result in a lower incentive for the manufacturer to offer a returns option. This is because it would reduce the supply for the used goods market in period 2 by inducing some period 1 customers to wait and, hence, would decrease the cannibalization effect of the P2P market on the demand for new goods in period 2. Finally, in our model, there is a renewable set of consumers arriving in two periods. A nonrenewable market, which is also used in the durable product literature, might shed light on issues not considered in this paper. We hope that our paper can act as a stepping stone toward more research dealing with optimal contracting strategies for durable products in an uncertain demand environment.

Acknowledgments

The authors thank the editor-in-chief, Preyas Desai, the previous editor-in-chief, Eric Bradlow, an anonymous associate editor, and two anonymous referees for constructive comments that led to significant improvements in the paper. The authors are also grateful to seminar attendees at Shanghai Jiaotong University, the University of British Columbia, the University of California at Berkeley, the University of California at Los Angeles, the University of California at San Diego, the University of Miami, the Indian School of Business, Southern Methodist University, and the University of Southern California for many helpful comments and suggestions. The works of M. Gümüş and S. Ray were supported in part by research grants from the Natural Sciences and Engineering Research Council of Canada [NSERC RGPIN 355570-09 and NSERC RGPIN 249493-12], the Social Sciences and Humanities Research Council of Canada [SSHRC 214832], and Fonds de recherche sur la Société et la culture of Québec [FQRSC NP-132114]. The work of S. Yin was supported in part by research grants from the University of California at Irvine.

Appendix

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

Proof of Proposition 1. We solve the multistage game in a backward fashion starting with the retailer's optimal sales quantity x_1 (or retail price p_1) in period 1. Note from §3 that the sales of period 1 are $x_1 = N(1 - p_1 + p_u)$. In period 2, only used goods are available for sale, which are valued at $\delta \cdot v$ by customers. Assuming that $\delta > 0$, a consumer choice model yields the sales of used goods in this period as $x_u = N(1 - \frac{p_u}{\delta})$. Also using the fact that p_u is determined based on $x_u = x_1$, we can solve x_1 and p_u in terms of p_1, where $x_1 = N(1 - \frac{p_1}{1+\delta})$ and $p_u = \frac{\delta}{1+\delta} p_1$. Hence, we have the inverse demand function $p_1 = (1+\delta)(1 - \frac{x_1}{N})$. For the case when $\delta = 0$, the model essentially degenerates to the case without used goods. It is easy to see that the period 1 demand and inverse demand functions derived above for the case when $\delta > 0$ can also be applied to the case when $\delta = 0$. The retailer sets x_1 to maximize his profit $\Pi_R = -wq + p_1 x_1 + \hat{b}(q - x_1)$ subject to $0 \le x_1 \le q$. Clearly, the retailer's profit is concave in x_1 with a unique unconstrained optimal $x_1 = \frac{N}{2}(1 - \frac{\hat{b}}{1+\delta})$. Because the retailer cannot sell more than the inventory held, the optimal sales quantity should be constrained from above; i.e., $(x_1^* \mid N) = \min[\frac{N}{2}(1 - \frac{\hat{b}}{1+\delta}), q]$.

Knowing his sales strategy, before the realization of demand uncertainty, the retailer orders q units to maximize

$$\begin{aligned}\Pi_R = {} & -wq + \tfrac{1}{2}[(p_1^* x_1^* + \hat{b}(q - x_1^*))|_{N=1-\theta}] \\ & + \tfrac{1}{2}[(p_1^* x_1^* + \hat{b}(q - x_1^*))|_{N=1+\theta}].\end{aligned}$$

Following $(x_1^* \mid N)$ above, it is intuitive that if the retailer orders a low quantity, he would sell all irrespective of demand states; if he orders a medium amount, he would sell all for $N = 1+\theta$ and sell part of it for $N = 1-\theta$; and if he orders a high volume, he would sell part of it in both demand states. We solve for the retailer's optimal order quantity using this logic for wholesale price-only and full-credit returns contracts.

Characterization of the Wholesale Price-Only Contract $(b = \hat{b} = 0)$. The three cases for order quantity are (low) $q \le \frac{1-\theta}{2}$, (medium) $\frac{1-\theta}{2} \le q \le \frac{1+\theta}{2}$, and (high) $q \ge \frac{1+\theta}{2}$. In each case, substituting the corresponding $(x_1^* \mid N)$ into the retailer's expected profit function results in a different form. We examine each case below.

- *Low order quantity* q: For low values of q, the retailer's profit function can be simplified as $\Pi_R = \frac{(\delta+1)q^2}{(-1+\theta^2)} + (\delta + 1 - w)q$, which is concave in q with the unconstrained optimal quantity $q = \frac{(1+\delta-w)(1-\theta^2)}{2(1+\delta)}$. It is less than $\frac{1-\theta}{2}$ if and only if $w \ge \frac{\theta(1+\delta)}{1+\theta}$.
- *Medium order quantity* q: For medium values of q, one can easily derive the unconstrained optimal quantity $q = \frac{(1+\delta-2w)(1+\theta)}{2(1+\delta)}$, which is within the range $[\frac{1-\theta}{2}, \frac{1+\theta}{2}]$ if and only if $w \le \frac{\theta(1+\delta)}{1+\theta}$.
- *Large order quantity* q: For high values of q, it turns out that the retailer's profit always linearly decreases in q. Because of the continuity of the retailer's profit function in q, we derive $q^* = \frac{(1+\delta-2w)(1+\theta)}{2(1+\delta)}$ if $w \le \frac{\theta(1+\delta)}{1+\theta}$ and $q^* = \frac{(1+\delta-w)(1-\theta^2)}{2(1+\delta)}$ otherwise.

The manufacturer next solves for her best wholesale price to maximize $\Pi_M = wq^*$. If she charges a low wholesale price $(w \le \frac{\theta(1+\delta)}{1+\theta})$, then the retailer will order a high q and subsequently sell all of it for the high demand state and sell part of it for the low demand state. However, if the manufacturer charges a high wholesale price ($w \ge \frac{\theta(1+\delta)}{1+\theta}$), the retailer will order a low amount and sell everything for both demand states. Following this logic, if $w \le \frac{\theta(1+\delta)}{1+\theta}$, the manufacturer's best unconstrained w is $\frac{1+\delta}{4}$, which is below the upper bound if $\theta \ge \frac{1}{2}$; if $w \ge \frac{\theta(1+\delta)}{1+\theta}$, the manufacturer's best unconstrained w is $\frac{1+\delta}{2}$, which meets the constraint. Comparing the two cases of w, we observe that for low demand uncertainty ($\theta \le \frac{1}{2}$), the manufacturer should charge a high wholesale price. Hence, $w^* = \frac{1+\delta}{2}$. Accordingly, $\Pi_M^* = \frac{1}{8}(1+\delta)(1-\theta^2)$, $q^* = \frac{1-\theta^2}{4}$, and $p_1^* = \frac{(1+\delta)(2+N)}{4}$. For high demand uncertainty ($\theta \ge \frac{1}{2}$), the low wholesale price dominates. That is, $w^* = \frac{1+\delta}{4}$. Accordingly, $\Pi_M^* = \frac{1}{16}(1+\delta)(1+\theta)$, $q^* = \frac{1+\theta}{4}$, and $p_1^* = \frac{1+\delta}{2}$ for $N = 1-\theta$ and $p_1^* = \frac{3(1+\delta)}{4}$ for $N = 1+\theta$.

Note that at $\theta = \frac{1}{2}$, the manufacturer has two options about the equilibrium wholesale price—$w^* = \frac{1+\delta}{4}$ and $w = \frac{1+\delta}{2}$—both of which yield equal profits for the manufacturer. So the manufacturer is indifferent between these two options. This also implies that the manufacturer's equilibrium profit under a price-only contract is continuous in θ. However, the retailer's equilibrium profit is discontinuous at $\theta = \frac{1}{2}$ and is higher at the lower wholesale price. Throughout the paper we assume that if a player is indifferent between multiple options, he or she will choose the one benefiting the partner. Therefore, at $\theta = \frac{1}{2}$, the equilibrium wholesale price is set at $w^* = \frac{1+\delta}{4}$, and all the other equilibrium decisions follow from this option.

Characterization of the Full-Credit Returns Contract ($\hat{b} = w$). Similar to the analysis of the price-only case above, the retailer evaluates and compares his profits for the three cases of order quantities (now the boundaries of these cases are contingent on the return price) and realizes that he should always order a sufficient amount to make his subsequent sales strategy unconstrained by the inventory. In other words, he would order assuming the demand state is high; i.e., $q^* = \frac{1+\theta}{2}(1 - \frac{\hat{b}}{1+\delta})$. Note that this quantity would lead to returns only for the low demand state. The manufacturer's expected profit can then be simplified to $\Pi_M = wq^* - \frac{1}{2}(w + c_r + c_m)(q^* - x_1^*)|_{N=1-\theta}$, which is concave in w with the optimal $w^* = \frac{1+\delta}{2} + \frac{\theta(c_r+c_m)}{2}$. Accordingly,

$$\Pi_M^* = \frac{(1+\delta-\theta(c_r+c_m))^2}{8(1+\delta)}, \quad b^* = w^* + c_r,$$

$$q^* = \frac{1}{4}(1+\theta)\left(1 - \frac{\theta(c_r+c_m)}{1+\delta}\right),$$

$$p_1^* = \tfrac{3}{4}(1+\delta) + \tfrac{1}{4}\theta(c_r+c_m),$$

for $N = 1-\theta$ and $1+\theta$.

Comparing the manufacturer's equilibrium profits under price-only and returns contracts as given above, we conclude that the returns contract dominates the price-only one iff $c_r + c_m \le \bar{c}$, where

$$\bar{c}(\delta,\theta) = \begin{cases} \dfrac{(1+\delta)(1-\sqrt{1-\theta^2})}{\theta} & \text{if } \theta < \dfrac{1}{2}, \\[2ex] \dfrac{(1+\delta)(2-\sqrt{2(1+\theta)})}{2\theta} & \text{if } \theta \ge \dfrac{1}{2}. \end{cases}$$

Finally, we can easily verify the nonnegativity of $\bar{c}(\delta,\theta)$ for $\delta \in [0,1]$ and $\theta \in (0,1)$.

This proves Proposition 1.

Proof of Proposition 2. Note from Table 3 that w^*, b^*, and p_1^* under both price-only and returns contracts are linear and increasing in δ, and q^* is independent of δ under price-only contracts and increasing in δ under returns contracts (although the rates of increase are different under the two contracts).

Proof of Proposition 3. Note from Proposition 1 that $\bar{c}(\delta,\theta)$ is linear in δ. Therefore, we need to analyze the coefficients of δ. Depending on whether $\theta < \frac{1}{2}$ or not, the coefficients are, respectively, $\frac{(1-\sqrt{1-\theta^2})}{\theta}$ and $\frac{(2-\sqrt{2(1+\theta)})}{\theta}$, both of which are nonnegative since $\theta < 1$.

Proof of Proposition 4. The derivative of $\bar{c}(\delta,\theta)$ with respect to θ is

$$\frac{\partial \bar{c}(\delta,\theta)}{\partial\theta} = \begin{cases} \dfrac{(1+\delta)(1-\sqrt{1-\theta^2})}{\theta^2\sqrt{1-\theta^2}} & \text{if } \theta < \dfrac{1}{2}, \\[2ex] \dfrac{-(1+\delta)(2\sqrt{2(1+\theta)}-(2+\theta))}{\theta^2\sqrt{2(1+\theta)}} & \text{if } \theta \ge \dfrac{1}{2}. \end{cases}$$

Note that when θ is less than $\frac{1}{2}$, both the numerator and the denominator of the derivative are nonnegative. When θ is greater than $\frac{1}{2}$, the numerator is nonpositive because $2\sqrt{2(1+\theta)} \ge (2+\theta)$ for all $\theta \in (0,1)$, and the denominator is nonnegative. Hence, the $\bar{c}(\delta,\theta)$ is increasing in θ when $\theta < \frac{1}{2}$ and decreasing in θ when $\theta \ge \frac{1}{2}$.

Proof of Proposition 5. For parts (i) and (ii), let us first derive the demand function for the retailer when demands in two periods are imperfectly correlated. Recall that forward-looking customers make purchasing decisions before the realization of demand uncertainty in period 2, and they need to form expectations about the state-dependent price of used goods, denoted by ep_u. The retailer's demand in period 1 can be written as $x_1 = N_1(1 - p_1 + ep_u)$.

Suppose $N_1 = 1+\theta$, $p_{ul} = p_u|_{N_2=1-\theta}$, and $p_{uh} = p_u|_{N_2=1+\theta}$. We have $ep_u = \frac{1-\rho}{2}p_{ul} + \frac{1+\rho}{2}p_{uh}$, where $\frac{1-\rho}{2}$ and $\frac{1+\rho}{2}$ are the conditional probabilities $\text{Prob}(N_2 = 1-\theta \mid N_1 = 1+\theta)$ and $\text{Prob}(N_2 = 1+\theta \mid N_1 = 1+\theta)$, respectively, derived from the joint distribution of (N_1, N_2) given in the paper. Note that p_{ul} and p_{uh} can be generated from jointly solving used goods market-clearing equations in period 2: $x_1 = x_u|_{N_2=1-\theta}$ and $x_1 = x_u|_{N_2=1+\theta}$. Or equivalently, solving $(1+\theta)(1-p_1+ep_u) = (1-\theta)(1-p_{ul}/\delta)$ and $(1+\theta)(1-p_1+ep_u) = (1+\theta)(1-p_{uh}/\delta)$ yields $p_{ul} = \frac{\delta(\delta\theta\rho+\delta\theta-p_1+2\theta-\theta p_1)}{-\delta+\delta\theta\rho-1+\theta}$ and $p_{uh} = \frac{\delta(\delta\theta\rho+\theta p_1-\delta\theta-p_1)}{-\delta+\delta\theta\rho-1+\theta}$. Consequently, the demand function becomes

$$x_1|_{N_1=1+\theta} = \frac{(1-\theta^2)(1+\delta-p_1)}{1+\delta-\delta\theta\rho-\theta},$$

or the inverse demand function becomes

$$p_1|_{N_1=1+\theta} = (1+\delta)\left(1 - \frac{1+\delta\mu_{N_1}}{1+\delta}\frac{x_1}{N_1}\right),$$

where $\mu_{N_1} = \frac{1-\theta\rho}{1-\theta}$.

A similar approach can be applied to the case of $N_1 = 1-\theta$, which yields

$$p_{ul} = \frac{(\delta\theta\rho + \theta p_1 - \delta\theta + p_1)\delta}{\delta + \delta\theta\rho + 1 + \theta},$$

$$p_{uh} = \frac{(p_1 + \delta\theta + \delta\theta\rho + 2\theta - \theta p_1)\delta}{\delta + \delta\theta\rho + 1 + \theta},$$

$$x_1|_{N_1=1-\theta} = \frac{(1-\theta^2)(1+\delta-p_1)}{1+\delta+\delta\theta\rho+\theta},$$

$$p_1|_{N_1=1-\theta} = (1+\delta)\left(1 - \frac{1+\delta\mu_{N_1}}{1+\delta}\frac{x_1}{N_1}\right),$$

where $\mu_{N_1} = \frac{1+\theta\rho}{1+\theta}$.

Given the demand function, backward induction is again applied to solve the problem starting with the retailer's sales strategy in period 1, x_1, to maximize $\Pi_R = -wq + p_1 x_1 + \hat{b}(q - x_1)$. Since the inverse demand p_1 takes different forms for different demand states N_1, which leads to different profit functions for the retailer, we consider the two states of N_1 separately. For each demand state, substituting p_1 into the retailer's profit function yields a concave function in x_1 with the unique unconstrained optimal $x_1^{ul} = x_1|_{N_1=1-\theta} = \frac{(1-\theta^2)(1+\delta-\hat{b})}{1+\delta+\theta(1+\delta\rho)}$ and $x_1^{uh} = x_1|_{N_1=1+\theta} = \frac{(1-\theta^2)(1+\delta-\hat{b})}{1+\delta-\theta(1+\delta\rho)}$. Intuitively, the retailer sells more for a high demand state.

Note that the retailer's actual sales are bounded by the inventory ordered from the manufacturer q. The two unconstrained sales volumes derived above, x_1^{ul} and x_1^{uh}, serve as the two breakpoints for q when the retailer determines his order quantity. Similar to the case of perfect demand correlation in the proof of Proposition 1, the retailer needs to consider three options of q: low, medium, or high. We study this problem in price-only and returns contracts separately.

Characterization of the Wholesale Price-Only Contract. Similar to the perfect demand correlation case in the proof of Proposition 1,

- if the retailer orders a low volume ($q \le x_1^{ul}$), the unconstrained optimal $q = \frac{(1-\theta^2)(1+\delta-w)}{2(1+\delta)}$;
- if he orders a medium volume ($q \in [x_1^{ul}, x_1^{uh}]$), the unconstrained optimal $q = \frac{(1-\theta^2)(1+\delta-2w)}{2(1+\delta-\theta(1+\delta\rho))}$; and
- if he orders a high volume ($q \ge x_1^{uh}$), his profit function linearly decreases in q, and hence it is always dominated by other options because of the continuity of his profit in q.

Comparison of the low and medium volume cases results in the retailer ordering a medium volume, $q^* = \frac{(1-\theta^2)(1+\delta-2w)}{2(1+\delta-\theta(1+\delta\rho))}$, if the wholesale price is low ($w \le \frac{\theta(1+\delta)(1+\delta\rho)}{1+\delta+\theta(1+\delta\rho)}$), and ordering a low volume, $q^* = \frac{(1-\theta^2)(1+\delta-w)}{2(1+\delta)}$, otherwise. Knowing the structure of the retailer's best order quantity, the manufacturer then evaluates and compares low and high wholesale prices to maximize $\Pi_M = wq^*$. Simple analysis indicates that the manufacturer would charge a high wholesale price, $w^* = \frac{1+\delta}{2}$, if demand uncertainty is low ($\theta \le \theta_1 = \frac{1+\delta}{2(1+\rho\delta)}$), since she would not lose much in the order quantity in this case. Accordingly, $\Pi_M^* = \frac{1}{8}(1-\theta^2)(1+\delta)$ and $q^* = \frac{1}{4}(1-\theta^2)$. However, for high demand uncertainty ($\theta \ge \theta_1$), the manufacturer would charge a low price, $w^* = \frac{1+\delta}{4}$, to encourage the retailer to order more. Accordingly, $\Pi_M^* = \frac{(1-\theta^2)(1+\delta)^2}{16(1+\delta-\theta(1+\delta\rho))}$ and $q^* = \frac{(1-\theta^2)(1+\delta)}{4(1+\delta-\theta(1+\delta\rho))}$. Similar to the characterization of the price-only contract in the base model in the proof of Proposition 1, at $\theta = \theta_1$, the manufacturer is indifferent between the two options for the equilibrium wholesale price. However, the retailer prefers the lower wholesale price, $w^* = \frac{1+\delta}{4}$. Hence, at $\theta = \theta_1$, the equilibrium decisions and profits follow from the lower equilibrium wholesale price.

Characterization of the Full-Credit Returns Contract ($\hat{b} = w$). The analysis of the retailer's best order quantity is analogous to that in the proof of Proposition 1 for $\rho = 1$. Because of the full-credit return, he should order a sufficient volume to match his sales quantity under the high demand state in period 1; i.e., $q^* = x_1^{uh} = \frac{(1-\theta^2)(1+\delta-w)}{2(1+\delta-\theta(1+\delta\rho))}$. Because returns occur only when N_1 is low, the manufacturer's profit function can be written as $\Pi_M = wq^* - \frac{1}{2}(w + c_r + c_m)\cdot(q^* - x_1^*)|_{N_1=1-\theta}$, which is concave in w with the optimal $w^* = \frac{1+\delta}{2} + \frac{\theta(c_r+c_m)(1+\delta\rho)}{2(1+\delta)}$. Accordingly,

$$\Pi_M^* = \frac{(1-\theta^2)[(1+\delta)^2 - \theta(c_r+c_m)(1+\delta\rho)]^2}{8(1+\delta)[1+\delta+\theta(1+\delta\rho)][1+\delta-\theta(1+\delta\rho)]},$$

$$b^* = w^* + c_r,$$

$$q^* = \frac{(1-\theta^2)[(1+\delta)^2 - \theta(c_r+c_m)(1+\delta\rho)]}{4[(1+\delta)^2 - \theta(1+\delta)(1+\delta\rho)]}.$$

Comparing the manufacturer's equilibrium profits under price-only and returns contracts as given above, we conclude that the returns contract dominates the price-only one if $c_r + c_m \le \tilde{c}$, where

$$\tilde{c}(\delta,\theta,\rho) = \begin{cases} \tilde{c}_1 = \dfrac{1+\delta}{\theta(1+\rho\delta)}[(1+\delta) - \sqrt{(1+\delta)^2 - \theta^2(1+\rho\delta)^2}] \\ \quad \text{if } \theta < \theta_1 = \dfrac{1+\delta}{2(1+\rho\delta)}, \\ \tilde{c}_2 = \dfrac{1+\delta}{2\theta(1+\rho\delta)}[2(1+\delta) - \sqrt{2(1+\delta)(1+\delta+\theta+\rho\delta\theta)}] \\ \quad \text{if } \theta \ge \theta_1. \end{cases}$$

When demands in the two periods are not perfectly correlated, $\rho < 1$, it is possible to observe inventory rationing issue where used goods cannot be all cleared out at a nonnegative price. Hence, to avoid this issue, we need to ensure the nonnegativity of the four used goods prices $p_u(N_1, N_2)$ under both contracts. Using the equilibrium values derived above, one can easily identify the condition to be $\theta \le \bar{\theta} = \frac{3(1+\delta)}{(\delta+4\rho\delta+5)}$ and $\bar{\theta} \ge \theta_1$.

For part (iii), we analyze the sensitivity of $\tilde{c}_1(\delta,\theta,\rho)$ and $\tilde{c}_2(\delta,\theta,\rho)$ that are characterized in the first part of this proof with respect to δ. First, we start with $\tilde{c}_2(\delta,\theta,\rho)$. Note that $\tilde{c}_2(\delta,\theta,\rho)$ can be written as $\tilde{c}_2(\delta,\theta,\rho) = \tilde{u}_2(\delta,\theta,\rho)\tilde{t}_2(\delta,\theta,\rho)$, where $\tilde{u}_2(\delta,\theta,\rho) = \frac{1+\delta}{2\theta(1+\rho\delta)}$ and $\tilde{t}_2(\delta,\theta,\rho) = 2(1+\delta) - \sqrt{2(1+\delta)(1+\delta+\theta+\rho\delta\theta)}$. Clearly, the first term $\tilde{u}_2(\delta,\theta,\rho)$ is increasing in δ, because $0 \le \rho \le 1$. For the second term, $\tilde{t}_2(\delta,\theta,\rho)$, taking its derivative with respect to δ, we obtain

$$\frac{\partial \tilde{t}_2(\delta,\theta,\rho)}{\partial\delta} = 2 - \sqrt{\frac{(1+\theta)(1+\delta\mu_\rho^+)}{2(1+\delta)}} - \sqrt{\frac{(1+\theta)(1+\delta)\mu_\rho^+}{2(1+\delta\mu_\rho^+)}},$$

where $\mu_\rho^+ = \frac{1+\theta\rho}{1+\theta}$. Using the fact that $\mu_\rho^+ \le 1$, we can easily show that the second and third terms in this expression are bounded by 2; hence, $\tilde{t}_2(\delta,\theta,\rho)$ is also increasing in δ. Now, we analyze $\tilde{c}_1(\delta,\theta,\rho)$. Note that it can be written as $\tilde{c}_1(\delta,\theta,\rho) = \tilde{u}_1(\delta,\theta,\rho)\tilde{t}_1(\delta,\theta,\rho)$, where $\tilde{u}_1(\delta,\theta,\rho) = \frac{1+\delta}{\theta(1+\rho\delta)}$, and $\tilde{t}_1(\delta,\theta,\rho) = (1+\delta) - \sqrt{(1+\delta)^2 - \theta^2(1+\rho\delta)^2} = (1+\delta) - \sqrt{(1+\theta)(1-\theta)(1+\delta\mu_\rho^+)(1+\delta\mu_\rho^-)}$, where $\mu_\rho^- = \frac{1-\theta\rho}{1-\theta}$.

The first term, i.e., $\tilde{u}_1(\delta, \theta, \rho)$, is always increasing in δ due to $\rho \le 1$. Now, taking the derivative of the second term with respect to δ, we obtain

$$\frac{\partial \tilde{t}_1(\delta,\theta,\rho)}{\partial \delta} = 1-\frac{1}{2} \cdot \frac{(1+\theta)(1-\theta)\mu_\rho^+(1+\delta\mu_\rho^-)+(1+\theta)(1-\theta)(1+\delta\mu_\rho^+)\mu_\rho^-}{\sqrt{(1+\theta)(1-\theta)(1+\delta\mu_\rho^+)(1+\delta\mu_\rho^-)}}.$$

Using the facts that $\mu_\rho^+ \le 1$ and $\mu_\rho^- \ge 1$, one can easily show that $\frac{\partial \tilde{t}_1(\delta,\theta,\rho)}{\partial \delta}$ is nonnegative as long as $\rho \ge \rho_1 = \frac{1-\sqrt{1-\theta^2}}{\theta^2}$, which implies that $\tilde{t}_1(\delta, \theta, \rho)$ is always increasing in δ.

Proof of Proposition 6. We first derive the inverse demand functions for the retailer in both periods.

Derivation of Inverse Demand Functions. Recall that in each period, N customers arrive with valuations uniformly distributed between 0 and 1. For period 1 customers, they consider resale value p_u in their purchase decisions and buy the product if $p_1 - p_u \le v$; otherwise, they leave the market. Hence, demand in period 1, x_1, can be expressed as $x_1 = N(1 - p_1 + p_u)$. For period 2 customers, recall that they discount used product with δ, where $\delta \in [0, 1]$. If $0 < \delta < 1$, period 2 customers have three options: (i) pay p_2 and buy a new product, (ii) pay p_u and buy a used product, or (iii) leave the market. So we can segment the customers into three subsegments depending on their valuations. Specifically, the customers whose valuations are between $\frac{p_2-p_u}{1-\delta}$ and 1 buy the new product, customers whose valuations are between $\frac{p_u}{\delta}$ and $\frac{p_2-p_u}{1-\delta}$ buy the used good, and the rest leave the market. Also note that the number of customers who buy used goods (x_u) should be equal to the sales in the first period (x_1); i.e., $x_1 = x_u$. Letting x_2 be the number of customers who purchase the new product in the second period, we can express the following relations: $x_u = N(\frac{p_2-p_u}{1-\delta} - \frac{p_u}{\delta})$ and $x_2 = N(1 - \frac{p_2-p_u}{1-\delta})$. Solving the above three equations for p_1, p_2, and p_u, we can express the inverse demand functions and clearance price for the used goods in terms of sales in the first and second periods x_1 and x_2 as follows:

$$p_1 = (1+\delta)\left[1-\frac{x_1}{N}-\frac{\delta x_2}{(1+\delta)N}\right], \quad p_2 = 1-\frac{\delta x_1}{N}-\frac{x_2}{N},$$
$$\text{and} \quad p_u = \delta\left(1-\frac{x_1+x_2}{N}\right).$$

If $\delta = 0$, there are essentially no used goods in the market in period 2, and the retailer's sales in both periods become independent, which can be simplified to $x_i = N(1 - p_i)$ for $i \in \{1, 2\}$. Or equivalently, the inverse demand functions for new goods become $p_i = 1 - \frac{x_i}{N}$ and $p_u = 0$.

If $\delta = 1$ in period 2, the used goods are valued the same as new goods, which leads to $p_2 = p_u$ and $x_1 = x_u = x_2 = \frac{N(1-p_2)}{2} = \frac{N(1-p_u)}{2}$. So $p_2 = p_u = 1 - \frac{x_1+x_2}{N} = 1 - \frac{2x_1}{N} = 1 - \frac{2x_2}{N}$, and subsequently, $p_1 = 2[1 - \frac{x_1}{N} - \frac{x_2}{2N}] = 2[1 - \frac{3x_1}{2N}]$. This indicates that the total demand realized in period 2 would be equally allocated to new and used goods.

By substituting $\delta = 0$ or $\delta = 1$ into the inverse demand functions given above for the case when $0 < \delta < 1$, it is then straightforward to verify that these inverse demand functions can also be applied to the extreme cases when $\delta = 0$ and $\delta = 1$.

Characterization of the Pricing/Sales Stage. Redefining $\hat{b}$ as $(b - c_r)^+$ and substituting the above price expressions, the retailer's optimization problem in the pricing stage can be expressed as follows:

$$\max_{0\le x_1\le q}\left\{p_1x_1 + \max_{0\le x_2\le (q-x_1)}\{p_2x_2 + \hat{b}(q-x_1-x_2)\}\right\}. \quad (9)$$

Using backward induction, we first solve for the retailer's best sales strategy in period 2 given his sales strategy in period 1, $x_2^*(x_1)$, to maximize the retailer's profit in period 2 only: $\Pi_R^2 = p_2x_2 + \hat{b}(q - x_1 - x_2)$, where $0 \le x_2 \le q - x_1$. Substituting the inverse demand function $p_2(x_1, x_2)$ into this profit expression results in a concave function in x_2 with the unconstrained optimal $x_2^u = \frac{N(1-\hat{b})}{2} - \frac{\delta x_1}{2}$. This value can be global optimum only if the leftover inventory from period 1 is sufficient; i.e., $q - x_1$ is high. Specifically, we have x_2^* as follows:

- For a low total inventory level ($q \le \frac{N(1-\hat{b})}{2}$), the retailer sells all and leaves no inventory; i.e., $x_2^* = q - x_1$.
- For a medium level of total inventory ($q \in [\frac{N(1-\hat{b})}{2}, \frac{N(1-\hat{b})}{\delta}]$), the retailer sells all if the leftover from period 1 is small and keeps some inventory otherwise; i.e., $x_2^* = q - x_1$ if $x_1 \ge \frac{2q-N(1-\hat{b})}{2-\delta}$ and $x_2^* = x_2^u$ otherwise.
- For a high level of total inventory ($q \ge q_{31} = \frac{N(1-\hat{b})}{\delta}$), $x_2^* = 0$ if $x_1 \ge \frac{N(1-\hat{b})}{\delta}$ and $x_2^* = x_2^u$ otherwise.

Knowing his sales strategy in period 2 as derived above, the retailer determines his sales strategy in period 1 contingent on the total inventory level q.

For a *low inventory level* ($q \le \frac{N(1-\hat{b})}{2}$), the retailer decides between selling all in period 1 and selling in both periods, since $x_2^* = q - x_1$. Indeed, if the inventory is very low, i.e., $q \ge q_{11} = \frac{N\delta}{2}$, he would sell all in period 1, i.e., $x_1^* = q$; otherwise, he would sell the unconstrained amount $x_1^* = \frac{N\delta+2q(1-\delta)}{2(2-\delta)}$.

Consider another extreme, the case of a *high inventory level* ($q \ge q_{31} = \frac{N(1-\hat{b})}{\delta}$). Some inventory will be left at the end of period 2. The retailer decides whether to sell only in period 1 and return the rest ($x_1 \ge \frac{N(1-\hat{b})}{\delta}$ and $x_2^* = 0$) or to sell in both periods ($x_1 \le \frac{N(1-\hat{b})}{\delta}$ and $x_2^* = x_2^u$). Indeed, if the return price is low ($\hat{b} \le b_2 = \frac{4+2\delta-3\delta^2}{4+2\delta-\delta^2}$), the latter case is optimal and ($x_1^* = \frac{2N(1-\hat{b}+\hat{b}\delta)}{4+4\delta-3\delta^2}$, $x_2^* = x_2^u(x_1^*)$); otherwise, the former dominates with $x_2^* = 0$ always and $x_1^* = \frac{N(1-\hat{b})}{\delta}$ if $b_2 \le \hat{b} \le b_3 = \frac{(1+\delta)(2-\delta)}{2+\delta}$ and $x_1^* = \min[q, q_{41} = \frac{N(1+\delta-\hat{b})}{2(1+\delta)}]$ otherwise.

Finally, for a *medium inventory level* ($q \in [\frac{N(1-\hat{b})}{2}, \frac{N(1-\hat{b})}{\delta}]$), the retailer will sell in both periods. But his trade-off now is whether to sell all ($x_1 \ge \frac{2q-N(1-\hat{b})}{2-\delta}$ and $x_2^* = q - x_1$) or leave some inventory unsold in the end ($x_1 \le \frac{2q-N(1-\hat{b})}{2-\delta}$ and $x_2^* = x_2^u$). In summary, if the inventory level is relatively low, selling all is optimal; otherwise, leaving some inventory unsold is optimal. Specifically, for

$$b \le b_1 = \frac{3\,\delta^3 - 7\,\delta^2 - 4\,\delta + 8 + \sqrt{-10\,\delta^6 + 4\,\delta^5 + 8\,\delta^4 + 3\,\delta^7}}{\delta^2 - 4\,\delta + 8},$$

we have

$$x_1^* = \min\left[q, \frac{N\delta + 2q(1-\delta)}{2(2-\delta)}\right], \quad x_2^* = q - x_1^*$$

if

$$q \le q_{12} = \big(N(4\delta\hat{b} - 6\delta - 4 + 4\hat{b} + 2\delta^2 + 3\delta^3 - 3\hat{b}\delta^2 - (1 - \hat{b} + \delta\hat{b})\sqrt{\delta^2(3\delta+2)})\big) \cdot (2(3\delta+2)(\delta^2 - \delta - 1))^{-1}$$

and

$$x_1^* = \frac{2N(1 - \hat{b} + \hat{b}\delta)}{4 + 4\delta - 3\delta^2}, \quad x_2^* = x_2^u(x_1^*)$$

otherwise. For $b_1 \le \hat{b} \le b_2$, we have $x_1^* = q$, $x_2^* = 0$ if

$$q \le q_{21} = \Big(N(3\delta^3 - \delta^2 - 8\delta + 4\delta\hat{b} + 4\hat{b} - 4 - 3\hat{b}\delta^2 - \sqrt{(3\delta+2)(\delta-2)(3\delta^4 - \delta^3 + \delta^3\hat{b}^2 - 8\delta^2 + 8\hat{b}\delta^2 - 8\hat{b} + 4\hat{b}^2 + 4)})\Big) \cdot (2(3\delta+2)(\delta-2)(1+\delta))^{-1}$$

and

$$x_1^* = \frac{2N(1 - \hat{b} + \hat{b}\delta)}{4 + 4\delta - 3\delta^2}, \quad x_2^* = x_2^u(x_1^*)$$

otherwise. Finally, for $\hat{b} \ge b_2$, we have $x_1^* = q$, $x_2^* = 0$.

Combining the above cases gives the optimal sales strategy (x_1^*, x_2^*) as provided in Proposition 6 where the threshold values b_i, $i = \{1, 2, 3\}$, q_{11}, q_{12}, and q_{21} are provided.

Proof of Proposition 7. We first prove the $\delta = 0$ case.

Equilibrium Characterization for $\delta = 0$. Note from the proof of Proposition 6 that when $\delta = 0$, the inverse demand functions for both periods become symmetric. Therefore, as shown in Proposition 6, the equilibrium sales in both periods are exactly the same and equal to x_1^* in Proposition 1. This implies that the equilibrium order quantity is now twice as large (to satisfy new goods demands for two periods) and so is the amount of returns. Indeed, the amount of leftovers in each period remains the same as before, but because all leftovers are now returned only at the end of period 2, the total return amount doubles. Consequently, the threshold returns logistics cost below which a returns contract is the equilibrium strategy remains the same as the one characterized in Proposition 1; i.e.,

$$\hat{c}(\delta = 0, \theta) = \begin{cases} (1 - \sqrt{1 - \theta^2})/\theta & \text{if } \theta < 0.5, \\ (2 - \sqrt{2(1+\theta)})/(2\theta) & \text{if } \theta \ge 0.5. \end{cases} \tag{10}$$

Equilibrium Characterization for $\delta = 1$. To simplify the proof of equilibrium characterization for the $\delta = 1$ case, we normalize the high and low demand states, i.e., $1 + \theta$ and $1 - \theta$, to 1 and γ, respectively, by setting $\gamma = \frac{1-\theta}{1+\theta}$. Note that high values of γ represent low levels of uncertainty, and vice versa. With this renormalization, the sales, order quantities, and expected profits can be redefined to be

$$N \to (1+\theta)\hat{N}, \quad q \to (1+\theta)\hat{q}, \quad \hat{x}_1 \to (1+\theta)\hat{x}_1,$$
$$\hat{x}_2 \to (1+\theta)\hat{x}_2, \quad \Pi_R \to (1+\theta)\hat{\Pi}_R, \quad \text{and} \quad \Pi_M \to (1+\theta)\hat{\Pi}_M.$$

Under the above transformation, the retail prices as well as the contract variables stay the same. Using the above renormalized decision variables and profit expressions, we now prove the $\delta = 1$ case.

We first characterize the equilibrium values under a wholesale price-only contract, i.e., $b = 0$, and under a full-credit returns policy, i.e., $\hat{b} = w$. We then compare the manufacturer's equilibrium profits under both scenarios to derive the threshold value for the logistics costs below which a full return is offered in equilibrium.

Characterization of the Wholesale Price-Only Contract Under $\delta = 1$. Given the retailer's selling strategy in the pricing stage, he needs to determine the order quantity before observing the demand randomness $\hat{N}$ to maximize his expected profit $\hat{\Pi}_R = -w\hat{q} + \frac{1}{2}[(p_1^*\hat{x}_1^* + p_2^*\hat{x}_2^*)|_{\hat{N}=\gamma} + (p_1^*\hat{x}_1^* + p_2^*\hat{x}_2^*)|_{\hat{N}=1}]$. Depending on low or high values of the low demand state γ, we consider two different scenarios.

(a) For high uncertainty levels (i.e., low values of γ, $\gamma \le \frac{5}{5+\sqrt{5}}$), according to Proposition 6, the retailer needs to evaluate five options for $\hat{q}$. The general idea is that, depending on realization of demand states, if order quantity $\hat{q}$ is low, the retailer would sell everything in one or both periods; otherwise, he would only sell part of his inventory to maintain high prices. Note that each option of $\hat{q}$ generates a corresponding concave profit function for the retailer, and one can easily derive the unique unconstrained optimal $\hat{q}$. Since the retailer's profit function is continuous in $\hat{q}$ for its whole range, a comparison of these options for $\hat{q}$ leads to

$$\hat{q}^* = \hat{q}_{31} = \frac{1-w}{2} \quad \text{if } w \le 1 - \gamma - \frac{\sqrt{10\gamma(1+2\gamma)}}{10},$$

$$\hat{q}^* = \hat{q}_{21} = \frac{(3-2w)\gamma}{2(1+2\gamma)} \quad \text{if } 1 - \gamma - \frac{\sqrt{10\gamma(1+2\gamma)}}{10} \le w \le 1 - \gamma,$$

and

$$\hat{q}^* = \hat{q}_{11} = \frac{(2-w)\gamma}{2(1+\gamma)} \quad \text{otherwise.}$$

(b) For low uncertainty levels (i.e., high values of γ, $\gamma \ge \frac{5}{5+\sqrt{5}}$), a similar approach to (a) yields $\hat{q}^* = \hat{q}_{21}$ if $w \le 1 - \gamma$, and $\hat{q}^* = \hat{q}_{11}$ otherwise. Combining the analysis in cases (a) and (b), the retailer's optimal order quantity is as follows:

$$\hat{q}^* = \begin{cases} \hat{q}_{31} = \dfrac{1-w}{2} \\ \quad \text{if } \gamma \le \dfrac{5}{8} \text{ and } w \le 1 - \gamma - \dfrac{\sqrt{10\gamma(1+2\gamma)}}{10}, \\ \hat{q}_{21} = \dfrac{(3-2w)\gamma}{2(1+2\gamma)} \\ \quad \text{if } \gamma \le \dfrac{5}{8} \text{ and } 1 - \gamma - \dfrac{\sqrt{10\gamma(1+2\gamma)}}{10} \\ \qquad \le w \le 1 - \gamma, \text{ or if } \gamma \ge \dfrac{5}{8} \text{ and } w \le 1 - \gamma, \\ \hat{q}_{11} = \dfrac{(2-w)\gamma}{2(1+\gamma)} \\ \quad \text{if } \gamma \le \dfrac{5}{8} \text{ and } w \ge 1 - \gamma, \\ \qquad \text{or if } \gamma \ge \dfrac{5}{8} \text{ and } w \ge 1 - \gamma. \end{cases} \tag{11}$$

Knowing the retailer's best order quantity, the manufacturer sets her optimal wholesale price w to maximize $\hat{\Pi}_M =$

$w\hat{q}$. According to (11), for low values of γ ($\boldsymbol{\gamma} \le \frac{5}{8}$), the manufacturer can charge a low, medium, or high wholesale price, which subsequently leads to optimal order quantity $\hat{q}_{31}$, $\hat{q}_{21}$, or $\hat{q}_{11}$. Each option of w yields a concave profit function for the manufacturer, and a comparison of the three options yields

$$(\hat{w}^*, \hat{q}^*) = \begin{cases} (1/2, \hat{q}_{31}) & \text{if } \gamma \le 0.287, \\ \left(1-\gamma-\dfrac{\sqrt{10\gamma(1+2\gamma)}}{10}, \hat{q}_{31}\right) & \text{if } 0.287 \le \gamma \le 0.327, \\ (1, \hat{q}_{11}) & \text{if } 0.327 < \gamma \le 5/8. \end{cases} \tag{12}$$

Note that at $\gamma = 0.327$, the manufacturer is indifferent between the two options for the equilibrium wholesale price ($1-\gamma-\frac{\sqrt{10\gamma(1+2\gamma)}}{10}$ and 1). However, the retailer prefers the lower wholesale price. Hence, at $\gamma = 0.327$, the equilibrium decisions and profits follow from the lower equilibrium wholesale price. For high values of γ ($\gamma \ge \frac{5}{8}$), according to (11), the manufacturer has two options about w: $w \le 1-\gamma$ or $w \ge 1-\gamma$. Similarly, one can derive $\hat{w}^* = 1$ and $\hat{q}^* = \hat{q}_{11}$, which extends the last case in (12) to all $\gamma > 0.327$. Accordingly, the manufacturer's equilibrium profit under a price-only contract is

$$\hat{\Pi}^*_M = \begin{cases} \dfrac{1}{8} & \text{if } \gamma \le 0.287, \\ \dfrac{1}{2}\left(1-\gamma-\dfrac{\sqrt{10\gamma(1+2\gamma)}}{10}\right)\left(\gamma+\dfrac{\sqrt{10\gamma(1+2\gamma)}}{10}\right) & \\ & \text{if } 0.287 \le \gamma \le 0.327, \\ \dfrac{\gamma}{2(1+\gamma)} & \text{if } \gamma > 0.327. \end{cases} \tag{13}$$

Characterization of the Full-Credit Returns Contract Under $\delta = 1$. Again, given $\hat{b} = w$ and knowing his selling strategy in the pricing stage, the retailer determines his order quantity before demand uncertainty $\hat{N}$ is realized to maximize his expected profit $\hat{\Pi}_R = -w\hat{q} + \frac{1}{2}[(p_1^*\hat{x}_1^* + p_2^*\hat{x}_2^* + \hat{b}(\hat{q} - \hat{x}_1^* - \hat{x}_2^*))|_{\hat{N}=\gamma} + (p_1^*\hat{x}_1^* + p_2^*\hat{x}_2^* + \hat{b}(\hat{q} - \hat{x}_1^* - \hat{x}_2^*))|_{\hat{N}=1}]$. Following $(\hat{x}_1^*, \hat{x}_2^*)$ in Proposition 6, contingent on w, we consider four cases.

(a) For high values of w ($w \ge \frac{2}{3}$), similar to the price-only case, the retailer needs to evaluate options of low, medium, or high order quantities, resulting in different but concave profit functions. Comparison of these options yields $\hat{q}^* = q_{21} = \frac{2-w}{4}$. Accordingly, $(\hat{x}_1^*, \hat{x}_2^*) = (\frac{\gamma(2-w)}{4}, 0)$ for $\hat{N} = \gamma$ and $(\hat{x}_1^*, \hat{x}_2^*) = (\hat{q}^*, 0)$ for $\hat{N} = 1$.

(b) For medium-high values of w ($\frac{3}{5} \le w \le \frac{2}{3}$), again, the retailer evaluates low, medium and high order quantities and compares his profit in these options. His best order quantity is $\hat{q}^* = q_{11} = \frac{\gamma(2-w)}{2(1+\gamma)}$ if $\gamma \le 0.825$, or if $\gamma \ge 0.825$ and

$$w \ge w_1 = \frac{2(2\gamma^2 + 5\gamma - 1 - 2\sqrt{\gamma^4 - \gamma^3 - \gamma^2 + \gamma})}{8\gamma^2 + 11\gamma - 1};$$

otherwise, $\hat{q}^* = q_{31} = \frac{2-w}{4}$. Also, when $\hat{q}^* = q_{31}$, $(\hat{x}_1^*, \hat{x}_2^*) = (\gamma(1-w), 0)$ for $\hat{N} = \gamma$ and $(\hat{x}_1^*, \hat{x}_2^*) = (\hat{q}^*, 0)$ for $\hat{N} = 1$. When $\hat{q}^* = q_{11}$, $(\hat{x}_1^*, \hat{x}_2^*) = (\hat{q}^*, 0)$ for $\hat{N} = \gamma$ or 1.

(c) For medium-low values of w ($\frac{\sqrt{5}}{5} \le w \le \frac{3}{5}$), the retailer considers another three options for his order quantities. A comparison of these options leads to $\hat{q}^* = q_{41} = \frac{2-w}{4}$ if $\gamma \le 0.689$, or if $0.689 \le \gamma \le 0.825$ and

$$w \ge w_2 = \frac{10\gamma^2 - 20\gamma + 10 + \sqrt{-80\gamma^4 + 110\gamma^3 + 100\gamma^2 - 90\gamma}}{5(2\gamma^2 - \gamma + 1)};$$

otherwise, $\hat{q}^* = q_{11} = \frac{\gamma(2-w)}{2(1+\gamma)}$. Also, when $\hat{q}^* = q_{41}$, $(\hat{x}_1^*, \hat{x}_2^*) = (\frac{2\gamma}{5}, (\frac{3}{10} - \frac{w}{2})\gamma)$ for $\hat{N} = \gamma$ and $(\hat{x}_1^*, \hat{x}_2^*) = (\hat{q}^*, 0)$ for $\hat{N} = 1$. When $\hat{q}^* = q_{11}$, $(\hat{x}_1^*, \hat{x}_2^*) = (\hat{q}^*, 0)$ for $\hat{N} = \gamma$ or 1.

(d) For low values of w ($w \le \frac{\sqrt{5}}{5}$), the analysis is slightly more involved since the retailer's profit function form depends on both γ and $\hat{q}$. We consider low and high values of γ. For low values of γ ($\gamma \le 0.691$), the retailer's profit function can take five different forms contingent on $\hat{q}$. Analyzing and comparing these options gives $\hat{q}^* = q_{41} = \frac{2-w}{4}$ if $\gamma \le 0.625$, or if $0.625 \le \gamma \le 0.662$ and

$$w \ge w_5 = \frac{10 - 10\gamma - \sqrt{20\gamma^2 + 10\gamma}}{5(1-2\gamma)},$$

or if $0.662 \le \gamma \le 0.689$ and $w \ge w_2$; $\hat{q}^* = q_{51} = \frac{\gamma(3-2w)}{2(1+2\gamma)}$ if $0.625 \le \gamma \le 0.662$ and $w \le w_5$, or if $0.662 \le \gamma \le 0.691$ and $w \le 1-\gamma$; otherwise, $\hat{q}^* = q_{11} = \frac{\gamma(2-w)}{2(1+\gamma)}$. Also, when $\hat{q}^* = q_{51}$, $(\hat{x}_1^*, \hat{x}_2^*) = (\frac{\gamma}{2}, \hat{q}^* - \frac{\gamma}{2})$ for $\hat{N} = \gamma$, and $(\hat{x}_1^*, \hat{x}_2^*) = (\hat{q}^*, 0)$ for $\hat{N} = 1$; when $\hat{q}^* = q_{41}$, $(\hat{x}_1^*, \hat{x}_2^*) = (\frac{2\gamma}{5}, (\frac{3}{10} - \frac{w}{2})\gamma)$ for $\hat{N} = \gamma$, and $(\hat{x}_1^*, \hat{x}_2^*) = (\hat{q}^*, 0)$ for $\hat{N} = 1$; and when $\hat{q}^* = q_{11}$, $(\hat{x}_1^*, \hat{x}_2^*) = (\hat{q}^*, 0)$ for $\hat{N} = \gamma$ or 1. For high values of γ ($\gamma \ge 0.691$), a similar analysis indicates that $\hat{q}^* = q_{51}$ if $w \le 1-\gamma$ and $\hat{q}^* = q_{11}$ otherwise, which continuously extends the cases for low values of γ.

To facilitate the manufacturer's problem, we next summarize the optimal $\hat{q}$ in terms of w for any given γ.

- For $\gamma \le 0.625$, $\hat{q}^* = q_{41}$ if $w \le \frac{3}{5}$ and $\hat{q}^* = q_{31}$ if $\frac{3}{5} \le w \le \frac{2}{3}$; otherwise, $\hat{q}^* = q_{21}$.
- For $0.625 \le \gamma \le 0.662$, $\hat{q}^* = q_{51}$ if $w \le w_5$, $\hat{q}^* = q_{41}$ if $w_5 \le w \le \frac{3}{5}$, and $\hat{q}^* = q_{31}$ if $\frac{3}{5} \le w \le \frac{2}{3}$; otherwise, $\hat{q}^* = q_{21}$.
- For $0.662 \le \gamma \le 0.825$, $\hat{q}^* = q_{51}$ if $w \le 1-\gamma$, $\hat{q}^* = q_{11}$ if $1-\gamma \le w \le w_2$, $\hat{q}^* = q_{41}$ if $w_2 \le w \le \frac{3}{5}$, and $\hat{q}^* = q_{31}$ if $\frac{3}{5} \le w \le \frac{2}{3}$; otherwise, $\hat{q}^* = q_{21}$.
- For $\gamma \ge 0.825$, $\hat{q}^* = q_{51}$ if $w \le 1-\gamma$, $\hat{q}^* = q_{11}$ if $1-\gamma \le w \le w_1$, and $\hat{q}^* = q_{31}$ if $w_1 \le w \le \frac{2}{3}$; otherwise, $\hat{q}^* = q_{21}$.

Next, the manufacturer determines $w = \hat{b}$ to maximize $\hat{\Pi}_M = w\hat{q} - \frac{1}{2}(\hat{b} + c_r + c_m)[(\hat{q}^* - \hat{x}_1^* - \hat{x}_2^*)|_{\hat{N}=\gamma} + (\hat{q}^* - \hat{x}_1^* - \hat{x}_2^*)|_{\hat{N}=1}]$. From the analysis for the optimal $\hat{q}$, it is known that when $\hat{N} = 1$, the retailer will always order a quantity such that all units will be sold in period 1, and hence there is no return. Thus, the manufacturer's expected profit function can be simplified to $\hat{\Pi}_M = w\hat{q} - \frac{1}{2}(w + c_r + c_m)[(\hat{q}^* - \hat{x}_1^* - \hat{x}_2^*)|_{\hat{N}=\gamma}]$. For each of the above four cases of the low demand state γ, contingent on the range of the wholesale price, the manufacturer's expected profit function takes different forms. Hence, she needs to compare her best possible profits in various ranges for the wholesale price to derive her best price. In each case of γ, it is fairly easy to identify that the manufacturer always charges $w^* = w_{21} = 1 + \frac{(1-\gamma)(c_r+c_m)}{2(1+\gamma)}$, and her equilibrium profit is

$$\hat{\Pi}_M^* = \frac{(2+2\gamma)^2}{32(1+\gamma)} - \frac{2(1-\gamma)(1+\gamma)(c_r+c_m)}{16(1+\gamma)} + \frac{(16\gamma^2-8\gamma+1)(c_r+c_m)^2}{32(1+4\gamma)}. \tag{14}$$

Comparing the manufacturer's equilibrium profits under price-only and returns contracts in (13) and (14), respectively, we conclude that the returns contract dominates the price-only one if $c_r + c_m \le \hat{c}$, where

$$\hat{c}(\delta=1,\gamma) = \begin{cases} \dfrac{2(1+\gamma-\sqrt{1+\gamma})}{1-\gamma} & \text{if } \gamma \le 0.287, \\[2ex] \dfrac{2\Big(5+5\gamma-\sqrt{10(1+\gamma)(9\gamma-12\gamma^2+(1-2\gamma)\sqrt{10\gamma(1+2\gamma)})}\Big)}{5(1-\gamma)} & \\ \qquad \text{if } 0.287 \le \gamma \le 0.327, \\[2ex] \dfrac{2(1+\gamma-2\sqrt{\gamma})}{1-\gamma} & \text{if } \gamma > 0.327. \end{cases} \tag{15}$$

Substituting $\gamma = \frac{1-\theta}{1+\theta}$ into this expression, we obtain the threshold in terms of θ, i.e., $\hat{c}(\delta=1,\theta)$, where

$$\hat{c}(\delta=1,\theta) = \begin{cases} \dfrac{2(1-\sqrt{1-\theta^2})}{\theta} & \text{if } \theta < 0.507, \\[2ex] \dfrac{2}{\theta}\left(1-\dfrac{\sqrt{2((3\theta-1)\sqrt{10(1-\theta)(3-\theta)}+9(1-\theta^2)-12(1-\theta)^2)}}{10\sqrt{1+\theta}}\right) & \\ \qquad \text{if } 0.507 \le \theta \le 0.554, \\[2ex] \dfrac{2-\sqrt{2(1+\theta)}}{\theta} & \text{if } \theta \ge 0.554. \end{cases} \tag{16}$$

Finally, by comparing $\hat{c}(\delta=1,\theta)$ and $\hat{c}(\delta=0,\theta)$, one can easily verify that $\hat{c}(\delta=1,\theta) \ge \hat{c}(\delta=0,\theta)$. Similarly, by comparing $\hat{c}$ and $\bar{c}$ values, one can easily verify that $\hat{c}(\delta=i,\theta) \ge \bar{c}(\delta=i,\theta)$, $i=\{0,1\}$. □

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