The Strategic Decentralization of Reverse Channels and Price Discrimination Through Buyback Payments

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Abstract

The economical and the environmental bene¯ts 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 post-consumer goods and the strategic product pricing decisions in the forward channel when retailing is competitive. To this end, we model a centralized product collection system, where the manufacturer collects used products directly from the consumers (e.g., print and copy cartridges) and a decentralized product collection system, where the retailers act as product return points (e.g. single use cameras, cellular phones). The paper ¯rst examines how the allocation of product collection to retail outlets impacts their strategic behavior in the product market, and discusses the implication of this on the economic trade-o®s that the manufacturer balances while choosing a centralized as opposed to a decentralized product collection system. When a centralized collection system is used, it is shown that the channel pro¯ts are driven by the cost e±ciency (i.e. scale economies) in collection whereas, in decentralized reverse channels the pro¯ts result from more intense competition in the product market. Secondly, we examine how the manufacturer can use the reverse channel for coordinating pricing decisions to retail markets with di®erent pro¯tability. We show that the buyback payments transfered to the retailers for post-consumer goods provide a wholesale pricing °exibility to the manufacturer, which can be used to price discriminate between retailers of non-identical markets.

1 Introduction

The importance of environmental performance of products and processes is increasingly being recognized as a competitive advantage in several industries such as electronics, automotive and chemicals. Companies like IBM, Interface and Xerox currently integrate environmental performance measures into their product design and manufacturing process, not only to abide with the evolving environmental regulations but also to make product take-back[1] and remanufacturing[2] an avenue to improved strategic positioning and profitability. Consequently, both in durable and non-durable goods categories, product remanufacturing is now an integral part of the current supply chain activities. Some examples of remanufactured products are communication network equipments (AT&T and Lucent Technologies), PCs (IBM, Compaq), one-time use cameras (Kodak, Canon), copy and print cartridges (Xerox, Canon, Accutone), car parts (BMW), carpets (Interface) and copiers (Agfa, Xerox).

The challenge of making product take-back and remanufacturing a value creating activity poses interesting questions with respect to the design and the management of collection channels (i.e., reverse channels) for used products. The choice of the reverse channel structure largely varies depending on the sales and the distribution strategy of the manufacturer, the economic life of the product with the consumers and the industry experience in product recovery and material recycling.

In the electronics industry, product take-back activities are managed by the equipment manufacturers in parallel to the distribution of the new products (Xerox Environmental Report 1999). Xerox has been a leader in reusing the high value, end of lease copiers in the manufacturing of new copiers, which meet the same strict quality standards. The company reports that launching the green manufacturing program saves the company $500 million a year through the reuse of parts and materials (Irina et al. 2000). In a similar vein, IBM and Compaq encourage consumers to use their asset recovery services, which provide easy disposal and replacement of end of life PCs.

[1]product take-back refers to the logistics process by which used products are collected back from the consumers for future reuse or disposal.

[2]remanufacturing refers to the production process, by which used products are disassembled, inspected and recovered into new parts/products.

For consumer goods such as one-time use cameras (Kodak), and print and copy cartridges (Xerox, Canon and Accutone), the distributor network operates as product return points due to their disposal convenience for the consumer. Kodak collects cameras from large retailers who also develop films for customers. The retailers are reimbursed both a fixed fee per unit and the transportation costs from the retail outlets to the Kodak remanufacturing facility. Print and copy cartridges, which are largely distributed through manufacturer outlets (Xerox and Canon), are directly collected from the consumers using prepaid mail boxes provided by the manufacturer. Similar to the one-time use cameras, they are disassembled and remanufactured into new products of the original quality.

This paper examines the implications of reverse channel choice on the manufacturer's strategic pricing decisions and the retail level competition in decentralized distribution systems. More specifically, we address the following research questions:

i) How does decentralization of product collection to the retailers affect the strategic behavior at the retail level and the manufacturer's product pricing decision in the distribution channel ?

ii) What implications the answer to question (i) has on the economic trade-offs the manufacturer balances while choosing between a centralized (i.e., she collects directly from the customers) and a decentralized reverse channel structure (i.e., the retail outlets assume the product collection activity)?

iii) What can be a potential use of buyback payments[3] for post-consumer goods in coordinating the forward channel pricing decisions in a competitive retail market?

To address these questions, two stylized models of reverse channel structures (i.e., centralized and decentralized) are analyzed with respect to their impact on forward channel prices and profits. Figure 1 shows the supply chain structures with reverse flows.

[3] Buyback payment refers to the per unit fixed fee transferred by the manufacturer to a retailer for each used product returned to the manufacturer.

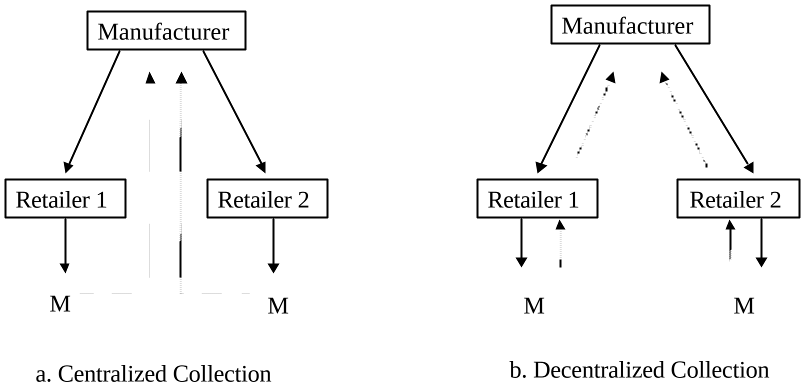

Figure 1: Reverse Channel Structures

The paper studies two types of competitive behavior at the retail level: Competition in quantities and competition in prices. Sing and Vives (1984) show that the capacity constraints on ordering decisions of the retailers lead to less intense competition between the stores than the case of pure price competition. As a result, higher retail prices and lower demand levels are observed in the market. The paper discusses the implications of this result on the reverse channel decision of the manufacturer and on the pro¯tability of product recovery activities.

The ¯rst part of the paper assumes symmetric demand structure for the retail outlets. This assumption enables us to focus solely on the strategic interaction between the stores. In the second part of the analysis, which investigates the role of buyback payments in channel coordination, we consider general (i.e., non-homogeneous) demand structures.

The rest of the paper is organized as follows. In the following section, we brie°y discuss the contribution of this study to reverse logistics research in operations management and in marketing literatures, and the research on distribution channel design and coordination issues. Section 3 is devoted to model conceptualization and formulation. Section 4 presents the analysis and the results of the model under price and quantity competition respectively. Channel coordination through buyback payments is examined in Section 5. Discussion and suggestions for future research are presented in Section 6.

2 Literature

The operations management literature on reverse logistics channels (Fleischmann et al. 1997, Dekker et al. 1998, Gungor and Gupta 1998) assumes that the decisions on reverse logistics planning (facility location, network design and routing) are set by a central decision maker to optimize total system performance, focusing on variable transportation and ¯xed cost of network structures. By adapting a game theoretic approach, we relax the centralized planner assumption and model the independent decision making of each channel member. Speci¯cally, we examine the implications of forward and reverse channel integration (i.e., compare centralized versus decentralized structures) on the economic incentives of retailers when they interact strategically in the product market.

The choice of centralized versus decentralized reverse logistics systems has been a discussion topic in the operations management literature. The main bene¯ts of centralization are given on the basis of lower ¯xed investment costs (i.e., equipment costs for recovery and dismantling) (Krikke 1998, Thierry 1997, Flapper et al. 1997), whereas the arguments favoring the decentralized structure are lower unit variable costs of inspection and transportation. By focusing on the gaming between the channel members, this paper extends the discussion on network design by identifying the strategic dimension of decentralization.

In the marketing literature, a number of studies have examined reverse channels with regards to the roles and the functions of the channel members (Stern et al. 1996, Ginter and Starling 1978, Pohlen and Farris 1992, Carter and Ellram 1998). The research methodology in these studies has been largely exploratory or descriptive and the ¯ndings do not provide insights into the relative performance of di®erent channel structures. The analysis in this paper is di®erent from this stream of research in terms of the methodology, the depth of exploration and the variety of issues considered.

In the analytical marketing literature, several authors have examined manufacturer return policies when retailing is competitive and demand is uncertain. The product returns, which are of interest in these studies occur at the end of the selling season due to overstocking decisions of the retailers (Padmanabhan and Png 1997, Pasternack 1985). In this context, Padmanabhan and

Png examine how retail level competition is a®ected by the use of product return policies. They show that the return policies provide an ordering °exibility for the retailers and this creates over stocking incentives and hence a more intense competition at the retail level. In this paper, we show that a similar strategic e®ect occurs through buyback payments for used products in the reverse channel. When one store reduces its retail price to impact the size of the product return market, this induces the other competing retailer to lower its retail price, as a consequence the competition pushes down the prices even further. In equilibrium, consumers face a product price which is lower than the market equilibrium attained in pure price competition without recovery.

The analytical marketing literature, starting with McGuire and Staelin (1983) has extensively analyzed strategic decentralization decisions in a distribution channel with two competing manufacturers, each selling his products through an independent retailer (Coughlan 1985, Mc Guire and Staelin 1983, Moorthy 1988, Coughlan and Wernerfelt 1989). When intra-channel contracts are observable, the literature shows that, as opposed to the bilateral monopoly case where vertical integration (i.e., channel coordination) is the optimal behavior, in an oligopolistic industry, manufacturers deliberately choose to decentralize their distribution functions in order to bu®er against the competition in the market. The current research in marketing focuses on competition between manufacturers. In this paper, we consider a single manufacturer with competing retailers and consider decentralization decision in the reverse channel. Interestingly, the analysis shows that the manufacturer can also deliberately choose to decentralize the product take-back activity to retailers in order to enhance the competition.

Ingene and Parry (1995) show that, unlike the bilateral monopoly case (Jeuland and Shugan 1983, Weng 1995), when a manufacturer sells through independent retail outlets with di®erent market sizes, a single wholesale price is not su±cient to coordinate the pricing decisions in the channel. The reason is that with non-homogeneous demand structure, the coordinated channel pro¯ts can be attained if the manufacturer charges a di®erent wholesale price (i.e., price discriminates) to each outlet as a function of their respective market size. Given the legal restraints, such a practice is not appropriate unless the manufacturer can justify the di®erential pricing strategy on the basis of costs of serving each retailer. In the second part of the paper, we show that the return payments for old products provide a second degree of freedom for the manufacturer in wholesale pricing, and enables him to adjust the average wholesale price of the product to each retailer's market profitability. We compare coordination via return channels to the quantity discount schedules presented in the literature (Ingene and Parry 1995).

The main contribution of this study to the research is the in-depth examination of interaction between the manufacturer's and the retailer's decisions in the forward and in the reverse channels. The paper extends the current discussion on channel decentralization in competitive retail markets to product take-back and remanufacturing systems. It also highlights the potential use of buyback payments as a price discrimination mechanism between retailers with non-homogeneous demand structure.

3 Basic Setting

In this section, a stylized model is developed to examine the effect of reverse flows on forward channel pricing decisions. To this end, we consider a single manufacturer selling her product through two competing retail outlets. The i-th retailer faces the following linear demand function:

$$D_i(p_i; p_j) = \alpha_i - p_i + \beta p_j \quad s.t.: \quad 0 \leq \beta < 1 \quad i; j \in (1; 2) \quad i \neq j \tag{1}$$

where α_i represents the store level factors, β the product substitution effect, p_i the retail price of the product at store i and p_j the retail price of the product at the competing store j. The demand is, by assumption, downward sloping in its own retail price, p_i (i.e. $\frac{dD_i(p_i; p_j)}{dp_i} < 0$); and upward sloping (or independent of, for completely differentiated outlets: $\beta = 0$) in the competitive retailer price p_j. Note that $\left|\frac{dD_i}{dp_i}\right| > \left|\frac{dD_i}{dp_j}\right|$ in order to ensure that the total demand $(D_1 + D_2)$, does not go up with an increase in either retail price. This form of modeling retail level competition is frequently found in the extant literature.

The first part of the paper assumes homogeneity of the retailers' demand structures (i.e. $\alpha_1 = \alpha_2 = \alpha$). In the section addressing channel coordination, without loss of generality, α_1 is set greater than α_2.

In the forward channel game, the manufacturer is modeled as the Stackelberg leader. Hence, she uses her foresight about each retailer's best response function while determining the optimal wholesale price of the product. The manufacturer treats each retailer equally and the two retailers compete in prices in a Nash framework.

The two supply chain structures are compared with respect to the collection effort shown in taking back the post consumer products, the retail price faced by the consumer, the profits of the manufacturer and the retail outlets. In order to highlight the structural differences and the interaction between the retail outlets, we will assume that the cost of investing in product take-back is the same for each reverse channel agent. More specifically, we will consider that the product return rate from the customers is a concave function of the fixed investment in product collection effort. For instance, the fixed cost of investment in product take-back would correspond to any promotional activities that would increase the consumer awareness about remanufacturing and recovery. Defining τ as the fraction of the consumers who turn in used products and I the fixed investment in product collection, then $\tau = B_o\sqrt{I}$ where B_o is a scaling factor. Equivalently, one can define $I = B\tau^2$ where $B = \frac{1}{B_0}$. Note that parameter B represents the difficulty of inducing product returns from the consumers. In case of single use cameras, the value of B would be small since the consumers already bring in the cameras to the retailers for film development.

If a product is returned to the manufacturer, we assume that it can be remanufactured into as new condition at the unit cost of c_r; while the unit cost of manufacturing is c_m and $c_r < c_m$[4]. Hence, the average cost of producing a unit as a function of the collection effort (return rate of used products) is given by $c(\tau) = (1-\tau)c_m + c_r\tau$. By rearranging terms, one can easily show that $c(\tau) = c_m - \Delta\tau$ where $\Delta = c_m - c_r$, and Δ denotes the unit manufacturing cost savings from recovery.

In the manufacturer collecting (centralized) system (Figure 1 a), the manufacturer maximizes

[4] Kodak remanufactures 76% of the material into a new product. Components such as lens and batteries are replaced new in each remanufactured camera to assure reliability and overall perceived quality of the new product.

the following objective function[5]:

$$\Pi_M^{MC} = \left(w^{MC} - \left(c_m - \Delta \ast \tau^{MC}\right)\right) \sum_{i=1} D_i(p_i^{\ast MC}, p_{3-i}^{\ast MC}) - B(\tau^{MC})^2 \tag{2}$$

$$p_i^{\ast MC} = \arg\max_{p_i^{MC}} \left[(p_i^{MC} - w^{MC}) D_i(p_i^{MC}, p_j^{MC}) \right] \quad i,j \in (1,2);\ i \neq j \tag{3}$$

Furthermore,

$$\Pi_{R,i}^{MC} = (p_i^{MC} - w^{MC}) D_i(p_i^{MC}, p_j^{MC}) \tag{4}$$

represents each retailer's objective function.

The manufacturer determines the profit maximizing values of the wholesale price w^{MC} and the collection effort τ^{MC}, by taking into account the reaction function of each retail outlet.

In the retailer collecting (decentralized) system (Figure 1 b) the manufacturer pays a fixed buyback price for each product returned from the retailers. The buyback price of a returned product is modeled by the parameter b and is equal for both retail outlets[6]. The objective functions of the manufacturer and each retail store in the retailer collecting reverse channel are given by the following expressions:

$$\max_{w^{RC}} \Pi_M^{RC} = \sum_{i=1} (w^{RC} - c_m + (\Delta - b) \ast \tau_i^{\ast RC}) D_i(p_i^{\ast RC}, p_{3-i}^{\ast RC}) \tag{5}$$

$$\tau_i^{\ast RC} = \arg\max_{\tau_i^{RC}} \left[(p_i^{RC} - w^{RC} + b \ast \tau_i^{RC}) D_i(p_i^{RC}, p_j^{RC}) - B(\tau_i^{RC})^2 \right] \tag{6}$$

$$p_i^{\ast RC} = \arg\max_{p_i^{RC}} \left[(p_i^{RC} - w^{RC} + b \ast \tau_i^{RC}) D_i(p_i^{RC}, p_j^{RC}) - B(\tau_i^{RC})^2 \right] \tag{7}$$

$$i,j \in (1,2); \quad i \neq j$$

$$\max_{p_i^{RC}, \tau_i^{RC}} \Pi_{R,i}^{RC} = (p_i^{RC} - w^{RC} + b \ast \tau_i^{RC}) D_i(p_i^{RC}, p_j^{RC}) - B(\tau_i^{RC})^2 \tag{8}$$

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[5] The following notation is used for the variable X : $\overline{X}^{\ast(NR,MC,RC)}_{(M,R_i)}$

where NR, MC and RC denote the no recovery case, the manufacturer collecting and the retailer collecting channels respectively, M and R represent the manufacturer and the retailer, index i denotes each retail outlet, * is the optimal value of the variable and $\overline{X}$ is used to denote the capacity restriction.

[6] In model development, the buyback price b is considered as a parameter in the manufacturer's and the retailer's decision making. The concavity of the profit functions in b later enables us to solve for the optimal b value in the RC channel.

4 A Model of Reverse Channel Choice

In this section, for both the MC and the RC channel structures, the implications of product recovery on the equilibrium prices and the channel profits are examined in comparison to the benchmark model without product remanufacturing. Insights on the optimal reverse channel structure are developed from the point of view of the manufacturer, the retailer and the consumer. Finally, we look at the equilibrium collection effort under a capacity restriction on order quantities[7].

4.1 Benchmark Model

The benchmark case assumes no product recovery. Hence, the demand for the product is satisfied only from newly manufactured units. In the forward channel game, the manufacturer sets the wholesale price and each retail outlet independently determines the retail price of the product.

Each retailer solves:

$$\max_{p_i^{NR}} \pi_{R,i}^{NR} = (p_i^{NR} - w^{NR})(\phi - p_i^{NR} + \beta p_j^{NR}) \tag{9}$$

for the optimal retail price, p_i^{*NR}:

>From the first order conditions, it follows that:

$$p_i^{*NR} = \frac{\phi + \beta p_j^{*NR} + w^{NR}}{2} \tag{10}$$

The demand faced by each retail outlet is given by:

$$D_i^{*NR} = \frac{\phi - (1-\beta)w^{NR}}{2-\beta} \tag{11}$$

Note that with competing retailers, sensitivity of the retail demand to the wholesale price is a decreasing function of β; the product substitution factor $(i.e., \frac{dD_i}{dwd\beta} < 0)$. In fact, it is this effect of retail competition which enables the manufacturer to increase her wholesale price without inducing the retail demand to drop extensively. In other words, the more intense the competition is between the retail outlets, the less impact the retailers' margin decisions have on the retail price and demand.

[7] Proofs of propositions are given in Appendix A.

Given the reaction function of each retail outlet, the manufacturer determines w^{*NR} by solving:

$$\underset{w^{NR}}{Max}\ \Pi_M^{NR} = 2(w^{NR} - c_m)\frac{\phi - (1-\beta)w^{NR}}{2-\beta} \tag{12}$$

One can easily show that $w^{*NR} = \frac{\phi+(1-\beta)c_m}{2(1-\beta)}$ and $p_i^{*NR} = \frac{\phi(3-2\beta)+(1-\beta)c_m}{2(1-\beta)(2-\beta)}$. The margins of the manufacturer and the retailer are calculated respectively as follows:

$$mm^{*NR} = w^{*NR} - c_m = \frac{\phi - (1-\beta)c_m}{2(1-\beta)} \tag{13}$$

$$rm_i^{*NR} = p_i^{*NR} - w^{*NR} = \frac{\phi - (1-\beta)c_m}{2(2-\beta)} \tag{14}$$

The complete list of results is provided in Table 1. Next, the channel pricing decisions are examined with product remanufacturing taking place at the manufacturer.

4.2 Manufacturer Collecting (Centralized) Reverse Channel

First, we analyze the case in which the manufacturer collects the used products directly from the consumers. Under this structure, the manufacturer incurs the total cost of collection and she receives returns from both retail markets. Her objective function is given by:

$$\underset{w^{MC},\tau^{MC}}{Max}\ \Pi_M^{MC} = (w^{MC} - \left(c_m - \Delta\tau^{MC}\right))[D_1^{*MC} + D_2^{*MC}] - B(\tau^{MC})^2 \tag{15}$$

where

$$p_i^{*MC} = \arg\max_{p_i^{MC}} \left[(p_i^{MC} - w^{MC})D_i(p_i^{MC}, p_j^{MC})\right] \tag{16}$$

$$D_i^{*MC} = D_i(p_i^{*MC}, p_j^{*MC}) \qquad i, j \in (1, 2), i \neq j \tag{17}$$

The optimal collection effort level is the outcome of the trade-off between the cost invested in the collection effort and the manufacturing cost savings which will be 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 potential consumers who can return a used product and hence, the higher the marginal benefit from investing in the collection effort. In other words, when there are fixed costs of investing in product collection, the size of the retail market and consequently the quantity of the product returns, would determine the incentives to invest in product take-back effort.

Each store determines the retail price of the product by taking into account the wholesale price charged by the manufacturer and the competition from the other store. The objective function of retailer i is given by:

$$\Pi_{R,i}^{MC} = \underset{p_i^{MC}}{Max}\ (p_i^{MC} - w^{MC})(\alpha - p_i^{MC} + \beta p_j^{MC}) \qquad i,j \in (1,2), i \neq j \tag{18}$$

For a fixed wholesale price w^{MC}, it follows that:

$$p_i^{*MC} = \frac{\alpha + w^{MC}}{(2-\beta)} \tag{19}$$

$$D_i^{*MC} = \frac{\alpha - (1-\beta)w^{MC}}{(2-\beta)} \tag{20}$$

Given the best response function of each retail outlet, the optimization of the manufacturer's profit function with respect to w^{*MC} and τ^{*MC} leads to:

$$w^{*MC} = \frac{(1-X)\alpha + (1-\beta)c_m}{(2-X)(1-\beta)} \tag{21}$$

$$\tau^{*MC} = \frac{\Delta}{B}\left(\frac{\alpha - (1-\beta)c_m}{(2-\beta)(2-X)}\right) \tag{22}$$

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

Substituting w^{*MC} and τ^{*MC} into the retailer's reaction function, the equilibrium retail price is obtained as follows:

$$p_i^{*MC} = \frac{[(1-X)(2-\beta) + (1-\beta)]\alpha + (1-\beta)c_m}{(2-\beta)(1-\beta)(2-X)} \tag{23}$$

One can also show that the margins of the manufacturer and each retailer equal:

$$mm^{*MC} = \frac{\alpha - (1-\beta)cm}{(2-X)(1-\beta)} \tag{24}$$

$$rm_i^{*MC} = \frac{\alpha - (1-\beta)cm}{(2-X)(2-\beta)} \tag{25}$$

Note that in order to characterize the effect of product take-back on the strategic behavior of the retail outlets and the manufacturer, we will focus on the profit margins. For a given unit production cost, the linear demand structure enables us to easily translate the wholesale and the retail pricing decisions into profit margins and vice versa.

A complete list of the model results is given in Table 1. We note the following observation on the equilibrium performance of the centralized system as compared to the benchmark scenario[8].

Observation 1: Vertical Externality in the Channel In the MC system, 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. This follows from the fact that $\frac{mm^{*MC}}{mm^{*NR}} = \frac{rm_i^{*MC}}{rm_i^{*NR}} = \frac{2}{(2-X)}$ and $\frac{2}{(2-X)} > 1$ where $X = \frac{(1-\beta)\Delta^2}{(2-\beta)B}$.

This result highlights the fact 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) since this 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, the other part is retained by the retailers.

4.3 Retailer Collecting (Decentralized) Reverse Channel

When the retailers engage in the product-take back independently, each one solves the following maximization problem for the retail price and the collection effort, p_i^{*RC} and τ_i^{*RC} by taking into account the wholesale price charged by the manufacturer, the retail price and the collection effort of the other store.

$$\underset{p_i^{RC},\tau_i^{RC}}{Max}\ \Pi_{R,i}^{RC} = (p_i^{RC} - w^{RC} + b \ast \tau_i^{RC})(\phi - p_i^{RC} + \beta p_j^{RC}) - B(\tau_i^{RC})^2; \quad i,j \in (1,2); i \neq j \tag{26}$$

The Nash equilibrium in prices and in collection effort results in:

$$p_i^{*RC} = \frac{(1-\gamma)\phi + w^{RC}}{(2-\gamma) - (1-\gamma)\beta} \tag{27}$$

[8]Proofs are listed in Appendix A.

$$\tau_i^{*RC} = \frac{b}{2B}\frac{\phi - (1-\beta)w^{RC}}{(2-\gamma) - (1-\gamma)\beta} \quad (28)$$

and for $i \in (1;2)$ and $\gamma = \frac{b^2}{2B}$.

The manufacturer maximizes her total profits by taking into account the effect of the wholesale price both on the retail demand and on the collection effort at each store.

$$\underset{w^{RC}}{\mathrm{Max}}\ \Pi_M^{RC} = \sum_{i=1} (w^{RC} - c_m + (\Delta - b)\tau_i^{*RC})D_i^{*RC} \quad (29)$$

The results are listed in Table 1. Below, several observations are made concerning the effect of product take-back on the pricing decisions in the channel .

Observation 2: The Manufacturer's Margin When the retailers engage in product collection, the average profit margin of the manufacturer with product recovery equals her margin in the benchmark case without product recovery (i.e., $mm^{*RC} = mm^{*NR} = \frac{\phi-(1-\beta)c_m}{2(1-\beta)}$). Furthermore, the margin is independent of the buyback payment b. From observation 1, it follows that $mm^{*RC} < mm^{*MC}$.

Observation 3: Impact on The Retail Demand The retail demand is an increasing function of the buyback price b. This follows from the fact that $\frac{dD_i^{RC}}{db} > 0$ for $0 \leq \beta < 1$[9].

Note that when the manufacturer's margin is independent of the buyback payment b, her profits increase with an increase in the market demand. Hence, it follows that the change in the market demand is maximum when b is set to its upper-bound Δ (i.e., when all unit cost benefits from recovery are fully transferred to the retailers). In the decentralized collection, the retail demand (price) in the market increases (decreases) with b due to the fact that for the retailers the product take-back and the accompanied buy-back payments function as a discount on the wholesale price of the product. This creates incentives to the retailers to lower their margins in order to impact the size of the return market and the frequency of the discounts (i.e., the return rate of used products). Consequently, reduction of the retail margin to benefit from the buy-back payments leads to even lower margins due to the competition in the market.

[9] It can easily be shown that $\frac{dD_i}{db} = \frac{B\Delta(1-\theta)(\alpha-(1-\theta)c_m)}{(4B - b\Delta - 2B\theta + b\Delta\theta)^2}$.

Observation 4: The Effect of Recovery on The Retail Margin When $b = \Delta$ (see observation 2 and 3), the retailer's margin on the product before any buyback payment is given by[10] :

$$rm^{RC}_{i;\text{before buyback}} = \left(1 - \frac{1}{1 + (1-\gamma)(1-\beta)}\right) rm_i^{*NR}$$

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

What observation 4 shows is that when product take-back is managed by the retailer outlets, each retailer competes more intensely (i.e., sets 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) remains the same in both cases[11]. Consequently, a lower retail margin increases the demand for the product in the market. Even though the margin per unit sold is lower, the retail outlets still benefit from product take-back since they are partially compensated for their loss through the buyback payment for the returned units. It can easily be shown that the average retail margin including the buyback payment is equal to:

$$rm_i^{*RC} = \frac{\phi - (1-\beta)cm}{[2(2-\beta) - \frac{(1-\beta)\Delta^2}{B}]} = rm_i^{*MC} > rm_i^{*NC}$$

Table 1 summarizes the results of the analysis.

	No Recovery	MC Reverse Channel	RC Reverse Channel
τ^*	N/A	$\frac{\Delta}{B}\left(\frac{\phi-(1-\beta)c_m}{(2-\beta)(2-X)}\right)$	$\frac{bH}{2B}\left[\frac{\phi-(1-\beta)c_m}{(1-\beta)(2-Y)}\right]$
w	$\frac{\phi+(1-\beta)c_m}{2(1-\beta)}$	$\frac{(1-X)\phi+(1-\beta)c_m}{(2-X)(1-\beta)}$	$\frac{\phi(1-Y)+(1-\beta)c_m}{(1-\beta)(2-Y)}$
p_i^*	$\frac{\phi(3-2\beta)+(1-\beta)c_m}{2(1-\beta)(2-\beta)}$	$\frac{[(1-X)(2-\beta)+(1-\beta)]\phi+(1-\beta)c_m}{(2-\beta)(1-\beta)(2-X)}$	$\frac{[(1-\beta)(2-Y)-H]\phi+H(1-\beta)c_m}{(1-\beta)^2(2-Y)}$
Π^*_M	$\frac{(\phi-(1-\beta)c_m)^2}{2(1-\beta)(2-\beta)}$	$\frac{(\phi-(1-\beta)c_m)^2}{(2-X)(1-\beta)(2-\beta)}$	$\frac{H}{[2-Y]}\frac{(\phi-(1-\beta)c_m)^2}{(1-\beta)^2}$
Π^*_R	$\frac{(\phi-(1-\beta)c_m)^2}{4(2-\beta)^2}$	$\frac{(\phi-(1-\beta)c_m)^2}{(2-\beta)^2(2-X)^2}$	$\left[1-\frac{b^2}{4B}\right]\frac{H^2}{[2-Y]^2}\frac{(\phi-(1-\beta)c_m)^2}{(1-\beta)^2}$
$\gamma = \frac{b^2}{2B}$	$H = \frac{(1-\beta)}{(2-\gamma)-(1-\gamma)\beta}$	$Y = \frac{(\Delta-b)b}{B}H$	$X = \frac{(1-\beta)\Delta^2}{(2-\beta)B}$

Table 1: General Results

[10] $rm^{RC}_{i;\text{before buyback}} = p_i^{*RC} - w^{*RC}$, $rm_i^{*RC} = p_i^{*RC} - w^{*RC} + \Delta * \tau_i^{*RC}$

[11] Note that when the manufacturer tranfers the unit cost savings directly to the retailer, her average cost of production is equal to the unit cost of no recovery, and so is the manufacturer's margin.

4.4 Comparison of Centralized versus Decentralized Product Return Channels

Based on the results listed in Table 1 and the observations on the equilibrium behavior in the reverse channel structures, proposition 1 summarizes our findings.

Proposition 1: When retailing is competitive, demand is a linear downward sloping function of the retail price and the manufacturer distributes her product through independent retailers using a uniform wholesale price : (a) the manufacturer finds the centralized and the decentralized systems equally profitable. ($\Pi_M^{*MC} = \Pi_M^{*RC}$): (b) the profit of each retail outlet in the centralized system is strictly higher than the profits in the decentralized case. ($\Pi_{R;i}^{*MC} > \Pi_{R;i}^{*RC}$). (c) the retail prices in both the reverse channels structures are equal. ($p_i^{*RC} = p_i^{*MC}$; $i,j \in (1,2)$; $i \neq j$ i.e., $D_i^{*RC} = D_i^{*MC}$) (d) the return rate of the used products in the centralized collection is higher than the return rate in the decentralized reverse channel format. ($\tau^{*MC} > \tau^{*RC}$):

Proposition 1 summarizes our findings on how the decision to centralize or to decentralize product collection impacts the channel behavior. More specifically, we find that in the centralized collection system, product returns and remanufacturing results in lowering the channels's unit production cost, which leads to lower wholesale price, lower retail price and higher profits for the manufacturer and for the retailer. In the decentralized collection system, even though there is no direct unit cost benefit from remanufacturing, product take-back is still profitable to the manufacturer since it functions as an incentive to the retailers to sell more and hence to lower their margins, for which they are partially reimbursed through the buyback payments. To summarize, we find that when the manufacturer centralizes the collection system, the supply chain benefits from scale economies and the channel profits are driven by lower unit cost of production (i.e., efficiency driven) as opposed to the decentralized retailer collecting case, in which the profits are driven by retailer's incentives to sell and the competition in the product market (i.e., demand driven). Table 2 summarizes the above findings.

	$c_{average}$[12]	mm^*	rm^*	D_i
MC System	$< c_m$	$> mm^{NR}$	$> rm_i^{NR}$	$> D_i^{NR}$
RC System	$= c_m$	$= mm^{NR}$	$< rm_i^{NR}$	$> D_i^{NR}$

Table 2: Distribution of the Channel Margin

It is also found that the retailers strictly prefer the manufacturer collecting reverse channel to the decentralized one as they can attain the same average profit margin and the sales volume without incurring the investment cost in collection. Even though the manufacturer is indifferent between a centralized versus decentralized structure on the basis of her channel profits, we also find that the performance of the reverse channel structure with respect to the return rate of the products differ. Due to pooling of retail markets, the centralized system benefits from scale economies and hence leads to a higher investment in product collection and a higher return rate of used products. By modelling the interaction between the forward and the reverse channels, the paper brings new insights with regards to the costs and the benefits of centralization versus decentralization.

In the following section, we briefly look at the case when the retailers compete in quantities as opposed to prices. Modeling competition in quantities enables us to examine whether the above findings are affected by the type of strategic interaction at the retail level. Since the analytical technique used is similar to the one presented in the previous section, we will only summarize our findings.

4.5 Implication of a Capacity Constraint on Remanufacturing

Kreps and Scheinkman (1983) show that when the competing sellers first order stocks and then compete on prices, given the fixed capacity to sell, the resulting equilibrium is similar to that when sellers compete directly in quantities. Singh and Vives (1984) show that retail price competition under a capacity constraint is less intense than the case of pure price competition, which results in higher retail prices and lower demand levels for the manufacturer.

[12] $c_{average} = c_m * \tau + c_r * (1 - \tau)$

In the light of these previous results, in this section we compare the centralized and decentralized product collection system when ordering decisions are made initially. Following the results of Kreps and Scheinkman (1983), we incorporate quantity competition into the modeling framework as a two stage decision making process for the retailers. Given the first stage capacity decision q_i of retailer i, in the second stage each retailer prices to sell his order quantity taking into account the competition from the other store. This leads to:

$$q_1 = \alpha - p_1 + \beta p_2 \tag{30}$$

$$q_2 = \alpha - p_2 + \beta p_1 \tag{31}$$

Solving for p_i in terms of the two capacity choices, we find $p_i = \frac{[\alpha(1+\beta) - \beta q_j - q_i]}{(1-\beta^2)}$. When retailers are the collecting agents, collection effort for products is also determined at the second stage. Looking forward from the first stage, each retailer maximizes his own profits by choosing his order quantities, taking into account how the capacity choice impacts the second stage decisions. Being the Stackelberg leader, the manufacturer sets the wholesale price (i.e., in case she is the collecting agent, she also determines the collection effort level) by taking into account how the retailers will react to her channel decisions. In analyzing this game structure, a methodology similar to the one presented in Section 4 is followed to determine the optimal values of the wholesale price, the retail price, the collection effort and the profit functions of the channel members. For clarity of exposition, the model details and the proofs are presented in Appendix B. Below, we highlight our findings.

Similar to the case of price competition, we find that the savings on unit production cost from remanufacturing increases the margins of the manufacturer and the retailers and the improvement is in fact by the same factor for both parties. This follows from the fact that $\frac{\Pi^{*MC}}{\Pi^{*NR}} = \frac{\pi_i^{*MC}}{\pi_i^{*NR}} = \frac{2}{(2-V)}$ where $V = \frac{\Delta^2(1-\beta^2)}{B(2+\beta)}$ and $\frac{2}{(2-V)} > 1$. However, interestingly, we also find that the impact of recovery on the final prices is lower with a capacity constraint than in the case of pure price competition (i.e., $V < X \Leftrightarrow \frac{2}{(2-X)} > \frac{2}{(2-V)}$).

Singh and Vives (1984) show that when retailers compete in prices constrained by their previous capacity choices, the competition between the retail outlets is less intense than in the case of pure price competition. As a result, this brings about higher retail prices and a lower demand level for the manufacturer. The observation stated above highlights the implication of this finding for product remanufacturing. Specifically, the joint effect of a smaller retail market to compensate for the collection costs of the manufacturer and a reduction in the manufacturer's channel power to manipulate the retailer's pricing decision results in a lower level of investment in collection effort than in the case of pure price competition.

Compared to the findings of the previous section, it is also found that the benefits of remanufacturing to the consumer in terms of lower retail price are less significant under a capacity constraint. Note that $\overline{D}_i^{*MC} < D_i^{*MC}$ (i.e., $\overline{p}_i^{*MC} > p_i^{*MC}$).

The results of the manufacturer and the retailer collecting channels are listed in Table 3. Below we highlight some observations on the performance of the decentralized (retailer) collecting channel.

When retailers assume the product take-back activity, similar to the case of price competition, it is found that the manufacturer's margin with product recovery equals her margin with no recovery (i.e., $\overline{mm}^{*RC} = \overline{mm}^{*NR}$): Furthermore, her margin is also independent of the buyback price b: Hence, it follows that $\overline{mm}^{*RC} < \overline{mm}^{*MC}$. Furthermore, we also find that retail demand is an increasing function of the buyback payment b. This follows from the fact that[13] $\frac{dD_i^{RC}}{db} > 0$ for $0 \le b \le \delta$: Thus, similar to the case of price competition, in the RC reverse channel, the retail outlets attain an average margin (i.e., after the product buyback payments) which equals their profit margins in the centralized system (i.e. $\overline{rm}_i^{*RC} = \overline{rm}_i^{*MC}$).

Based on the observations presented above, proposition 2 compares the centralized and the decentralized product collection channels under capacity constraint.

[13] $\frac{dD_{RC;i}}{db} = \frac{(\alpha - c_m(1-\theta))(1+\theta)\left(\frac{b(1-\theta^2)}{B} + \frac{(\delta-b)(1-\theta^2)}{B}\right)}{\left(-\frac{b(\delta-b)(1-\theta^2)}{B} + 2(2+\theta - \frac{b^2(1-\theta^2)}{2B})\right)^2}$

	MC Reverse Channel	RC Reverse Channel
$\overline{\tau}^{*}$	$\frac{\Delta(1+\beta)(\phi-(1-\beta c_m))}{B(2+\beta)(2-V)}$	$\frac{b(1+\beta)(\phi-(1-\beta c_m))}{2B(2+\beta-H)(2-K)}$
$\overline{w}$	$\frac{\phi(1-V)+(1-\beta)c_m}{(1-\beta)(2-V)}$	$\frac{\phi(1-K)+(1-\beta)c_m}{(1-\beta)(2-K)}$
$\overline{D}_i^{*}$	$\frac{(1+\beta)(\phi-(1-\beta c_m))}{(2+\beta)(2-V)}$	$\frac{(1+\beta)(\phi-(1-\beta c_m))}{(2+\beta-H)(2-K)}$
$\overline{\Pi}_M^{*}$	$\frac{(1+\beta)(\phi-(1-\beta c_m))^2}{(2+\beta)(1-\beta)(2-V)}$	$\frac{2(1+\beta)(\phi-(1-\beta c_m))^2}{(2-K)^2(2+\beta-H)(1-\beta)}$
$\overline{\Pi}_R^{*}$	$\frac{(1+\beta)(\phi-(1-\beta c_m))^2}{(2+\beta)^2(1-\beta)(2-V)^2}$	$\frac{(2-H)(1+\beta)(\phi-(1-\beta c_m))^2}{2\ast(2-K)^2(2+\beta-H)(1-\beta)}$
$V=\frac{\Delta^2(1-\beta^2)}{B(2+\beta)}$	$K=\frac{(\Delta-b)b(1-\beta^2)}{B[2+\beta-H]}$	$H=\frac{b^2}{2B}(1-\beta^2)$

Table 3: General Results with Capacity Constraint

Proposition 2: When the retailers make their ordering decisions (capacity choices) prior to their pricing decisions and the manufacturer distributes through independent retailers using a uniform wholesale price: (a) the manufacturer finds the MC and the RC systems equally profitable. ($\overline{\Pi}_M^{*MC}=\overline{\Pi}_M^{*RC}$): (b) the retailer's profits are strictly greater under the MC reverse channel than under the RC reverse channel. ($\overline{\Pi}_R^{*MC}>\overline{\Pi}_R^{*RC}$). (c) the retail prices in the MC reverse channel and in the RC reverse channel are equal. ($\overline{p}_i^{*MC}=\overline{p}_i^{*RC}$; $i;j\in(1;2)$; $i\neq j$ i.e., $q_i^{*MC}=q_i^{*RC}$) (d) The return rate of used products in the MC reverse channel is greater than the return rate in the RC reverse channel. ($\overline{\tau}^{*MC}>\overline{\tau}^{*RC}$):

Proposition 2 also highlights an interesting finding concerning the impact of supply chain responsiveness on the attractiveness of product take-back and remanufacturing. More specifically, we find that the incentive to invest in product collection and remanufacturing is driven by the sensitivity of the market demand to changes in the cost structure of the manufacturer and the responsiveness of the supply chain while reflecting cost improvements into channel decisions. Kodak and the market for single use cameras is a good example of this. Kodak faces intense competition in the single use camera market both from other OEMs such a Canon, Fuji or Konica and the third party no-name remanufacturers. Consequently, the demand for cameras has become very sensitive to pricing decisions and facing very low retail margins, the company has initiated a program to lower unit production costs. In this respect, remanufacturing is perceived as a competitive advantage at Kodak as it enables the company to operate at lower unit cost ¯gures as compared to its competitors.

Taking a step further, one can also conjecture that in product markets where there are many echelons between the manufacturing and the demand, one would observe less investment on the manufacturer's side to collect and remanufacture used products. Addressing such dimensions of remanufacturing is an interesting future research direction which would lead to an understanding of how the industry structure in°uences the remanufacturing activity in di®erent product markets.

In the next section, we look into more detail at the retailer collecting (decentralized) reverse logistics system. More speci¯cally, we explore the ways in which the product return channel can be used as a tool for channel coordinations with multiple competing retailers.

5 Coordination via Reverse Channel with Non-identical Retail Markets

This section examines channel coordination with competing and non-identical retailers. The key to channel coordination is inducing the independent retailers to set a ¯nal price that maximizes joint channel pro¯ts. Thus, the manufacturer must set a wholesale price that induces the retailer's full marginal cost to equal the channel's total marginal cost. With competing, non-identical retailers, Ingene and Parry (1995) show that the full marginal cost of the channel di®ers by each retail outlet. And so, the channel can be coordinated only if the wholesale price is set di®erently for each retailer. In the same study, Ingene and Parry (1995) demonstrate that for certain parameter ranges[14], the manufacturer is better o® using a linear quantity discount scheme, by which she can attain the coordinated channel performance.

In this section, we show that in a supply chain with product returns, the buyback payments for used products can be a means to adjust the average wholesale price to each retail outlet's market potential. To demonstrate this, we ¯rst summarize the results on the linear quantity discount

[14] The parameter range is given by the di®erence in retailer's ¯x costs. De¯ne f_i and f_j the ¯xed cost of retailer i and retailer j respectively where $D_i < D_j$. It is shown that the linear discount schedule coordinates the channel if $¡\pm < f_i ¡ f_j$ where $\pm$ is non-negative (Ingene and Parry 1995).

scheme proposed by Ingene and Parry and then examine the potential use of buyback payments for price discrimination among the retailers.

5.1 Linear Quantity Discounts and Non-identical Retailers

Consistent with the notation in Ingene and Parry and the notation in this paper, we denote the non-homogeneity of retail markets by the following demand function:

$$D_i(p_i; p_j) = \phi_i - p_i + \beta p_j \tag{32}$$

where ϕ_i $(i \in 1; 2)$; model the difference in absolute demand between the two retail outlets[15].

Ingene and Parry (1995) show that a centrally coordinated channel would charge an optimal retail price of $p^{*NR}_{C;i} = \frac{\phi_i + \theta\phi_j + (1-\theta^2)c_m}{2(1-\theta^2)}$; which leads to demand equaling $D^{NR*}_{C;i} = \frac{\phi_i - (1-\theta)c_m}{2}$: Since the retail markets are identical, it follows that if $\phi_i > \phi_j$ then $p^{*NR}_{C;i} > p^{*NR}_{C;j}$ and $D^{NR*}_{C;i} > D^{NR*}_{C;j}$:

An alternative approach proposed in the paper, which yields the centrally coordinated channel outcome is to charge a different wholesale price to each retail outlet and to allow them to choose the retail price of the product independently. Under this scenario, one can easily show that the wholesale price adjusted to each retailer's market size is given by: $w^{*NR}_i = \frac{\beta^2 D^{NR*}_{C;i} + \beta D^{NR*}_{C;j}}{(1-\beta^2)} + c_m$:

Note that if the demand faced by each retail outlet were completely independent $(\beta = 0)$ then w^{*NR}_i would equal c_m[16]: Or, if the demand structures were homogeneous $(\phi_i = \phi_j)$; then $w^{*NR}_i = w^{*NR}_j = \frac{\beta D^{NR*}_{C;i}}{(1-\beta)} + c_m$. Hence, it is the non-homogeneity and the inter-dependence of the demand functions which forces the manufacturer to charge different wholesale prices to each retail outlet to attain the coordinated channel profits. Furthermore, it is also important to note that $w^{*NR}_i \gtrless w^{*NR}_j$ as $D^{NR*}_{C;j} \gtrless D^{NR*}_{C;i}$: Hence, the retailer with the lower quantity sold pays the higher wholesale price for the product.

The manufacturer can transfer some part of the retail profits by setting a fixed franchisee fee F^{*NR}_i for each retail outlet: Thus, the channel coordinating wholesale pricing scheme is given by

[15] Without loss of generality, it is assumed that the variable cost of retailing is zero for both stores but they are differentiated with respect to fixed costs. More specifically, it is assumed that when $\phi_i > \phi_j$; $-\delta < f_i - f_j$ where δ is a non-negative constant.

[16] Note that this is the channel coordinating fixed wholesale price in the bilateral monopoly case.

(w_i^{*NR}, F_i^{*NR}) which is similar to a two-part tariff. The difficulty of employing this two-part tariff rises from the fact that due to legal considerations (such as the Robinson Patman Act of 1936), the manufacturer is precluded from giving different terms (discriminating in prices) to different retailers unless their cost differences are justified. Hence, the above analysis shows that with a single wholesale price for both retail outlets, the manufacturer is not able to obtain the retail price and demand levels of a coordinated channel. On the other hand, charging each retail outlet a unique two-part tariff is not practically viable due to the legal considerations.

By using a linear quantity discount schedule of the form $T = W - wD_i$, where W is the vertical intercept of the wholesale pricing scheme and w is the slope of the per-unit wholesale pricing schedule, the manufacturer can in fact replicate the coordinated channel demand and price level at each retail outlet.

The intuition underlying the above result is that, if retail markets are non-identical, then the manufacturer needs a flexible wholesale pricing scheme in order to coordinate the two retail variables p_i^{*NR} and p_j^{*NR} where $p_i^{*NR} \neq p_j^{*NR}$. A linear quantity discount schedule which is defined by two parameters W and w provides two degrees of freedom to the manufacturer, by which she can adjust her wholesale price to each retailer's profitability and thus achieve the coordinated channel performance. In the next section, we show that by using the reverse channel, the manufacturer can actually exercise this flexibility in pricing by using the buyback payment b.

5.2 Coordination Using Reverse Channel

For comparison, we first determine the profits of the coordinated supply chain with product returns. The optimal coordinated channel values for the retail price, the total supply chain profits and the collection effort are determined. Following a similar methodology to the one outlined above, next we determine the buyback payments, by which the manufacturer can attain the coordinated channel performance in a decentralized setting.

Consider a centrally coordinated channel structure with product recovery where all decisions are made in a coordinated fashion by a central planner. In such a system, the total system profits are given by:

$$\Pi_C = \sum_i (p_{C;i} - c_m + \Delta\tau_{C;i}) D_i(p_{C;i}; p_{C;j}) - B(\tau_{C;i})^2 \tag{33}$$

Maximization of Π_C with respect to $p_{C;i}$ and $\tau_{C;i}$ leads to the following expressions:

$$p_{C;1} = \frac{A\phi_1 + B\beta\phi_2 + C(1-\beta^2)c_m}{(1-\theta^2)M} \tag{34}$$

$$p_{C;2} = \frac{A\phi_2 + B\beta\phi_1 + C(1-\beta^2)c_m}{(1-\theta^2)M} \tag{35}$$

where $A = (1-X)(2-X(1-\beta^2))$; $Z = 2(1-X) + X^2(1-\beta^2)$; $C = 2 - X(1+\beta)$; $M = (2-X)^2 - X^2(2-\beta^2)$, $X = \frac{\Delta^2}{2B}$.

One can easily show that $p^*_{C;i}$ approaches $p^{*NR}_{C;i}$ as $B \to \infty$ (or equally $X \to 0$).

In a decentralized channel structure, the manufacturer sets a single wholesale price W for new products and a buyback price b for the returned units. Specifically, W and b can be chosen such that the coordinated channel demand and the retail price levels are obtained when the channel members take their decisions in a decentralized fashion.

Hence, for a fixed W and b, each retail outlet maximizes the following objective function by taking the other retailer's action as given:

$$\underset{p_i, \tau_i}{Max}\ \Pi_{R;i} = (p_i - W + b \ast \tau_i)(\phi_i - p_i + \beta \ast p_j) - B \ast \tau_i^2 \tag{36}$$

The Nash equilibrium in prices in terms of W and b is given by:

$$p_i^* = \frac{(1-r)(2-r)\phi_i + \beta(1-r)^2\phi_j + W(2+\beta-r(1+\beta))}{(2-r)^2 - \beta^2(1-r)^2} \tag{37}$$

where $r = \frac{b^2}{2B}$.

>From p_i^*, it follows that the buyback payments for returned products function as a price discount on new units procured by the retailers. When there are fixed costs to product collection, then the collection effort shown by each retailer becomes proportional to each store's market size (i.e., scale). This enables the manufacturer to set a buyback price b such that the average wholesale price faced by each retailer reflects the profitability (i.e., scale) of their respective markets. Hence,

a large market size induces a higher level of investment in product collection which results in a lower average wholesale price.

The channel coordinating W^* and the buyback payment b^* is determined from the solution to equations $p_i^* = p_{C;i}^*$ for $(i = 1; 2)$: Explicit expressions are given in Appendix C. Consequently, the average wholesale price charged to each retail outlet is given by:

$$T^* = W^* - b^* \tau^* \tag{38}$$

Note the similarity of expression T^*, the average wholesale price faced by each outlet and the linear quantity discount scheme proposed previously. Put differently, we find that the reverse channel can actually provide the wholesale pricing flexibility needed to coordinate the distribution channel with non-identical retail markets. Specifically, by carefully setting the wholesale price of a new product W and, the buyback payment b for used products, the manufacturer can reflect the market size differences on the average wholesale price charged to each retailer. The payments in the reverse channel can be used as a means to price discriminate between markets of different profitability. Furthermore, a fixed part of the retail profits can be transferred to the manufacturer in the form of a franchisee fee, F.

The finding in this section draws attention to an important use of reverse flows in coordinating forward channel decisions when the manufacturer serves retail markets with different profitability. Below, we provide a summary of the important insights of the paper, discuss the limitations of the analysis and suggest directions for future research.

6 Discussion and Direction for Future Research

This paper is one of the first formal studies which looks at the interaction between decisions in the forward and the reverse logistics channels and the implications on the supply chain profits. More specifically, we question how the allocation of product take-back responsibility to the retail outlets impacts their strategic behavior (i.e., pricing decisions) in a competitive market and how this shapes the trade-off faced by the manufacturer when using a centralized versus a decentralized collection system. The paper also demonstrates that the return channel can be a means to price discriminate between retail outlets of di®erent market pro¯tability. We provide the equilibrium values of the wholesale price, the retail price and the product return rates under both price and quantity competition.

6.1 Centralization versus Decentralization

To highlight the costs and the bene¯ts of centralization versus decentralization, two channel structures are compared: a centralized collection channel (the MC system) where the used products are directly collected from the customers by the manufacturer, and a decentralized system where each retailer assumes the product take-back responsibility from their local markets, and are reimbursed on a per unit basis for each item returned.

The analysis highlights an interesting trade-o® between centralization versus decentralization of the product collection activity. When product collection is centralized by the manufacturer, the investments in product take-back are driven by scale economies. It is shown that the ability to collect from both retail markets induces the manufacturer to invest more than each retailer, for whom the returns occur only from their local markets. Centralization is preferred by the retailers as they avoid the direct cost of investing in product collection, and also they bene¯t from the vertical externality in the channel due to savings in unit production costs. Centralization is also preferred by the customers as they face a lower retail price and a higher return rate of used products from the market, hence lower environmental and product disposal costs.

An immediate bene¯t of decentralization for the manufacturer comes from savings in direct ¯xed investment costs of product collection. The indirect bene¯t derives from the strategic interaction between competing retailers. It is shown that the decentralization of product collection activities results in new incentives for retailers to reduce their margins on the product, with the expectation that they compensate the reduction in retail price through the buyback payments for used products. However, since the retail market is competitive, the strategic interaction between the stores drives down the retail prices even further. The manufacturer bene¯ts from this interaction e®ect as the total sales volume is increased. The modeling framework also highlights the fact that decentralization leads to under investment in the product collection e®ort due to the fact that the economic incentives of each retailer are based on their own product markets. In comparison with the centralized structure, the channel operates at higher unit production costs.

The design of centralized and decentralized reverse logistics systems has been a discussion topic in the operations management literature. The main arguments for centralization are given on the basis of fixed costs (i.e. equipment costs) (Krikke 1998, Thierry 1997, Flapper et al. 1997) whereas the arguments that favor the decentralized structure are made considering variable costs such as unit cost of inspection and transportation. In this paper, we model the trade-off between the scale effect of centralization and the strategic effect of decentralization. Focusing on both reverse and forward channel incentives of the agents, the paper contributes to the literature on network design by identifying a strategic dimension of decentralization. In that respect, the findings are related to the marketing stream, which examines the strategic interaction in distribution channels (Coughlan 1985, Mc Guire and Staelin 1983, Moorthy 1988). The analysis shows that the manufacturer can in fact deliberately choose to decentralize the reverse channel in order to benefit from the competitive interaction between the retailers.

In the extension of the original model where we look at the supply chain with a constraint on the order quantities, we find that the incentives to take back used products are determined by the sensitivity of the channel decisions to changes in the product cost structure and the responsiveness of the supply chain to reflect these changes to the market demand.

The modeling framework has made several assumptions which have to be relaxed to develop a more comprehensive understanding of "green" manufacturing practices in general, and product recovery systems in particular. There is certainly a need for explicit modeling of the consumer's utility from product consumption including the disposal and environmental aspects. It is conjectured that high product transportation and disposal costs for the consumers would favor a decentralized product collection system. However, proper characterization of trade-offs would yield further insights into the subject.

The analysis also assumed no secondary markets. The implications of third party remanufacturing and the existence of secondary markets on the incentives of channel members to invest in product collection is another future research issue to be considered in the reverse channel logistics context.

Our key assumptions include retail demand functions that are linear and cross-price effects that are symmetric. In a recent paper, Lee and Staelin (1997) show that the vertical strategic interaction in a distribution system and the optimality of the channel strategies depend on the convexity of the demand functions. Therefore, it should be pointed out that while the modeling assumptions with regard to the retail demand structure are consistent with the literature, the generalizability of the results to non-linear or non-symmetric retail demand functions is a question of future research.

The analysis has assumed that all variables in the model are deterministic. Since uncertainty is a significant inherent characteristic of reverse channels, future research should also include this factor.

This analytical study indicates that the design of reverse channel structures involves not only the balancing of fixed and variable costs, but also strategic considerations. Future research should conduct a more in-depth analysis of this problem considering multiple factors besides the ones examined here.

6.2 Coordination with Non-Identical Retailers

The paper draws attention to how the manufacturer can use the reverse channel to leverage her supply chain profits, specifically when she serves retail outlets of different profitability. Here, we show that with non-identical retail markets, the buyback payments for returned products provide a second degree of flexibility in pricing to the manufacturer, by which she can adjust the average wholesale price charged to each store to the profitability of their respective markets. As a result, the manufacturer can attain the price and demand levels of a centrally coordinated channel in a decentralized setting. Furthermore, she can extract part of the profits from the retail outlets through a fixed franchisee fee. We compare coordination through reverse channel to coordination by linear quantity discounts proposed in the literature (Ingene and Parry 1995). A natural direction to extending the analysis is to incorporate how information asymmetry in the channel would impact the efficiency of the coordination scheme using the reverse channel.

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A Appendix

Manufacturer Collecting Reverse Channel: In the MC reverse channel, given the wholesale price w^{MC} and the collection effort τ^{*MC}, each retailer solves: $\max_{p_i^{MC}} (p_i^{MC} - w^{MC})(\phi - p_i^{MC} + \beta p_j^{MC})$ The optimal value of p_i^{MC} satisfies: $\frac{d\Pi_{R,i}^{MC}}{dp_i^{MC}} = (\phi - p_i^{MC} + \beta p_j^{MC}) - (p_i^{MC} - w + b * \tau_i^{MC}) = 0$ for $i, j \in (1;2)$ and is equal to $D_i^{*MC} = \frac{\phi - (1-\beta)w^{MC}}{2-\beta}$. Using the derived demand function, the manufacturer's problem can be stated as: $\max_{w,\tau} \Pi_M^{MC} = 2(w^{MC} - c_m + \Delta * \tau^{MC})(\frac{\phi - (1-\beta)w^{MC}}{2-\beta}) - B(\tau^{MC})^2$

The equilibrium values of w^{MC} and τ^{MC} satisfy: $\frac{d\Pi}{dw^{MC}} = -\frac{(1-\beta)}{(2-\beta)}(w^{MC} - c_m + \Delta\tau^{MC}) + (\frac{\phi - (1-\beta)w^{MC}}{2-\beta}) = 0$; $\frac{d\Pi_M^{MC}}{d\tau^{MC}} = \Delta(\frac{\phi - (1-\beta)w^{MC}}{2-\beta}) - 2B\tau^{MC} = 0$.

It can easily be shown that $w^{*MC} = \frac{(1-X)\phi + (1-\beta)c_m}{(1-\beta)(2-X)}$ and $\tau^{*MC} = \frac{\Delta}{B}\frac{(\phi - (1-\beta)c_m)}{(2-\beta)(2-X)}$ where $X = \frac{(1-\beta)\Delta^2}{(2-\beta)B}$.

Substituting w^{*MC} into the appropriate reaction functions, the equilibrium values for the retail price and the retail demand are found.

Note that the manufacturer and the retailer profit margins are given by: $mm^{*MC} = w^{*MC} - c_m + \Delta\tau^{*MC} = \frac{\phi - (1-\beta)c_m}{(2-X)(1-\beta)}$; $rm_i^{*MC} = \frac{\phi - (1-\beta)c_m}{(2-X)(2-\beta)}$.

Evaluating the objective function of the manufacturer and the retailer at w^{*MC}; τ^{*MC} and p_i^{*MC}, the optimal profits are found as $\Pi_M^{*MC} = \frac{(\phi - (1-\beta)c_m)^2}{(2-\beta)(2-X)(1-\beta)}$; $\Pi_{R;i}^{*MC} = \frac{(\phi - (1-\beta)c_m)^2}{(2-\beta)^2(2-X)^2}$.

Proof of Observation 1: Proof. Note that $\frac{p^{*MC}}{p^{*NR}}$ equals $\frac{2[((1-X)(2-\beta)+(1-\beta))\phi+(1-\beta)cm]}{(2-X)[(3-2\beta)\phi+(1-\beta)cm)]}$. To prove that the inequality $\frac{p^{*MC}}{p^{*NR}} < 1$ always holds, one needs to show that the expression $\frac{p^{*MC}}{p^{*NR}} - 1 = \frac{-X((3-2\beta)\phi-(1-\beta)c_m)}{(2-X)[(3-2\beta)\phi+(1-\beta)cm)]}$ is negative. Note that since $D_i^{*MC} > 0$; $(3-2\beta)\phi - (1-\beta)c_m > 0$ holds. From $X > 0$ and $\beta < 1$; it follows that $\frac{p^{*MC}}{p^{*NR}} - 1 < 0$. ■

Proof of Observation 2: Proof. Note that $\frac{mm^{*MC}}{mm^{*NR}} = \frac{\frac{\phi-(1-\beta)c_m}{(2-X)(1-\beta)}}{\frac{\phi-(1-\beta)*c_m}{2(1-\beta)}} = \frac{2}{2-X}$ and $\frac{rm_i^{*MC}}{rm_i^{*NR}} = \frac{\frac{\phi-c_m(1-\beta)}{(2-X)(2-\beta)}}{\frac{\phi-c_m(1-\beta)}{2(2-\beta)}} = \frac{2}{2-X}$. Since $\beta < 1$, $B > 0$ and $\Delta^2 > 0$; it follows that $X = \frac{(1-\beta)\Delta^2}{(2-\beta)B} > 0$; $(2-X) < 2$ and $\frac{2}{2-X} > 1$. ■

Retailer Collecting Reverse Channel: In the RC reverse channel, given the wholesale price w and the buy-back price b, each retailer solves the following maximization problem: $\max_{p_i^{RC},\tau_i^{RC}} \Pi_{R,i}^{RC} = (p_i^{RC} - w^{RC} + b * \tau_i^{RC})(\phi - p_i^{RC} + \beta * p_j^{RC}) - B(\tau_i^{RC})^2$ for $i,j \in (1,2), i \neq j$. The equilibrium values for p_i^{RC} and τ_i^{RC} satisfy: $\frac{d\Pi_{R,i}^{RC}}{dp_i^{RC}} = \left(\phi - p_i^{RC} + \beta p_j^{RC}\right) - (p_i^{RC} - w^{RC} + b * \tau_i^{RC}) = 0$; $\frac{d\Pi_{R,i}^{RC}}{d\tau_i^{RC}} = b(\phi - p_i^{RC} + \beta p_j^{RC}) - 2B\tau_i^{RC} = 0$. The Nash equilibrium in prices and the collection effort are given by $p_i^{*RC} = \frac{(1-\gamma)\phi + w^{RC}}{(2-\gamma)-(1-\gamma)\beta}$, $D_i^{*RC} = \frac{(\phi-(1-\beta)w^{RC})}{((2-\gamma)-(1-\gamma)\beta)}$ and $\tau_i^{*RC} = \frac{b(\phi-(1-\beta)w^{RC})}{2B((2-\gamma)-(1-\gamma)\beta)}$ where $\gamma = \frac{b^2}{2B}$. Being the Stackelberg leader, the manufacturer maximizes: $\max_{w^{RC}} \Pi_M^{RC} = 2(w^{RC} - c_m + (\Delta - b)\frac{b(\phi-(1-\beta)w^{RC})}{2B((2-\gamma)-(1-\gamma)\beta)})(\frac{(\phi-(1-\beta)w^{RC})}{((2-\gamma)-(1-\gamma)\beta)})$. The optimal wholesale price satisfies $\frac{d\Pi_M^{RC}}{dw^{RC}} = 0$ which leads to $w^{*RC} = \frac{(1-Y)\phi+(1-\beta)c_m}{(1-\beta)(2-Y)}$ where $Y = \frac{b(\Delta-b)}{B}\frac{(1-\beta)}{(2-\gamma)-(1-\gamma)\beta}$.

Proof of Observation 3: Proof. The manufacturer's profit margin equals $mm^{*RC} = w^{*RC} - c_m + (\Delta - b)\tau^{*}_{RC} = \frac{\phi-(1-\beta)*c_m}{2(1-\beta)}$. Hence $mm^{*RC} = mm^{*NR}$. Since $mm^{*RC} = \frac{\phi-(1-\beta)c_m}{(2-X)(1-\beta)}$ and $X > 0$ (See observation 1) it follows that $mm^{*RC} < mm^{*MC}$. ■

Proof of Observation 4: Proof. The retail demand in the RC reverse channel is given by $D_i^{*RC} = \frac{H(\phi-(1-\beta)c_m)}{(1-\beta)(2-Y)}$ where $H = \frac{(1-\beta)}{(2-\gamma)-(1-\gamma)\beta}$ and $Y = \frac{b(\Delta-b)}{B}\frac{(1-\beta)}{(2-\gamma)-(1-\gamma)\beta}$. The first derivative of demand w.r.t. b is given by: $\frac{dD_i^{*RC}}{db} = \frac{B\Delta(1-\beta)(\phi-(1-\beta)c_m)}{(4B-b\Delta-2B\beta+b\beta\Delta)^2}$. Since $\beta < 1$; $B > 0$ and $\Delta > 0$, it naturally follows that $\frac{dD_i^{*RC}}{db} > 0$. Since the profit margin of the manufacturer is independent of b, the profits of the manufacturer are maximized when $b = \Delta$. ■

Proof of Observation 5: Proof. The retailer's margin before any buy-back payment is given by: $p_i^{*RC} - w^{*RC} = (\frac{(1-\gamma)(1-\beta)}{1+(1-\gamma)(1-\beta)})(\frac{\phi-c_m(1-\beta)}{2(2-\beta)})$. Alternatively, $rm^{*RC}_{i,before\ buy-back} = p_i^{*RC} - w^{*RC} = (\frac{(1-\gamma)(1-\beta)}{1+(1-\gamma)(1-\beta)})rm^{*NR}$ which is less than rm^{*NR} since $(\frac{(1-\gamma)(1-\beta)}{1+(1-\gamma)(1-\beta)}) < 1$. Note that after the buy-back payments for the returned post-consumer products, the retailer's profit margin is given by: $p_i^{*RC} - w^{*RC} + \Delta * \tau_i^{*RC} = \frac{\phi-(1-\beta)c_m}{(2-X)(2-\beta)}$. Thus it is found that $rm^{*RC} = rm^{*MC}$. ■

Proof of Proposition 1: Proof. 1. Setting $b = \Delta$ in the expression for Π_M^{*RC} (Table 1), it follows that: $\Pi_M^{*RC} = \frac{(\phi-(1-\beta)c_m)^2}{2(1-\beta)((2-\gamma)-(1-\gamma)\beta)}$ where $\gamma = \frac{\Delta^2}{2*B}$. Simplification of the expression for Π_M^{*RC} leads to: $\Pi_M^{*RC} = \frac{(\phi-(1-\beta)c_m)^2}{(2(2-\beta)(1-\beta)-\frac{(1-\beta)^2\Delta^2}{B})}$. Furthermore, Π_M^{*RC} equals $\Pi_M^{*MC} = \frac{(\phi-(1-\beta)c_m)^2}{(2-X)(1-\beta)(2-\beta)}$

where $X = \frac{(1-\beta)\Delta^2}{(2-\beta)B}$. 2. The profits of the retailer under the RC system are given by: $\Pi^{*RC}_{R,i} = (1-\frac{\Delta^2}{4B})\frac{(\phi-(1-\beta)c_m)^2}{4(2-\beta)^2-2(1-\beta)(2-\beta)\frac{\Delta^2}{B}+\frac{(1-\beta)^2\Delta^2}{B^2}}$. Arranging terms, one can show that $\Pi^{*RC}_{R,i} = (1-\frac{\Delta^2}{4B})\Pi^{*MC}_{R,i}$ where $(1-\frac{\Delta^2}{4B}) < 1$ since $\Pi^{*RC}_{R,i} > 0$. 3. Note that $D_i^{*MC} = \frac{\phi-(1-\beta)c_m}{(2-\beta)(2-X)}$ and $D_i^{*RC} = H\frac{(\phi-(1-\beta)c_m)}{2(2-\beta)}$ where $H = \frac{(1-\beta)}{(2-\gamma)-(1-\gamma)\beta}$ and $\gamma = \frac{\Delta^2}{2B}$. Hence, by rearranging terms, one can easily show that $D_i^{*RC} = D_i^{*MC}$ and therefore $p_i^{*RC} = p_i^{*MC}$. 4. Since $\tau_i^{*MC} = \frac{\Delta}{B}D_i^{*MC}$, $\tau_i^{*RC} = \frac{\Delta}{2B}D_i^{*RC}$ and $D_i^{*RC} = D_i^{*MC}$, it follows that $\tau_i^{*MC} > \tau_i^{RC}$. ■

B Appendix

Manufacturer Collecting Reverse Channel under Capacity Constraint: In this case, each retailer plays a two-stage game. In the first stage, the order quantities are set in a Nash framework and in the second stage, a pricing game is resolved. The sub-game perfect equilibrium results in order quantities which will be cleared in the second stage. To solve this two stage game, backward induction is used. Given the first stage decisions q_1^{MC} and q_2^{MC}, the final retail prices are given by: $\bar{p}_i = \frac{\phi(1+\beta)-\beta q_j - q_i}{1-\beta^2}$ for $i, j \in (1,2)$, $i \neq j$. In the first stage, each retailer maximizes the following function w.r.t. q_i^{MC} while assuming that the other retailer's quantity choice is given: $\max_{q_i^{MC}} \bar{\Pi}^{MC}_{R,i} = (\frac{\phi(1+\beta)-\beta q_j^{MC}-q_i^{MC}}{1-\beta^2} - \bar{w}^{MC})q_i^{MC}$. q_i^{*MC} satisfies the following FOC: $\frac{d\bar{\Pi}^{MC}_{R,i}}{dq_i^{MC}} = -\frac{1}{(1-\beta^2)}q_i^{MC} + (\frac{\phi(1+\beta)-\beta q_j^{MC}+q_i^{MC}}{1-\beta^2}) = 0$ for $i,j \in (1,2); i \neq j$.

As the Stackelberg leader, the manufacturer solves: $\max_{\bar{w}^{MC},\bar{\tau}^{MC}} \bar{\Pi}^{MC}_M = 2*\frac{1+\beta}{2+\beta}(\phi-(1-\beta)\bar{w}^{MC})(\bar{w}^{MC} - c_m + \Delta\bar{\tau}^{MC}) - B(\bar{\tau}^{MC})^2$. The FOCs w.r.t. $\bar{w}^{MC}$ and $\bar{\tau}^{MC}$ are given by: $\frac{d\bar{\Pi}^{MC}_M}{d\bar{w}^{MC}} = -(1-\beta)(\bar{w}^{MC} - c_m + \Delta\bar{\tau}^{MC}) + (\phi-(1-\beta)\bar{w}^{MC}) = 0$; $\frac{d\bar{\Pi}^{MC}_M}{d\bar{\tau}^{MC}} = 2\frac{1+\beta}{2+\beta}(\phi-(1-\beta)\bar{w}^{MC})\Delta - 2B\bar{\tau}^{MC} = 0$, which lead to $\bar{w}^{*MC} = \frac{\phi(1-V)+c_m(1-\beta)}{(1-\beta)(2-V)}$, $\bar{\tau}^{*MC} = \frac{\Delta(1+\beta)(\phi-(1-\beta)c_m)}{B(2+\beta)(2-V)}$ where $V = \frac{\Delta^2(1-\beta^2)}{B(2+\beta)}$.

Substituting $\bar{w}^{*MC}$, one obtains $\bar{q}_i^{*MC} = \frac{(1+\beta)(\phi-(1-\beta)c_m)}{(2+\beta)(2-V)}$, $\bar{p}_i^{*MC} = \frac{((1-V)(2+\beta)+1)\phi+(1-\beta^2)c_m}{(1-\beta)(2+\beta)(2-V)}$; $\bar{\Pi}^{*MC}_M = \frac{(1+\beta)(\phi-(1-\beta)c_m)^2}{(2+\beta)(2-V)(1-\beta)}$ and $\bar{\Pi}^{*MC}_{R,i} = \frac{(1+\beta)(\phi-(1-\beta)c_m)^2}{(2+\beta)^2(2-V)^2(1-\beta)}$.

The profit margin of the manufacturer is given by $\overline{mm}^{*MC} = \bar{w}^{*MC} - c_m + \Delta\bar{\tau}^{*MC}$, which amounts to $\overline{mm}^{*MC} = \frac{(\phi-(1-\beta)c_m)}{(1-\beta)(2-V)}$. Similarly, one can show that $\overline{rm}_i^{*MC} = \bar{p}^*_{MC,i} - \bar{w}^{*MC} = \frac{(\phi-(1-\beta)c_m)}{(1-\beta)(2-V)(2+\beta)}$.

Proof of Observation 6: Proof. The profit margins of the manufacturer and the retailer without product recovery are calculated by taking the limit of $\overline{mm}^{*MC}$ and $\overline{rm}_i^{*MC}$ as $B \to \infty$. Note that $\lim_{B \to \infty} V = 0$. Thus it follows that $\overline{mm}^*_{NR} = \frac{(\alpha-(1-\beta)c_m)}{(1-\beta)(2)}$ and $\overline{rm}^*_{NR} = \frac{(\alpha-(1-\beta)c_m)}{(1-\beta)(2)(2+\beta)}$. The ratios of the retail margins result in: $\frac{\overline{mm}^{*MC}}{\overline{mm}^*_{NR}} = \frac{\frac{(\alpha-(1-\beta)c_m)}{(1-\beta)(2-V)}}{\frac{(\alpha-(1-\beta)c_m)}{(1-\beta)(2)}} = \frac{2}{2-V} = \frac{\overline{rm}_i^{*MC}}{\overline{rm}^*_{NR}}$. Note that $\frac{\overline{mm}^{*RC}}{\overline{mm}^*_{NR}} = \frac{\overline{rm}_i^{*MC}}{\overline{rm}^*_{NR}} = \frac{2}{2-V} > 1$. To show that $V < X$ where $V = \frac{\Delta^2(1-\beta^2)}{B(2+\beta)}$ and $X = \frac{(1-\beta)\Delta^2}{(2-\beta)B}$, one needs to show that the inequality $\frac{\Delta^2(1-\beta^2)}{B(2+\beta)} < \frac{(1-\beta)\Delta^2}{(2-\beta)B}$ is satisfied for $0 \le \beta < 1$ and $B > 0$, by simplification of both sides, $\frac{(1+\beta)}{(2+\beta)} < \frac{1}{(2-\beta)}$ should equally be satisfied for $0 \le \beta < 1$. It is easy to see that the right hand side of the inequality is increasing in β and has a minimum value of $\frac{1}{2}$ and a limiting value of 1 as $\beta \to 1$. The derivative of the left hand side of the expression w.r.t. β is given by $\frac{1}{(2+\beta)^2}$ which is always positive for $0 \le \beta < 1$. Hence, the left hand side is also increasing in β and has a minimum value of $\frac{1}{2}$ at $\beta = 0$ and a limiting value of $\frac{2}{3}$ as $\beta \to 1$. Hence, the value of V is increasing in β and is always less than X. ■

Proof of Observation 7: Proof. Note that the inequality $q_i^{*MC} < D^*_{MC,i}$ can be written as: $\frac{(1+\beta)(\alpha-(1-\beta)c_m)}{(2+\beta)(2-V)} < \frac{\alpha-(1-\beta)c_m}{(2-\beta)(2-X)}$, which simplifies to $\frac{(1+\beta)}{(2+\beta)(2-V)} < \frac{1}{(2-\beta)(2-X)}$. Since $\frac{(1+\beta)}{(2+\beta)} < \frac{1}{(2-\beta)}$ and $\frac{1}{(2-V)} < \frac{1}{(2-X)}$ (see observation 6) it follows that $\frac{(1+\beta)}{(2+\beta)(2-V)} < \frac{1}{(2-\beta)(2-X)}$. ■

Retailer Collecting Reverse Channel under Capacity Constraint: In the RC reverse channel, each retailer plays a two-stage game where they determine the order quantities in the first stage, the retail price and the collection effort in the second stage. In both stages the retail outlets compete in a Nash framework. The sub-game perfect equilibrium results in order quantities which will be cleared in the second stage. Therefore, given the first stage decisions q_i^{RC} and q_j^{RC}, the retail prices in the second stage are given by: $\overline{p}_i^{RC} = \frac{\alpha(1+\beta)-\beta q_j^{RC}-q_i^{RC}}{1-\beta^2}$ for $i, j \in (1,2)$, $i \neq j$. The optimal collection effort level is determined by solving: $\underset{\overline{\tau}_i^{RC}}{\mathrm{Max}} \left(\frac{\alpha(1+\beta)-\beta q_j^{RC}-q_i^{RC}}{1-\beta^2} - \overline{w}^{*RC} + b\overline{\tau}_i^{RC}\right) * q_i^{RC} - B(\overline{\tau}_i^{RC})^2$. The optimal $\overline{\tau}_i^{*RC}$ is given by $\overline{\tau}_i^{*RC} = \frac{bq_i^{RC}}{2B}$. In the first stage, each retailer maximizes the following function w.r.t. q_i^{RC} while assuming that the other retailer's quantity choice is given. $\underset{q_i^{RC}}{\mathrm{Max}}\ \overline{\Pi}^{RC}_{R,i} = \left(\frac{\alpha(1+\beta)-\beta q_j^{RC}-q_i^{RC}}{1-\beta^2} - \overline{w}^{RC} + b\frac{bq_i^{RC}}{2B}\right)q_i^{RC} - B\left(\frac{bq_i^{RC}}{2B}\right)^2$. The optimal order quantity satisfies the following condition: $\frac{d\overline{\Pi}^{RC}_{R,i}}{dq_i^{RC}} = \left(-\frac{1}{1-\beta^2} + \frac{b^2}{2B}\right)q_i^{RC} + \left(\frac{\alpha(1+\beta)-\beta q_{RC,j}-q_i^{RC}}{1-\beta^2} - \overline{w}^{RC} + b\frac{bq_i^{RC}}{2B}\right) - \frac{bq_i^{RC}}{2B} = 0$ for $i, j \in (1,2)$, $i \neq j$. The Nash equilibrium in quantities is given by $q_i^{RC} = \frac{(1+\beta)(\alpha-(1-\beta)\overline{w}^{RC})}{(2+\beta-H)}$ where $H = \frac{b^2(1-\beta^2)}{2B}$ for $i \in (1,2)$. Going back to stage 2, the optimal collection effort $\overline{\tau}_i^{*RC}$ equals $\frac{b}{2B}\frac{(1+\beta)(\alpha-(1-\beta)\overline{w}^{RC})}{(2+\beta-H)}$. As the Stackelberg leader, the manufacturer solves: $\underset{\overline{w}^{RC}}{Max}\ \Pi_{M}^{RC} = 2\frac{(1+¯)(Á ¡ (1 ¡ ¯)\overline{w}^{RC})}{(2+¯ ¡ H)}(\overline{w}^{RC}\ ¡\ c_m + (¢\ ¡\ b)\frac{b\frac{(1+¯)(Á ¡ (1 ¡ ¯)\overline{w}^{RC})}{(2+¯ ¡ H)}}{2B})$

The optimal value $\overline{w}^{RC}$ satis¯es : $\frac{d\Pi_M^{RC}}{d\overline{w}^{¤RC}} = (1\ ¡\ \frac{(¢ ¡ b)b(1 ¡ ¯^2)}{2B(2+¯ ¡ H)})M\ ¡\ \frac{(1 ¡ ¯)}{(2+¯ ¡ H)}(\overline{w}^{¤RC}\ ¡\ c_m + (¢\ ¡\ b)\frac{b}{2B}M) = 0$; where $M = (\frac{(1+¯)(Á ¡ (1 ¡ ¯)\overline{w}^{¤RC})}{(2+¯ ¡ H)})$: It follows that $\overline{w}^{¤RC} = \frac{Á(1 ¡ K)+(1 ¡ ¯)c_m}{(1 ¡ ¯)(2 ¡ K)}$ where $K = \frac{(¢ ¡ b)b(1 ¡ ¯^2)}{B(2+¯ ¡ H)}$ and $H = \frac{b^2(1 ¡ ¯^2)}{2B}$: Substituting $\overline{w}^{¤RC}$ into the reaction function of the retailers, one can solve for $q_i^{¤RC} = \frac{(1+¯)(Á ¡ (1 ¡ ¯c_m))}{(2+¯ ¡ H)(2 ¡ K)}$; $\Pi_M^{¤RC} = \frac{2(1+¯)(Á ¡ (1 ¡ ¯c_m))^2}{(2 ¡ K)^2(2+¯ ¡ H)(1 ¡ ¯)}$; $\Pi_{R;i}^{¤RC} = \frac{(2 ¡ H)(1+¯)(Á ¡ (1 ¡ ¯c_m))^2}{2¤(2 ¡ K)^2(2+¯ ¡ H)(1 ¡ ¯)}$ and $¿_i^{¤RC} = \frac{b(1+¯)(Á ¡ (1 ¡ ¯)c_m)}{2B(2+¯ ¡ H)(2 ¡ K)}$ where $K = \frac{(¢ ¡ b)b(1 ¡ ¯^2)}{B[2+¯ ¡ H]}$ and $H = \frac{b^2}{2B}(1\ ¡\ ¯^2)$:

Proof of Observation 8:Proof. The pro¯t margin of the manufacturer is given by: $\overline{mm}^{¤RC} = \frac{Á(1 ¡ K)+(1 ¡ ¯)c_m}{(1 ¡ ¯)(2 ¡ K)}\ ¡\ c_m + (¢\ ¡\ b)\frac{b(1+¯)(Á ¡ (1 ¡ ¯)c_m)}{2B(2+¯ ¡ H)(2 ¡ K)}$ which amounts to $\overline{mm}^{¤RC} = \frac{Á ¡ c_m(1 ¡ ¯)}{2(1 ¡ ¯)}$: Note that it is independent of the buy-back price of the post-consumer products and is equal to the pro¯t margin of the manufacturer without product recovery (See observation 6). ■

Proof of Observation 9: Proof. To show that the retail demand is an increasing function of the buy-back price b, the derivative of $q_i^{¤RC}$ w.r.t. b is taken and it results in : $\frac{dq_i^{¤RC}}{db} = \frac{(Á ¡ c_m(1 ¡ ¯))(1+¯)(\frac{b(1 ¡ ¯^2)}{B}+\frac{(¢ ¡ b)(1 ¡ ¯^2)}{B})}{(¡\frac{b(¢ ¡ b)(1 ¡ ¯^2)}{B}+2(2+¯ ¡ \frac{b^2(1 ¡ ¯^2)}{2B}))^2} > 0$ for $0 \cdot b \cdot ¢$: Therefore, it follows that the manufacturer sets $b = ¢$ to maximize his pro¯ts. ■

Proof of Observation 10: Proof. The pro¯t margin of each retailer is given by: $\overline{rm}_i^{¤RC} = \overline{p}_i^{¤RC}\ ¡ \overline{w}^{¤RC}+b¤¿_i^{¤RC} = \frac{(Á ¡ (1 ¡ ¯)c_m)}{(2+¯ ¡ H)(1 ¡ ¯)(2 ¡ K)}$. Since $b = ¢$, it follows that $\overline{rm}_i^{¤RC} = \frac{(Á ¡ (1 ¡ ¯)c_m)}{(1 ¡ ¯)(2(2+¯) ¡ \frac{¢^2(1 ¡ ¯^2)}{B})} = \overline{rm}_i^{¤MC}$: ■

Proof of Proposition 2: Proof. 1. Substituting $b = ¢$, it follows that $\Pi_M^{¤RC} = \frac{³\ (1+¯)(Á ¡ (1 ¡ ¯c_m))^2}{2(2+¯) ¡ \frac{¢^2}{B}(1 ¡ ¯^2)\ (1 ¡ ¯)} = \Pi_M^{¤MC}$: 2. Each retailer's pro¯t function in the MC reverse channel is given by: $\Pi_{R;i}^{¤MC} = \frac{(1+¯)(Á ¡ (1 ¡ ¯)c_m)^2}{(2+¯)(1 ¡ ¯)(2 ¡ V)^2}$ where $V = \frac{¢^2(1 ¡ ¯^2)}{B(2+¯)}$: Substituting for V; $\Pi_{R;i}^{¤MC} = \frac{(1+¯)(Á ¡ (1 ¡ ¯)c_m)^2}{(1 ¡ ¯)(2(2+¯) ¡ \frac{¢^2(1 ¡ ¯^2)}{B})}$: The pro¯t function of each retail outlet in the RC system is given by: $\Pi_{R;i}^{¤RC} = \frac{(1+¯)(2 ¡ H)(Á ¡ (1 ¡ ¯)c_m)^2}{8¤(2+¯ ¡ H)(1 ¡ ¯)}$ where $H = \frac{¢^2(1 ¡ ¯^2)}{2B}$: Substituting for H, we obtain $\Pi_{R;i}^{¤RC} = \frac{(2 ¡ \frac{¢^2(1 ¡ ¯^2)}{2B})(1+¯)(Á ¡ (1 ¡ ¯)c_m)^2}{4¤(1 ¡ ¯)(2(2+¯) ¡ \frac{¢^2(1 ¡ ¯^2)}{B})}$: Note that for $\Pi_{R;i}^{¤RC} > 0$; $2\ ¡\ \frac{¢^2(1 ¡ ¯^2)}{2B} > 0$ should be satis¯ed. This in turn implies that $\frac{2 ¡ \frac{¢^2(1 ¡ ¯^2)}{2B}}{4} < 1$ and hence $\Pi_{R;i}^{¤RC} < \Pi_{R;i}^{¤MC}$: 3. In the MC reverse channel, each retailer orders $q_i^{¤MC} = \frac{(1+¯)(Á ¡ (1 ¡ ¯)c_m)}{(2+¯)(2 ¡ V)}$ where $V = \frac{¢^2(1 ¡ ¯^2)}{B(2+¯)}$ and in the RC reverse channel, the order quantity is given by $q_i^{¤RC} = \frac{(1+¯)(Á ¡ (1 ¡ ¯)c_m)}{(2+¯ ¡ H)2}$ where $H = \frac{¢^2(1 ¡ ¯^2)}{2B}$: Substituting V and H into the respective equations, it can easily be shown that : $q_i^{¤MC} = q_i^{¤RC} = \frac{(1+¯)(Á ¡ (1 ¡ ¯)c_m)}{2(2+¯) ¡ \frac{¢^2(1 ¡ ¯^2)}{B}}$: Hence, $\overline{p}_i^{¤RC} = \overline{p}_i^{¤MC}$: 4. The return rate of the products in the MC reverse channel are given by: $\tau^{*MC} = \frac{\Delta}{B} q_i^{*MC}$ and $\tau_i^{*RC} = \frac{\Delta}{2B} q_i^{*RC}$. Since $q_i^{*MC} = q_i^{*RC}$, it follows that the MC system benefits from scale economies with regards to the investment in the collection effort and therefore $\tau^{*MC} > \tau_i^{*RC}$. ■

C Appendix

Coordination by a Linear Discount Schedule: In the centrally coordinated channel structure, the manufacturer's problem is given by: $\Pi_C^{*NR} = \max_{p_{C,1}^{NR},\, p_{C,2}^{NR}} (p_{C,1}^{NR} - c_m)(\phi_1 - p_{C,1}^{NR} + \beta p_{C,2}^{NR}) + (p_{C,2}^{NR} - c_m)(\phi_2 - p_{C,2}^{NR} + \beta p_{C,1}^{NR})$

Assuming the concavity of Π_{NR}^{I} in $p_{NR,1}^{I}$ and $p_{NR,1}^{I}$, the optimal retail prices satisfy the following FOC: $\frac{d\Pi_C^{*NR}}{dp_{C,i}^{NR}} = (\phi_i - p_{C,i}^{NR} + \beta p_{C,j}^{NR}) - (p_{C,i}^{NR} - c_m) + \beta(p_{C,j}^{NR} - c_m) = 0$ for $i, j \in (1,2)$ $i \neq j$. Simultaneous solution leads to $p_{C,i}^{*NR} = \frac{\phi_i + \beta * \phi_j + (1-\beta^2) * c_m}{2*(1-\beta^2)}$, $D_{C,i}^{*NR} = \frac{\phi_i - (1-\beta)c_m}{2}$. Next, the unique transfer prices that would induce the same channel profits in a decentralized setting are determined. Suppose the manufacturer charges a wholesale price of w_i^{*NR} for retailer i, then the problem of each retail outlet takes the form: $\max_{p_i^{NR}} \Pi_{R,i}^{NR} = (p_i^{NR} - w_i^{*NR})(\phi_i - p_i^{NR} + \beta p_j^{NR}) \quad i, j \in (1,2)$

The retail outlets compete in a Nash framework. The optimal retail prices p_i^{*NR} satisfy the FOC: $\frac{d\Pi_{R,i}^{NR}}{dp_i^{NR}} = \phi_i - p_i^{NR} + \beta * p_j^{NR} - (p_i^{NR} - w_i^{*NR}) = 0$ for $i, j \in (1,2)$ $i \neq j$.

One can easily show that $p_i^{*NR} = \frac{2\phi_i + \beta\phi_2 + 2T_i^* + \beta T_j^*}{(4-\beta^2)}$. In order to induce the retail outlets to charge the coordinated channel price, the manufacturer chooses w_i^{*NR} such that $p_i^{*NR} = p_{C,i}^{*NR}$. Hence, from these two equations in two unknowns, the manufacturer determines $w_i^{*NR} = \frac{\beta^2 D_i^{*NR,C} + \beta D_j^{*NR,C}}{(1-\beta^2)} + c_m$. The change in the channel profits as a result of the coordination can be transferred to the manufacturer by a franchisee fee F_i^* .

Coordination Through Product Take-Back: The total channel profits in a centrally coordinated system are given by: $\Pi_C = \sum_i (p_{C,i} - c_m + \Delta\tau_{C,i}) D_i(p_{C,i}, p_{C,j}) - B(\tau_{C,i})^2$. The concavity of the objective function w.r.t. $p_{C,i}, \tau_{C,i}$ is assumed. The optimal values $p_{C,i}^*, \tau_{C,i}^*$ satisfy the following FOCs: $\frac{d\Pi_C}{dp_{C,i}} = (\phi_i - p_{C,i} + \beta p_{C,j}) - (p_{C,i} - c_m + \Delta\tau_{C,i}) + \beta(p_{C,j} - c_m + \Delta\tau_{C,i}) = 0$, $\frac{d\Pi_C}{d\tau_{C,i}} = \Delta(\phi_i - p_{C,i} + \beta * p_{C,j}) - 2B\tau_{C,i} = 0$ for $i \in (1,2)$ $i \neq j$.

Solving the four equations in four unknowns, it follows that: $p_{C,i}^* = \frac{A*\phi_1 + B*\beta*\phi_2 + C*(1-\beta^2)*c_m}{(1-\beta^2)*M}$ where $A = (1-X)(2-X(1-\beta^2))$, $Z = 2(1-X) + X^2(1-\beta^2)$; $C = 2 - X(1+\beta)$, $M =$

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

Next, the channel coordinating values of W and b are found: Given W and b, each retail outlet competes in a Nash framework and solves the following optimization problems for p_i and τ_i: $\max_{p_i,\tau_i} \Pi_{R,i} = (p_i - W + b*\tau_i)(\phi_i - p_i + \beta*p_j) - B*\tau_i^2.$

The optimal values satisfy the following FOCs: $\frac{d\Pi_{R,i}}{dp_i} = (\phi_i - p_i + \beta*p_j) - (p_i - W + b*\tau_i) = 0;$ $\frac{d\Pi_{R,i}}{d\tau_i} = b(\phi_i - p_i + \beta*p_j) - 2B\tau_i = 0.$ The solution to the FOCs yield $p_i^* = \frac{(1-r)(2-r)\phi_i + (1-r)^2\phi_2 + (2+\beta - r*(1+\beta))}{(2-r)^2 - (1-r^2)\beta^2}$ where $r = \frac{b^2}{2B}.$ The channel coordinating W and b are determined from the solution to equation $p_i^* = p_{C,i}^*$ for $i \in (1,2)$ and they amount to:

$$W^* = \frac{(\phi_1+\phi_2)\beta(Z*M(1-\beta^2) - A^2 + Z^2\beta) + C*c_m*(1-\beta^2)(M(1-\beta^2) - 2*\beta(A - Z*\beta))}{M*(1-\beta^2)(1+\beta)(M*(1-\beta) + Z*\beta - A)}$$

$$r = \frac{(A - Z*\beta)(2+\beta) - M*(1-\beta^2)}{(1+\beta)(A - M(1-\beta) - Z*\beta)} = \frac{b^2}{2*B}$$

$$b^* = \sqrt{\frac{(A - Z*\beta)(2+\beta) - M*(1-\beta^2)}{(1+\beta)(A - M(1-\beta) - Z*\beta)}*2B}$$