Reverse Channel Design: The Case of Competing Retailers

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The economical and environmental benefits of product remanufacturing have been widely recognized in the literature and in practice. In this paper, we focus on the interaction between a manufacturer's reverse channel choice to collect postconsumer goods and the strategic product pricing decisions in the forward channel when retailing is competitive. To this end, we model a direct product collection system, in which the manufacturer collects used products directly from the consumers (e.g., print and copy cartridges) and an indirect product collection system, in which the retailers act as product return points (e.g., single-use cameras, cellular phones). We first examine how the allocation of product collection to retailers impacts their strategic behavior in the product market, and we discuss the economic trade-offs the manufacturer faces while choosing an optimal reverse channel structure. When a direct collection system is used, channel profits are driven by the impact of scale of returns on collection effort, whereas in the indirect reverse channel, supply chain profits are driven by the competitive interaction between the retailers. Subsequently, we show that the buy-back payments transferred to the retailers for postconsumer goods provide a wholesale pricing flexibility that can be used to price discriminate between retailers of different profitability.

Key words: reverse logistics; product remanufacturing; supply chain coordination; distribution channels

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1. Introduction

The importance of the environmental performance of products and processes for the operation of the overall business is increasingly being recognized. Although legislation issued by the state in Europe, North America, and Japan encourages this awareness, the corporate response to the evolving environmental performance requirements has been proactive in many cases. For example, car manufacturers, including DaimlerChrysler and BMW (Therry 1995), have insisted that their suppliers also abide by the same strict environmental guidelines that they follow. Recently, joint ventures for research and development on recovery processes have been set up—e.g., the one by BMW, Renault, and Fiat, who agree to recover and process each other's cars abroad. Other examples of product recovery are one-time-use cameras (Kodak), copy and print cartridges (Xerox, Canon, and Accutone), copiers (Agfa Gevaert, Oce, and Xerox), and mobile phones (ReCellular). In all these cases, product recovery activities are perceived as an integral part of the product development and original manufacturing process of the products.

The organization of product take-back systems and the reuse of old products varies largely, depending on the product characteristics, the structure of the supply chain, and industry experience. In some industries, equipment manufacturers manage the product collection process in parallel with the distribution of new products. Xerox has been a leader in reusing their high-value, end-of-lease copiers in the manufacturing of new copiers that meet the same strict quality standards (Fiona 1993). Similar activities are undertaken by Hewlett Packard (HP) with their used computers and peripherals, and by Xerox and Canon with their print and copy cartridges, which are directly collected back from the customers using prepaid mailboxes provided by the manufacturer. In some cases, the manufacturers assign product collection activities to their distribution partners. Kodak collects cameras back from large retailers who also develop films for customers, and recovers 76% of the weight of a returned camera in the production of a new one. Each time a camera is returned to Kodak, the retailer is reimbursed both a fixed fee per camera and the transportation costs. In electronics, retailers/distributors also act as product return points for the manufacturers.
Given the different reverse channel formats that companies use to collect their used products, our goal in this paper is to understand when a manufacturer would choose to collect used products directly from consumers (model used by Xerox and HP), and when it would prefer to allocate the reverse channel responsibility to the retailers (model used by Kodak), and manage collection indirectly via the retailers and why. To develop an in-depth understanding of these important research questions, our intent is to identify the key trade-offs governing the decision-making process of a manufacturer. Therefore, we start by characterizing how the strategic behavior of supply chain members changes under different reverse channel structures and the implications of this on the manufacturer’s, the retailers’, and the total channel profits. We identify the effect of reverse channel structure on wholesale prices and the intensity of the competitive behavior at the retail level. Subsequently, in the retailer collecting system, we investigate the implications of buy-back payments for used products on forward channel pricing decisions.

To this end, we formulate and analyze two decentralized closed-loop supply chain models: (i) Model DD (decentralized direct collection), in which the manufacturer collects used products directly from the customers; and (ii) Model DI (decentralized indirect collection), in which the manufacturer contracts the reverse channel to the retailers and collects used products indirectly via the retailers. For comparison, we also model two centrally coordinated supply chain models with remanufacturing: Model CD (centralized direct collection) and Model CI (centralized indirect collection).

While controlling for differences in reverse channel cost structures, we demonstrate that in Model DD the improvement in the manufacturer’s and the total channel profits and the growth in retail demand follow from the immediate effect of unit-cost savings of product remanufacturing on the pricing decisions of the manufacturer and retailers. Surprisingly, in Model DI we find that a different set of factors drive supply chain profits and retail demand. Here, the allocation of product collection activity to the retailers induces them to compete more intensely in the market, which inevitably drives the retail prices down and increases demand and profits for the manufacturer and for the channel. We find that the strategic benefits of an indirect collection channel to the manufacturer are not so pronounced when the retailers’ products are highly substitutable. When this is the case, the double marginalization problem in the forward channel is less acute, and the competition between the retailers is more intense.

Subsequently, we show that if the indirect collection channel has cost advantage due to its proximity to the market, the manufacturer and the retailers might prefer the indirect collection system, even though it induces retailers to compete more intensely. Interestingly, we find that the amount of collection cost advantage retailers would look for to change their preference is larger than the cost advantage the manufacturer would require to prefer an indirect reverse channel structure.

Besides considerations of cost reduction and retail competition, we show that the benefits of supply chain coordination also drive a manufacturer’s decision to indirectly collect used products. Here, the payments in the reverse channel are identified as a means to coordinate the wholesale prices across retailers of different market sizes. We find that this aspect is critical, particularly when the retailers have comparable market sizes so that the profits that can be extracted by the manufacturer using the franchisee fee are not constrained by the size of a particular retail market.

These findings open up future avenues of research linking the roles of forward and reverse channel agents. Using a game-theoretic modeling framework, we provide insights into how independent and strategic decision making of each supply chain member in the forward and reverse channels determines the performance of closed-loop supply chains. Thus, we provide a better understanding of trade-offs faced by managers in designing such closed-loop remanufacturing operations.

The rest of the paper is organized as follows. In the next section, we briefly discuss the current literature and the contributions of this paper. Section 3 is devoted to the assumptions of the modeling framework. The formulations and analysis are presented in §§4 and 5. Section 6 discusses coordination opportunities in the retailer collecting system. Section 7 is devoted to discussion of the results and possible directions for future research.

2. Literature

This paper draws on and contributes to several streams of literature, each of which we review below. A growing literature in operations management studies closed-loop supply chain design for remanufacturable products. We refer the reader to Dekker et al. (2004) for complete discussion and reviews of this work stream. The basic underlying assumption in these papers is that the planning of closed-loop supply chain operations, such as network design, shop floor control, and inventory control, is done by a central decision maker to optimize total system cost. By adopting a game-theoretic approach, we relax the centralized planner assumption and model the independent decision making of each supply chain member. By focusing on the gaming between the channel members, we extend the discussion on network design by
identifying incentive issues and strategic considerations of reverse channel choice.

In the supply chain management literature, papers such as Enmons and Gilbert (1998) and Donohue (1996) discuss optimal product return contracts for short-life-cycle products. The returns considered in these studies are from retailers at the end of a selling season due to the demand uncertainty and the retailers' overstocking of inventory. In contrast, we consider postconsumer (used) products returned from customers for remanufacturing and discuss the implications of reverse channel choice on the forward channel pricing decisions.

A group of papers in the supply chain management literature consider two-echelon distribution systems with competing retailers. Li (2002) discusses two effects of information sharing: the first-degree effect on ordering decisions of the retailers, and the second-degree effect on their strategic behavior. In this paper, we discuss the trade-offs between the first-degree effect of reverse channel choice on the manufacturing costs from product reuse and its second-degree effect on retail competition and channel profits.

In a series of papers, Chen et al. (2001), Bernstein et al. (2002), and Bernstein and Federgruen (2005) investigate coordination mechanisms in two-echelon distribution systems with nonidentical competing retailers. An interesting finding of this group of research is that no (traditional) discount scheme, based only on order quantities, suffices to optimize channel-wide profits when retailers are nonidentical. Coordination is achieved via periodically charged fixed fees and a nontraditional discount scheme under which the discount is the sum of three discount components driven by the retailers' annual sales volume, order quantity, and order frequency, respectively. In the present work, we model two retailers with nonidentical markets and focus only on pricing decisions in the forward and the reverse channel, i.e., no inventory decisions are considered. In the retailer collecting system, we show that the manufacturer can coordinate the pricing decisions at the retailers by manipulating a single buy-back price for used products. The insights from this group of research papers are interesting for this paper because they suggest that a variable buy-back price based on each retailer's sales volume can be a possible means to coordinate forward channel prices when the manufacturer distributes to two or more retailers.

Some recent papers on reverse logistics and supply chain management also use game theory to model remanufacturing decisions (Majumder and Groenevelt 2002, Debo et al. 2002, Savaskan et al. 2004). Unlike the present paper, in these studies, the reverse channel choice of the manufacturer is assumed exogenous to the model structure. In a recent paper, Savaskan et al. (2004) investigate a manufacturer's reverse channel choice in a single-manufacturer, single-retailer supply chain structure. The present paper extends the findings of this work to a competitive retailing environment.

In the analytical marketing literature, our work relates to the paper by Ingene and Parry (1995), which investigates coordination in the nonidentical multiple-retailer channel structure. Our results add to their discussion because we show that the wholesale price and the buy-back payments can be chosen such that the double marginalization problem can be overcome in a multiretailer setting.

The main contribution of this study to the extant research is an in-depth examination of the interactions between decisions of the manufacturer and retailers in the forward and reverse channels. This paper also extends the current discussion on channel choice in competitive retail markets to product take-back and remanufacturing systems. In a remanufacturing context, it identifies the reverse channel as a means to coordinate forward channel decisions, especially when retailers have nonidentical market sizes.

3. Modeling Assumptions

The goal of this paper is to develop an understanding of the trade-offs governing the reverse channel choice of a manufacturer, who distributes new products through competing retailers and reuses used ones in the manufacturing of new ones. To this end, we introduce product remanufacturing into the well-known single-manufacturer-two-retailer, multiechelon distribution model and present two decentralized and two coordinated closed-loop supply chain models. The single-manufacturer-two-retailer, multiechelon distribution model without remanufacturing, referred to as Model NR (Figure 1a) is well known in the literature and has been extensively analyzed (McGuire and Staelin 1983). For comparison, we list the results of this model in appendix and refer to them in the following sections of the paper.

In the rest of the paper, the following notation is used: $c_n$ denotes the unit cost of manufacturing a new product, and $c_r$ the unit cost of remanufacturing a returned product into a new one. $T_i^k$ denotes the profit function for channel member $i$ in model $k$. Superscript $k$ takes the values of $NR$, $CD$, $CI$, $DD$, and $DI$, denoting no remanufacturing, centralized direct collection, centralized indirect collection, decentralized direct collection, and decentralized indirect collection models, respectively. $i$ denotes the values of $C$, $M$, $R_1$, and $R_2$, denoting the central planner, the manufacturer, the retailer 1, and

\footnote{Whenever necessary, we also use the superscript $k$ to differentiate the optimal values of variables under different models.}
Figure 1 Channel Structures

(a) No remanufacturing (model NR)
(b) Decentralized direct collection (model DD)
(c) Decentralized indirect collection (model DI)
(d) Coordinated direct collection (model CD)
(e) Coordinated indirect collection (model CI)

the retailer 2, respectively. \( D_j(p_{R_j}, p_{R_{-j}}) \) denotes the demand at retailer \( j \) (\( j = 1, 2 \)) as a function of his own and the other retailer’s price. While \( \tau \) denotes the reverse channel performance in the direct collection models, \( \tau_{R_j} \) is the reverse channel performance at retailer \( j \) (\( j = 1, 2 \)) in the indirect collection models. In the decentralized models DD and DI, the structure of the games played between the manufacturer and the retailers in the forward and reverse channels are as follows.

In Model DD, the manufacturer decides on the wholesale price of the product \( w \), and the collection effort \( \tau \) in the reverse channel by considering the effect of these decisions on the strategic behavior of the retailers (Figure 1b). Given the wholesale price \( w \) and the collection effort \( \tau \), each retailer chooses the price of the product while considering competition from the other retailer.

In Model DI, the manufacturer allocates the reverse channel responsibility to the retailers, and products are collected indirectly via the retailers (Figure 1c). In this reverse channel model, collected used products are transferred to the manufacturer by the retailers in return of a fixed per-unit buy-back payment, \( b \). Given the wholesale price \( w \) and the buy-back payment \( b \), each retailer \( j \) (\( j = 1, 2 \)) solves for the optimal retail price \( p_{R_j} \), and the collection effort \( \tau_{R_j} \), taking into consideration the competition from the other retailer. The manufacturer chooses the wholesale price \( w \) and the buy-back price \( b \), taking into consideration the effect of these decisions on the strategic decisions of the retailers. Consistent with the extant literature (McGuire and Staelin 1983), we assume that in both decentralized models, the manufacturer has sufficient channel power over the retailers to act as a Stackelberg leader, and the retailers compete in a Bertrand pricing game.

The paper also discusses two coordinated models, Model CD with a direct product collection structure (Figure 1d) and Model CI with an indirect product collection structure (Figure 1e). Because pricing and product collection effort decisions are made by a central planner, \( w \) and \( b \) are irrelevant in these models. The results of the centrally coordinated models are used to benchmark the performance of the decentralized models DD and DI. We characterize the supply chain performance for each model in terms of the pricing decisions of the manufacturer and retailers, the collection effort, total supply chain profits, and the allocation of total profits between the manufacturer and the retailers.

As stated above, we consider a manufacturer who has incorporated remanufacturing of used products into its original production system, so that it can manufacture a new product directly from raw materials or remanufacture part or whole of a returned unit into a new product.
We assume that the primary incentive of the manufacturer to remanufacture used products is production economics. More specifically, we consider a scenario in which producing a new product by reusing a used product is less costly than manufacturing from scratch, i.e., $c_r < c_m$ and $c_r$ is the same for all remanufactured products. This assumption implies that savings from materials and assembly of subsystems within the new product dominate the additional costs of disassembly and remanufacturing. Therefore, ceteris paribus, the manufacturer strictly prefers a higher product return rate to a lower product return rate from the market because through remanufacturing it can lower production costs. The assumption of identical $c_r$ for all returned products can be relaxed by incorporating a yield rate on returned product quality. The yield rate models the uncertainty in the reusability of used products due to different usage patterns.

The reverse channel performance is characterized by $\tau$, the return rate of used product from the customers. $\tau$ denotes the fraction of current generation product supplied from returned and thus remanufactured units, i.e., $0 \leq \tau \leq 1$. We model $\tau$ as a function of the product collection effort, which is denoted by $1$, the level of investment in promotional activities aiming to generate awareness of the manufacturer’s remanufacturing activities among consumers and thus induce product returns.

Hence, one can think of $\tau$ as the response of consumers who have an incentive/enthusiasm for the remanufacturing of their used products as a result of the promotional/advertising activities of the agent in the reverse channel. Note that we do not model any direct financial incentives given to consumers to return their used products. These incentives, known as trade-in offers, not only have an impact on the consumer’s decision to replace used products but also influence the initial product choice of the consumer. By focusing only on promotional expenses to collect used products, we control for the strategic consumer behavior and solely focus on the channel behavior of the manufacturer and the retailers. Hence, consumers in our model react only to new product prices.

To characterize the diminishing returns to investment, we use the cost structure $\tau = \sqrt{1/B}$, where $B$ is a scaling parameter. Similar forms of response functions have been widely used in the advertising response models of consumer retention and product awareness (Lilien et al. 1992) and in sales force effort response models in the marketing literature (Coughlan 1993). In the operations literature, Fine and Porteus (1989) use similar investment functions to investigate opportunities for process improvement and lot sizing by investing in setup cost reduction. This paper investigates trade-offs similar to those in the above studies in a remanufacturing context. Consequently, we define the average unit cost of manufacturing by $c = c_m (1 - \tau) + c_r$ or $c_{m - \Delta \tau}$ where $\Delta = c_m - c_r$. Note that when every consumer returns his/her used product (i.e., $\tau = 1$), $c = c_r$. If the return rate of used products is zero, then all demand will be satisfied from newly manufactured units, and therefore $c = c_m$. Similar cost structures can also be found in the literature that looks at process improvement decisions and cost reduction incentives in supply chains (Gupta and Loulou 1998). The similarity in formulation is consistent because in this paper, an increase in product remanufacturing would also mean a reduction in the average unit cost of manufacturing. Note that the total cost of collection $C(\tau)$ can be characterized as a function of the return rate of used products and is given by $C(\tau) = I = B\tau^2$.

Several papers in the operations management literature address network design problems taking into consideration the differences in collection costs resulting from product inspection and disposal activities and economies of scale in transportation (Dekker et al. 2004). In this paper, our intent is to control for such cost differences across different reverse channel structures and identify incentive-related factors affecting the profitability of closed-loop supply chain models. Therefore, in the first part of the analysis, we assume parameter $B$ to be the same in all closed-loop supply chain models, and then we discuss the implications of relaxing this assumption on our results.

Consistent with the existing literature (Lee and Staelin 1997), we assume that retailer $j$ faces the following linear demand function

$$D_j(p_{R_j}, p_{R_{k-j}}) = \phi_j - p_{R_j} + \beta p_{R_{k-j}}, \quad \text{s.t. } 0 \leq \beta < 1, \quad j = 1, 2,$$

where $\phi_j$ represents the market size of retailer $j$, $\beta$ the product substitution effect, $p_{R_j}$ the price of the product at retailer $j$, and $p_{R_{k-j}}$ the price of the product at the competing retailer. The demand at retailer $j$ is, by assumption, downward sloping in its own retail price, $p_{R_j}$ (i.e., $dD_j/dp_{R_j} < 0$), and upward sloping (or independent of, for completely differentiated retailers: $\beta = 0$) in the competitive retailer price $p_{R_{k-j}}$.

Finally, we assume that all supply chain members have access to the same information while optimizing their objective functions. This enables us to control for inefficiencies and risk-sharing issues resulting from information asymmetry (Corbett and De Groote 2000).

4. Model Formulation and Solution

In this section, starting with the centrally coordinated models, we present the general formulations and solutions to the four supply chain models with remanufacturing. Insights are developed in terms of pricing behaviors of the manufacturer and retailers, the allocation of profits among supply chain members, and the impact of cost and revenue parameters on the profitability of the closed-loop supply chain.
members, used product return rates, and intensity of competitive strategic interaction between the two retailers. The profit functions of the channel members are shown to be concave in the decision variables, so the first-order conditions are used throughout to characterize the optimality of the decision variables.

4.1. Centralized Models
The centrally coordinated models provide a benchmark scenario to compare the decentralized ones with respect to the supply chain profits and the reverse channel performance. We consider two structures: direct collection from the consumers, Model CD; and indirect collection via the retailers, Model CI. Because there is a single planner of the forward and reverse channel decisions, the double marginalization problem in the forward channel is avoided. In case of remanufacturing, the double marginalization problem affects the supply chain profits in two ways: It leads to a higher retail price, which reduces the demand and the forward channel profits. In terms of reverse channel performance, a low level of resulting in a low level of returns for remanufacturing reduces the incentives of the reverse channel agent to invest in product collection, which in turn diminishes the profitability of remanufacturing operations. In the centrally coordinated models, we avoid these inefficiencies.

Direct Collection (Model CD). When used products are returned directly from the market, the central planner solves for the optimal retail prices and as well as the optimal product collection rate. Hence, he solves

$$\max_{p_{R_1}, p_{R_2}, r} \prod^C_{D} = (p_{R_1} - c_m + \Delta \tau)(\phi_1 - p_{R_1} + B p_{R_2})$$
$$+ (p_{R_2} - c_m + \Delta \tau)(\phi_2 - p_{R_2} + B p_{R_1}) - B r^2.$$ 

The simultaneous solution of the first-order conditions gives

$$p^*_R = \frac{\phi_j}{1 + \beta} \left( \frac{1}{(1 - \beta)} - X \right) + \frac{\phi_{3-j}}{1 + \beta} \left( \frac{\beta}{(1 - \beta)} - X \right) + c_m$$
$$+ \frac{4}{\beta} \left( \frac{X - (1/(1 - \beta))}{(3 + \beta)} \right)$$

and

$$r^* = \frac{\Delta \phi_1 + \phi_2 - 2c_m(1 - \beta)}{2B - \Delta^2(1 - \beta)}, \quad \text{where} \quad X = \frac{\Delta^2(3 + \beta)}{4B}.$$

A complete list of results is given in an online companion (available at mansci.pubs.informs.org/e companion.html). Next is the formulation of the centrally coordinated model with indirect collection. The two reverse channel models are compared in Figures 2a and 2b.

Figure 2a
Coordinated Collection Models $B_0 = 1,000, B_1 = k B_0$

Supply chain profits

Direct model dominates due to pooling of product returns from both markets

Indirect model dominates due to collection cost advantage

Figure 2b
Comparison of Prices Centrally Coordinated vs. No Recovery

Retail price

No recovery

Indirect collection

Direct collection

Indirect Collection (Model CI). The central planner using an indirect collection structure via the retailers solves

$$\max_{p_{R_1}, p_{R_2}, r_1, r_2} \prod^C_{I} = (p_{R_1} - c_m + \Delta \tau_{R_1})D_1(p_{R_1}, p_{R_1})$$
$$+ (p_{R_2} - c_m + \Delta \tau_{R_2})D_2(p_{R_2}, p_{R_2})$$
$$- B r^2_{R_1} - B r^2_{R_2}.$$ 

The simultaneous solution of the first-order conditions results in

$$p^*_R = \frac{G \phi_j + L \phi_{3-j}}{\left( (1 - \beta^2) \right)} + (2 - 2X(1 + \beta))c_m$$
$$+ \frac{4(1 - X - XB)(1 - X + XB)}{4(1 - X - XB)(1 - X + XB)} - \Delta^2[X(1 - \beta)] - (1 - X(1 + \beta))\Delta$$

$$r^*_R = \frac{\phi_j(1 - X) - X \beta \phi_{3-j} - c_m(1 - \beta)}{4B + \Delta^2[X(1 - \beta^2) - 2] - \Delta^2}$$

$$X = \frac{\Delta^2}{4B}, \quad G = (2 - 6X + 2X \beta^2 + 4X^2 - 4X^2 \beta^2),$$
$$L = (2 \beta - 4X \beta + 4B X^2 - 4B \beta X^2), \quad \text{and} \quad j = 1, 2.$$

Because there are no strategic considerations, a central planner would choose the optimal product
collection structure based purely on the reverse channel costs and their impact on product return rates and supply chain profits. Figure 2a shows how the preference of the central planner would change as a function of the cost structure, i.e., parameter $B$. Note that when there are no collection cost differences, i.e., $k = 1$, the direct model leads to higher profits for the supply chain than the indirect one. This results from having returns pooled from both markets, which increases the marginal returns to investing in collection effort and leads to a higher product return rate and lower manufacturing costs for the supply chain.

Figure 2b compares the retail prices charged with remanufacturing to the one charged without remanufacturing. The difference is increasing with savings in unit production cost. In other words, part of the system profit gains from reduced unit variable costs are passed on to the customers as lower retail price, which also enhances the demand for the product. This, in turn, increases the marginal benefits from investing in product collection effort and therefore leads to a higher return rate from the market. This second-degree effect drives down the prices even further, which we observe from the convexity of the price difference. Investigating the closed-form solutions to $p_{Ri}^{CD}$ and $p_{Ri}^{CI}$, one can also easily show that as $B \to \infty$ (i.e., as $\tau$ and $\tau_{Ri}$ approaches zero), $p_{Ri}^{CD}$ and $p_{Ri}^{CI}$ approaches to the optimal retail prices in the coordinated model with no remanufacturing.

4.2. Decentralized Models

In this subsection, we formulate decentralized decision making in forward and reverse channel structures, compare the results, and derive model insights.

Direct Collection Model (Model DD). In Model DD, the manufacturer determines how much to invest in product collection effort by considering the product returns from both retail markets. As discussed above, pooling of product returns from both markets justifies a larger investment in product collection effort. As an example of this model, Xerox and HP use a direct reverse channel structure for their copiers and cartridges.

In this reverse channel model, retailers engage only in the sale of the product. Each retailer determines the retail price of the product by taking into account the wholesale price charged by the manufacturer and the competition from the other retailer. Each solves

$$\text{Max}_{p_{R_j}} \Pi_{Rj}^{DD} = (p_{Rj} - w)(\phi_j - p_{Rj} + \beta \psi_{Rj})$$

From the concavity of the objective functions, we determine the best response functions from the simultaneous solution of the first-order conditions for $p_{Rj}$. Thus, one can easily show that

$$p_{Rj}(w) = \frac{2\phi_j + \beta \phi_{Rj} + (2 + \beta)w}{4 - \beta^2}$$

and

$$D_j(w) = \frac{2\phi_j + \beta \phi_{Rj} - (2 + \beta)(1 - \beta)w}{4 - \beta^2}.$$

Given the retailers’ reaction functions, the manufacturer solves

$$\text{Max}_{\omega, \tau} \Pi_{M}^{DD} = [D_j(w) + D_k(w)](w - c_m + \Delta \tau) - B \tau^2$$

to determine the wholesale price and the investment in product collection effort. The optimal collection-effort level is the outcome of the trade-off between investment in collection effort and manufacturing cost savings achieved from remanufacturing of returned products. The optimal wholesale price is set by considering two effects: the direct effect of the wholesale price on the retail demand and its indirect effect on the collection effort. Specifically, the higher the demand (i.e., the lower the wholesale price) in the market for the product, the higher the number of product return for remanufacturing, and hence the higher the marginal benefit from investing in the collection effort. Because the objective function is jointly concave in $w$ and $\tau$, one can easily show that the optimal wholesale price and the product return rates are given by

$$w^* = \frac{(\phi_1 + \phi_2)(1 - X) + 2(1 - \beta)\Delta m}{2(1 - \beta)(2 - X)}$$

and

$$\tau^* = \frac{[\phi_1 + \phi_2 - 2(1 - \beta)\Delta m] \Delta}{2[2B(2 - \beta) - \Delta^2(1 - \beta)]},$$

where

$$X = \frac{\Delta^2(1 - \beta)}{B(2 - \beta)}.$$

Indirect Collection (Model DI). Under this reverse channel model, the retailers decide on the price of the product as well as the investment in product collection effort. The manufacturer decides on the wholesale price of the product and reimburses each retailer a fixed fee $b$, per unit returned. As an example of this channel structure, Kodak currently engages its retailers to take part in the collection program of its single-use cameras. Kodak reimburses retailers a fixed fee per camera returned. Similarly, for electronics products such as television sets, home appliances, and personal computers, retailers also act as collection points.
when products are returned to them at the moment of new sales.

Given \(w\) and \(b\), each retailer solves

\[
\max_{p_{R_j}, \tau_{R_j}} \Pi_{DMD_j} = (p_{R_j} - w + b\tau_{R_j})(\phi_1 - p_{R_j} + \beta p_{R_{j+1}}) - B(\tau_{R_j})^2 \quad j = 1, 2.
\]

From the concavity of the objective functions, the best response functions are determined by the simultaneous solution of first-order conditions for \(p_{R_j}, \tau_{R_j}\). The induced demand function at each retailer is given by

\[
D_j(w, b) = (2 - M)\phi_j + \beta(1 - M)\phi_{j-1} - (1 - \beta)\left[\frac{[2 - M + \beta(1 - M)]w}{(2 - M)^2 - \beta^2(1 - M)^2}\right].
\]

The optimal product return rate is given by

\[
\tau_{R_j}(w, b) = \frac{(b(2 - M)^2\phi_j + \beta(2 - M)(1 - M)\phi_{j-1} - w(2 - M)\cdot[(2 - M) - \beta^2(1 - M) - \beta)]}{(4\beta - b^2)^{-1}}.
\]

Given \(p_{R_j}(w, b)\) and \(\tau_{R_j}(w, b)\) for \(j = 1, 2\), the manufacturer optimizes

\[
\max_w \Pi_{DMD} = D_1(w, b)[w - c_m + (\Delta - b)\tau_{R_1}(w, b)] + D_2(w, b)[w - c_m + (\Delta - b)\tau_{R_2}(w, b)].
\]

From the concavity of the objective function in \(w\), it follows that

\[
w^* = \frac{N(\phi_1 + \phi_2 + (1 - \beta)c_m)}{2(1 + N)(1 - \beta)},
\]

where

\[
N = \left[1 - (\Delta - b)\frac{b}{B}\right] - \frac{(1 - \beta)}{(2 - M) - \beta(1 - M)}.
\]

The optimal value of the wholesale price can then be used to compute the demand at each retailer, the collection effort, and the manufacturer's, the retailers', and the channel profits.

5. Insights with Homogenous Retailers

In this section we discuss the strategic considerations that affect the optimal reverse channel choice of a manufacturer. To isolate these aspects, we focus on a special case of the general formulation, in which we assume identical retail markets, i.e., we set \(\phi_1 = \phi_2 = \phi\). We refer to this as the homogenous retailer case.\(^4\) A main focus of the analysis is to understand how the forward and reverse channel decisions interact, i.e., how the allocation of product collection to retailers alters their strategic interaction. Ceteris paribus, we define retail competition to be more intense with remanufacturing if each retailer charges a lower margin on the wholesale price than they would have charged without remanufacturing. Therefore, in this section we present the wholesale and retail prices in terms of the margins of the manufacturer and retailers. Also, note that because the average unit production cost varies as a function of the remanufacturing activity, focusing on the margins enables us to decouple the price reduction resulting from production cost savings of remanufacturing from the price reductions resulting from the competitive behavior of the retailers. For the homogenous retail case, a complete list of results is given in the online appendix. The next subsections present our insights from this analysis.

5.1 Implications of Reverse Channel Choice on the Strategic Behavior of Supply Chain Members

Below we present insights about the implications of reverse channel choice on the pricing behavior of the supply chain partners. This provides a simple framework to characterize trade-offs under the two reverse channel structures. Proposition 2 builds upon these insights and gives a complete comparison of the two models.

**Remark 1 (Model DD vs. Model NR).** In Model DD, even though the manufacturer is the Stackelberg leader in the forward channel game, product take-back increases the margins of the manufacturer and each retailer by the same factor when compared to the no-recovery case.

Let \(mm^k\) and \(rm^j\) denote the manufacturer's and the retailer \(j\)'s margin in model \(k\), respectively. Remark 1 follows from the fact that

\[
\frac{mm^{DD}}{mm^{NR}} = \frac{rm^{DD}}{rm^{NR}} = \frac{2}{(2 - X)}
\]

and

\[
\frac{2}{(2 - X)} > 1 \quad \text{where} \quad X = \frac{(1 - \beta)\Delta^2}{(2 - \beta)B}.
\]

\(^4\)To isolate the strategic effect of competition on reverse channel choice, we also have identical reverse channel cost structures in the direct and indirect collection models. Note that compared to the retailers who receive returns only from their respective market, the manufacturer collects returns from both markets, which leads to economies-of-scale benefits for it while investing in collection effort. At the end of §5, we further elaborate on this point and discuss the impact of nonidentical collection cost structure on reverse channel choice.
This result illustrates that the investment in collection effort creates "vertical externality" within the channel. For the manufacturer, the marginal benefit of investing in the collection effort depends on the total retail sales volume (i.e., the potential size of the return market) as it determines the total cost savings from recovery. This dependence induces the manufacturer to reduce her wholesale price, which in turn benefits the retailers. In other words, the manufacturer captures only part of the gains generated by lower production costs; some are retained by the retailers.

One could conjecture that the externality would be amplified when the supply chain consists of several echelons including the wholesalers or distributors. However, in that case, because the manufacturer's production cost reduction through remanufacturing would be only partially reflected in the final consumer demand, the incentives to invest in collection would be dimmed in a direct collection model.

**Remark 2 (Model DI vs. Model NR).** When the retailers engage in product collection, the average profit margin of the manufacturer with product recovery equals its margin in the benchmark case without product recovery, i.e.,

$$mm^{**JR} = mm^{**NR} = \frac{\phi - (1 - \beta)c_m}{2(1 - \beta)}.$$

The manufacturer’s margin is independent of the buy-back payment $b$; therefore, it follows that $mm^{**JR} < mm^{**DI}$.

**Remark 3 (Model DI vs. Model DD).** In Model DI, the average retail margin of each retailer including the buy-back payment is equal to

$$rm^{**DI}_j = \frac{\phi - (1 - \beta)c_m}{2(2 - \beta) - \frac{(1 - \beta)\Delta^2}{B}} = rm^{**DD}_j$$

and is greater than the retail margin without remanufacturing, $rm^{**NR}_j$.

This follows from the effect of buy-back payments on the pricing decisions of the retailers. A higher buy-back payment $b$ impacts the retailers’ channel behavior and profits in two countervailing ways. A higher $b$ creates incentives for retailers to reduce their price in anticipation of future buy-back payments, and to invest in collection effort. This increases their profits by $brD(p) - C(r)$. On the other hand, a higher $b$ results in a higher wholesale price from the manufacturer and leads to a more intense price competition between retailers. Competition drives down the retail prices even further and reduces the retailers’ profits. We illustrate this by fixing $b = \Delta$. Focusing on $b = \Delta$ is particularly interesting because at this value of $b$, the wholesale price of the manufacturer with remanufacturing equals the wholesale price without remanufacturing. Hence, we can directly compare the reaction functions of the retailers to isolate the impact of product take-back on their strategic behavior. When $b = \Delta$, the retailers’ margin per unit sold before any buy-back payment is given by

$$rm^{**JR}_j \text{ before buy-back} = \left(1 - \frac{1}{(1 + (1 - \gamma)(1 - \beta))}\right) rm^{**NR}_j,$$

where

$$0 < 1 - \frac{1}{1 + (1 - \gamma)(1 - \beta)} < 1 \quad \text{and} \quad \gamma = \frac{\Delta^2}{2B}.$$

Hence, when product take-back is managed by the retailers, they compete more intensely (i.e., set a lower margin per unit sold) than in the case of no recovery, even though the wholesale price (the manufacturer’s margin and the unit cost of production) is identical to the wholesale price in Model NR. Consequently, a lower retail margin increases the demand for the product in the market. Even though the margin per unit sold is lower, the retailers still benefit from product take-back because they are partially compensated for their margin loss through the buy-back payments for returned units.

**Remark 4 (Model DI).** The manufacturer’s profits are increasing in the buy-back payment $b$.

Because the manufacturer’s margin is independent of the buy-back payment $b$, a high value for $b$ leads to a high $w$ for the retailers. The manufacturer wants to increase $b$ because it induces the retailers to reduce their price in anticipation of future buy-back payments for used products and to exert more collection effort. However, the manufacturer avoids setting $b$ too high because this leads to a high value of $w$, which reduces the profitability of its product for the retailers. Remark 5 summarizes the effect of $b$ on retail profits.

**Remark 5 (Model DI).** We find that the retailers’ profits are increasing in $b$ for $b < 2\Delta(1 - \beta)/(2 - \beta)$ and decreasing in $b$ for $b > 2\Delta(1 - \beta)/(2 - \beta)$. Table 1 summarizes insights from the homogenous retailer case.

**Proposition 1.** Because the wholesale price is increasing in the buy-back payment $b$, to ensure nonnegative profits for the retailers, $b$ can assume a maximum value of $b = 2\sqrt{B}$ where $B > (1 - \beta)\Delta^2/(2 - \beta)$.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Comparison of Model DD and DI to the No-Remanufacturing Case</th>
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<tr>
<td>Comparison measure</td>
<td>Model DD</td>
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<tr>
<td>Demand $D_I$</td>
<td>Higher</td>
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<tr>
<td>Retail margin $mm_j$</td>
<td>Higher</td>
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<td>Manufacturer margin $mm$</td>
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<td>Average unit production cost $c$</td>
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<tr>
<td>Retail profits $\Pi_{\ell_j}$</td>
<td>Higher</td>
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Proposition 1 gives an upper bound for $b$ in Model DI, which ensures nonnegative channel profits for retailers. It is interesting to note that in addition to the wholesale price, the buy-back payments in the reverse channel provide a second degree of flexibility to the manufacturer to manipulate the pricing behavior of the retailers. In §6 we discuss how such payments can be used to coordinate the retail pricing decisions.

5.2. Comparison of Direct and Indirect Collection Models

For the homogeneous case, in Proposition 2 we provide a comparison of Model DD to Model DI in terms of channel profits and return rate of products. Subsequently, we summarize our main findings from the analysis of this special case.

**Proposition 2.** When retailing is competitive, demand is a linear downward sloping function of the retail price, and the manufacturer distributes its product through independent retailers using a uniform wholesale price:

(a) Manufacturer's profits compare as follows: For $\tilde{b} > \Delta$ (or equivalently $\beta > 2/3$), $\Pi^{DD}_{M} > \Pi^{DI}_{M}$. For $b < \Delta$ (or equivalently $\beta > 2/3$), $\Pi^{DD}_{M} > \Pi^{DI}_{M}$.

(b) The profits of each retailer in Model DD are strictly higher than the profits in Model DI ($\Pi^{DD}_{R} > \Pi^{DI}_{R}$).

(c) The return rates of the used products compare as follows: For $\tilde{b} < \Delta$, $\tau^* > \tau^*_R$. For $b > \Delta$ and $\Delta < b < 4B(2 - \beta)/(2B(2 - \beta) + \Delta^2(1 - \beta))$, $\tau^* > \tau^*_R$, and for $\tilde{b} > \Delta$ and $4B(2 - \beta)/(2B(2 - \beta)) < b < \tilde{b}$, $\tau^*_R > \tau^*$.

Part (a) of Proposition 2 states that the manufacturer finds Model DI more profitable than Model DD when the substitutability of the products is below a threshold value. In this case, the manufacturer can induce more competition and extract the retailer profits by carefully choosing the $b$ value. Retailers can afford to reduce their margins for two reasons. First, through the buy-back payments they are partially compensated for their lost profits. Second, a larger demand justifies a larger investment in product collection effort that, as a second-degree effect, improves the retailers' profits. In this case, using the reverse channel to increase competitive behavior is more valuable to the manufacturer. If the retail products are highly substitutable, i.e., the price competition is already intense, then the manufacturer benefits from a direct collection system in which the immediate benefit of product remanufacturing in terms of lower production costs drives the supply chain profits both for the manufacturer and the retailers. Part (b) of Proposition 2 states that the retailers always benefit from a direct collection system in which they do not need to incur the direct cost of collection but benefit from the vertical externality discussed in Remark 1. Part (c) of Proposition 2 compares the collection efforts under the two reverse channel structures. We find that in most cases, a direct collection channel (Model DD) leads to a higher fraction remanufactured. This is because a direct collection system benefits from pooling returns from both markets. More specifically, the manufacturer trades off the profit impact of returns from both retail markets to the cost of collection effort. However, the drawback of a direct collection system is that the recovered value of used products in the form of lower manufacturing costs can be only partially reflected in the final demand because some of this value is retained by the retailers due to double marginalization, i.e., the vertical externality in the channel. Only if $b$ can be set very high, i.e., the last part of (c), does the fraction remanufactured in Model DI dominate the fraction remanufactured in Model DD.

The analysis of the special case shows that the manufacturer’s decision to establish a direct versus an indirect reverse channel is driven by the following trade-off. When the products are collected by a direct channel (Model DD), the profits are driven by the pooling effect of returns from both markets and the savings in the average unit cost of production. The inefficiency of a direct system derives from the double marginalization problem, as a result of which the cost reduction from remanufacturing is reflected only partially to the retail prices. The indirect collection model (Model DI) is preferred when the competition is less intense in the market. In this case the manufacturer can generate additional profits from manipulating the buy-back price $b$ to induce retailers to engage in more competitive pricing behavior. This drives the retail prices down, increases demand, and therefore increases the manufacturer’s profits. Table 1 compares the two models to the no remanufacturing case. We also identify that the retailers strictly prefer the manufacturer collecting model to the retailer collecting one as they can attain higher profit margins from the vertical externality in the forward supply chain without incurring the investment cost in collection effort. We also find differences in the return rate of used products under the two channel structures. In most cases, the direct model dominates the indirect one because it benefits from the pooling of returns from both markets and its impact on incentives to promote remanufacturing. Only if the manufacturer can set $b$ very high does Model DI result in a higher fraction remanufactured.

To isolate the strategic interactions, the analysis presented above assumed identical cost structures for Model DD and Model DI. However, in practice a particular reverse channel agent might have reverse channel cost advantage due to his/her proximity to the consumers or to experience/learning in product collection and remanufacturing. Here, we allow for differences in collection costs.
We find that in some cases both the manufacturer and the retailer might prefer the indirect retailer collecting system to the direct collection model. They would prefer so despite the fact that indirect collection induces more intense pricing competition between the retailers. We also find that the critical value of \( B \) that retailers would look for to change their preference to the indirect collection is much smaller than the critical value of \( B \) that the manufacturer would require. We demonstrate this aspect in Figure 3.5

6. Channel Coordination with Heterogeneous Retailers

In this section, we consider a case in which indirect collection is preferred by the manufacturer and the retailer due to collection cost advantage. Under this scenario, we discuss coordination opportunities in the forward channel via the buy-back payments in the reverse channel with nonidentical competing retailers. As discussed in much of the recent literature, the key to channel coordination and overcoming the double marginalization problem in supply chains is inducing the independent retailers to set a final price that maximizes total channel profits. To this end, conventional wisdom states that the manufacturer should choose a wholesale price that induces the retailer's full marginal cost to equal the channel's total marginal cost. With competing nonidentical retailers, Ingene and Parry (1995) show that the full marginal cost of the channel differs by each retailer; the channel can be coordinated only if the wholesale price is set differently for each retailer. Hence in a coordinated channel, a manufacturer would set a lower wholesalprice for large-scale retailers such as Walmart and a higher wholesale price for smaller-size retailers such as 7-Eleven. Theoretically, with multiple nonidentical retailers, one can deal with this problem with a menu of two-part tariffs, which adjust the wholesale price to each retailer’s market size. The difficulty of deploying such two-part tariffs arises from legal considerations such as the Robinson Patman Act of 1936, according to which manufacturers are precluded from giving different terms (discriminating in prices) to different retailers unless their cost differences are justified. Hence, with a single wholesale price for both retailers the manufacturer is not able to obtain the retail price and the demand levels of a fully coordinated supply chain.

Current literature identifies linear quantity discount schedules as a coordinating mechanism with nonidentical retailers. Such quantity discount schedules take the form \( T = W - wD_i \), where \( W \) is the vertical intercept of the wholesale pricing scheme, \( w \) is the slope of the per-unit wholesale pricing schedule, and \( D_i \) is the demand of retailer \( i \). When inventory costs are included, Chen et al. (2001) shows that coordination with nonidentical multiple retailers is achieved via periodically charged fixed fees, and a nontraditional discount scheme under which the discount is the sum of three discount components driven by the retailer’s annual sales volume, order quantity, and order frequency, respectively.

Interestingly, we find that the reverse channel enables the manufacturer to exercise an additional degree of freedom in pricing retailers (i.e., the wholesale price and the buy-back price). In Model DI, the manufacturer decides on the wholesale price \( w \) and the buy-back price \( b \), in response to which each retailer chooses price of the product in a Bertrand price competition and the product collection effort, which in turn determines the average buy-back payments to the retailer. Hence, the manufacturer can manipulate \( w \) and \( b \) such that the reaction functions of the

---

5 Parameter values are \( \phi_1 = 200, \phi_2 = 100, \beta = 0.3, c_w = 20, \Delta = 10, \) and \( B_1 = 2000, B_i = k \cdot B_1, \) where \( k \in [0, 1] \).
retailers satisfy $p^{CL}_{R_i}(w, b) = p^{CL}_{R_j}$. The manufacturer can extract the coordinated channel profits by charging a fixed franchisee fee $\bar{F}$. Because the manufacturer offers the same contract to both retailers, the maximum amount of fixed fee charged is bounded from above by the profits of the smaller (i.e., less profitable) retailer. The following proposition summarizes the form of the coordinating contract.

**Proposition 3.** In Model DI, the manufacturer can overcome the double marginalization in the forward channel by using a contract of the form $(\bar{F}, \bar{w}, b)$ where

$$\bar{F} = \min(\Pi^{CL}_{R_i}, \Pi^{CL}_{R_j})$$

$$\bar{w} = \frac{p^{CL}_{R_i}[(2-M) - \beta(1-M)]}{2-M+\beta(1-M)}$$

$$b = \sqrt{2BM} \quad \text{and} \quad \phi = \frac{(1-M)^2}{2-M+\beta(1-M)} \phi_2$$

where

$$M = \frac{(2+\beta)p^{CL}_{R_i} - \phi_2}{(1+\beta)p^{CL}_{R_i} - \phi_2}$$

and $p^{CL}_{R_i} = p^{CL}_{R_i} - p^{CL}_{R_j}$, $\phi = \phi_2 - \phi_1$.

Note that the buy-back payments for returned products function as a price discount on new units procured by the retailers. Because the collection effort is determined by the size of the retail market, the manufacturer can set the buy-back price $b$ such that the average wholesale price faced by each retailer reflects the profitability (i.e., the size) of their respective markets. Hence, a large market size inducing a higher level of investment in product collection results in a lower average wholesale price. Note that Proposition 2 considers only two retailers. One can easily extend this contract structure to multiple retailers such that the manufacturer either allocates collection activity only to some of the retailers or charges different buy-back prices to different retailers to adjust the average wholesale price of the product for a particular retailer to its respective business volume. Next, we compare the profits of the manufacturer and retailers in the coordinated channel to the uncoordinated Model DI as a function of the difference in the market size of the retailers.

The coordinating contract specifies $w$ and $b$ to ensure that the retailers choose prices and collection effort equal to their channel coordinating values. The manufacturer extracts profits from the retailers via a franchisee fee common for both retailers. The franchisee fee ensures that the least profitable, i.e., the smaller retailer, obtains profits at least as much as its profits in the uncoordinated Model DI. Because the same franchisee fee is applied to both retailers, the manufacturer cannot fully extract profits from the larger, more profitable retailer. Coordination is preferred by the manufacturer if the difference in market sizes is not very large, i.e., $\phi_3 < \phi_{d_{2}}$ (Figure 4).

![Figure 4 Coordinated vs. Uncoordinated Model DI](image)

Otherwise, the manufacturer leaves too much profits with the larger retailer due to using a common franchisee fee for both retailers. On the contrary, the larger retailer prefers coordination if the difference in market sizes is not very small, i.e., $\phi_3 > \phi_{d_{1}}$ (Figure 4). Therefore, we find that there is a range of values for $\phi_3$, i.e., $\phi_{d_{1}} < \phi_3 < \phi_{d_{2}}$ for which coordination is pareto improving for all channel members.

The contract specified above coordinates the product collection effort and retail prices when it is optimal that the retailers assume the reverse channel responsibility. Another reverse channel choice would be that the manufacturer collects products directly from consumers. In this case, a different type of contract is needed to coordinate the product collection effort and the pricing decisions. We conjecture that a two-part tariff in the form of a fixed fee and a wholesale price that decreases linearly in the quantity demanded by each retailer would be sufficient to coordinate retail demand and collection effort. Such a contract would be similar to the one suggested by Ingene and Parry (1995).

7. Discussion

This paper is one of the first formal studies investigating the interaction between decisions in the forward and reverse logistics channels and the implications on closed-loop supply chain profits. More specifically, we investigate when a manufacturer would choose to collect used products directly from the consumers, and when it would prefer to collect used products indirectly via retailers, and why.

The analysis highlights an interesting trade-off between direct versus indirect collection systems. When product collection is done by the manufacturer, the investment in collection effort is driven by the remanufacturing cost savings in production. Direct collection by the manufacturer is preferred by the retailers as they avoid the cost of investing in product

* Parameter values are $\phi_i = 200 + \phi_{d_{i}}$, $\beta = 0.3$, $\beta_i = 2000$, $c_w = 20$, $\Delta = 15$. 

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collection and benefit from the vertical externality in the channel due to lower wholesale prices.

An immediate benefit of the indirect collection system for the manufacturer comes from saving the investment costs of collection effort. The second-degree effect is the strategic interaction between competing retailers. It is shown that the allocation of product collection to retailers results in additional incentives for retailers to reduce their margins on the product, with the expectation that they compensate the reduction in retail price through the buy-back payments for used products. Because the retail market is competitive, the strategic interaction between the retailers drives down retail prices even further. The manufacturer benefits from this interaction effect as the total sales volume is increased. This channel structure is preferred by the manufacturer, particularly when the products of the retailers are not direct substitutes, as a result of which the retailers are fairly independent in their pricing decisions and the double marginalization is pronounced.

The paper also identifies additional coordination benefits of reverse channels. It is shown that in Model D1, the manufacturer can overcome the double marginalization problem in the forward channel by setting $b$ and $w$ such that the average unit price paid by each retailer reflects its respective market size. Benefits of coordination are substantial, particularly when the market sizes of the retailers do not differ too much.

The results suggest that for consumer products in which competition is an important determinant of prices, the retailer collecting system would be the preferred option for the manufacturer. This suggests that Kodak’s single-use camera product line, for which the ability to compete in prices with other manufacturer’s products is critical, the indirect collection system via the retailer is in fact the better channel structure. However, in product categories for which the retailers have less impact on the prices, the manufacturer benefits from a direct collection system. For Xerox print cartridges, distributed via company-owned distributors where the distributors are constrained in their pricing decisions, a direct collection model is the preferred structure for the manufacturer.

The modeling framework has made several assumptions that have to be relaxed to develop a more comprehensive understanding of reverse logistics practices in general and product recovery systems in particular. The literature discusses several operational factors that have an effect on reverse logistics network design decisions. A primary factor is mentioned as the number and the type of steps involved in the remanufacturing process of a product. These steps include, but are not limited to, inspection of returned products, sorting, preprocessing, recovery, and redistribution. Product characteristics such as product weight and volume impact transportation costs for used products and consequently determine which processing steps to perform in decentralized facilities, and which steps to perform in more centralized locations (Fleischmann et al. 2001). Incorporation of transportation and disposal costs into our modeling framework would have a direct impact on the choice between direct versus indirect reverse logistics channels, particularly when some of the returned products are in a nonremanufacturable condition and have to be disposed or recovered in other forms such as material recycling. When this is the case, an indirect collection system would be preferred if inspection and disposal can be performed at the retailers, thereby avoiding unnecessary transportation of nonrecoverable used products to the manufacturer. Compared to direct collection from consumers, indirect collection model can also benefit from scale economies in transportation of used products. For instance, Kodak uses retailers as return points for its single-use cameras. This allows the company to transport used cameras in batches from retailers to remanufacturing facilities. Modeling these aspects into the present framework would make the indirect collection model a more preferred alternative for the manufacturer.

We have also used a specific form of collection cost structure that models promotional investments of the reverse channel agent to induce returns and increase awareness of product remanufacturing among consumers. The cost structure model does not assume any variable collection costs that would depend on the number of units returned. Our model can easily be extended to include linear collection costs in the form $ArD(w)$ where $A$ is the per-unit fee paid for each returned product. For instance, if the manufacturer uses prepaid mailboxes to collect used products, then $A$ would be the unit mailing cost. Similarly, when the retailers are undertaking product collection, the retailer might provide financial incentives to the consumers. An example is the reverse vending machines, which pay back a per-unit fee for each used-can returned to the retailer. In this case, the retailer’s collection cost structure would include $ArD(p)$, where $A$ is the per-unit fee paid for each product returned. Note that inclusion of a linear cost structure would not alter the model insights, except it would reduce the marginal returns from remanufacturing, i.e., to $(\Delta - A)$ for the direct collection and to $(b - A)$ for the indirect collection model. Therefore, it would reduce the incentives to invest into product collection and

1. Product recovery is used as a common term for remanufacturing, refurbishing, cannibalization, and recycling.
result in higher buy-back payments and higher retail prices.

We have also assumed that there is already an existing reverse logistics network in place, therefore, the reverse channel agent does not face any fixed costs of installing a collection system. If such costs were incurred, then a minimum number of returns would be required to justify the remanufacturing operations.

Last but not least, our cost formulation does not include any capacity/operational constraints in the product collection network. Capacity constraint on the collection network can be incorporated into the model by defining an upper bound on the number collected via each channel. Another possibility is to model the collection cost as a quadratic function of the quantity returned. Modeling this aspect would result in additional trade-offs for the reverse channel agent. The prices and the collection effort would be set such that the marginal benefits from collection would balance the increase in the marginal cost of collection resulting from the quadratic form. Therefore, the collection effort would not monotonically increase with the demand and the quantity returned. We leave the complete analysis of the extensions of our cost model for future research.

In summary, this paper makes a contribution to the literature on reverse logistics channel choice and coordination by drawing attention to closed-loop supply chains with competing retailers and developing a model of the trade-offs underlying such systems. Our recommendation is that firms make a conscious choice of the reverse channel structure by considering both collection cost and competitive factors. We also show that the interaction between forward and reverse channel decisions are particularly important for channel coordination. Finally, an integrated design of the closed-loop supply chain not only can provide the firm with much needed flexibility to reduce logistics costs for forward and reverse activities, but can also enable it to signal continued concern and action on environmental issues.

An online companion to this paper is available on the Management Science website at http://mansci.pubs.informs.org/ecompanion.html.

References


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