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Coordinating Contracts for a Closed Loop Supply Chain under Different Recollection Strategies

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Abstract: Globally, manufacturers are increasingly adopting sustainable processes in recognition of environmental concerns and to grow their businesses. In this article, we devise coordination strategies for a closed loop supply chainnetwork based on different recollection strategies namely retailer driven,manufacturer driven, and third party driven.Existing literatureindicates that enough attention has not been paid to manufacturer and third party driven recollection strategies whereas these mechanisms are prevalent in practice. For each of the recollection strategies, we derive coordinating mechanisms and perform extensive comparative analysis.

Keywords:Closed loop supply chain; Supply chain coordination; Whole Price contract; Linear Two-Part Tariff contract;

1.Introduction

Manufacturers, around the world, are increasingly adopting sustainable processes due to economic incentives, social pressures and legislations. Many manufacturing companies have proactively taken measures in anticipation of stringent environmental performance requirements. As part of incorporating sustainability measures, companies such as Caterpillar, Xerox, Ford, Hewlett Packard, and Kodak have focused on remanufacturing operations.Most of the remanufacturing activities handle refurbishment which signifies distribution of products previously returned to the manufacturer.Remanufacturing provides the manufacturer with economic benefits. Industry experts opine that the profit margins on the sale of capital intensive remanufactured goods such as engine parts can be as high as 40% (Brat, 2006). Caterpillar Inc., realizing the importance of this business,haveestablished dedicated remanufacturing facilities under the brand name Cat Reman.Recollection of used products and putting them back into the market after refurbishment hasled to proliferation of closed-loop supply chains.

Selection of the right partner for recollection and adopting proper business model has remained a challenge for closed-loop supply chain systems. Savaskan et al. (2004) show that the retailer is the most effective recollection agent for the manufacturer.Savaskan et al. (2004) suggested two other recollection strategies: manufacturer driven and third-party vendor driven recollection; however, their work does not shed any light on coordination mechanisms for thesestrategies. Jayaraman (2006) adopts mathematical programming model and RAPP (Remanufacturing Aggregate Production Planning) approach for designing an aggregate production planning and control model of a closed-loop supply chain with product recovery and reuse. Chung et al. (2008) design the inventory system with third-party vendor collecting the used products. Huang et al. (2013) analyze optimal strategies for closed-loop supply chains with dual recollection channel; they model the reverse supply chain such that the retailer and a third-party vendor competitively collect used products. However, their models do not address the coordination issue. In this article, we study a dyadic closed loop supply chain comprising one retailer and one manufacturer. For the sake of simplicity, we ignore the difference between refurbished product and remanufactured product. Here, we focus on the coordination between the closed loop supply chain members.We analyzedifferent recollection strategies namelyretailer driven, manufacturer driven andthird-party driven.

2. Modeling Framework

Figure 1describes the closed loop supply chain structure adopted in our model. It integrates both the forward and the reverse supply chain. The market demand of the product is: $q(p) = \phi - \beta p$, where ϕ represents the total market potential, p is the retail price and β is the own-price

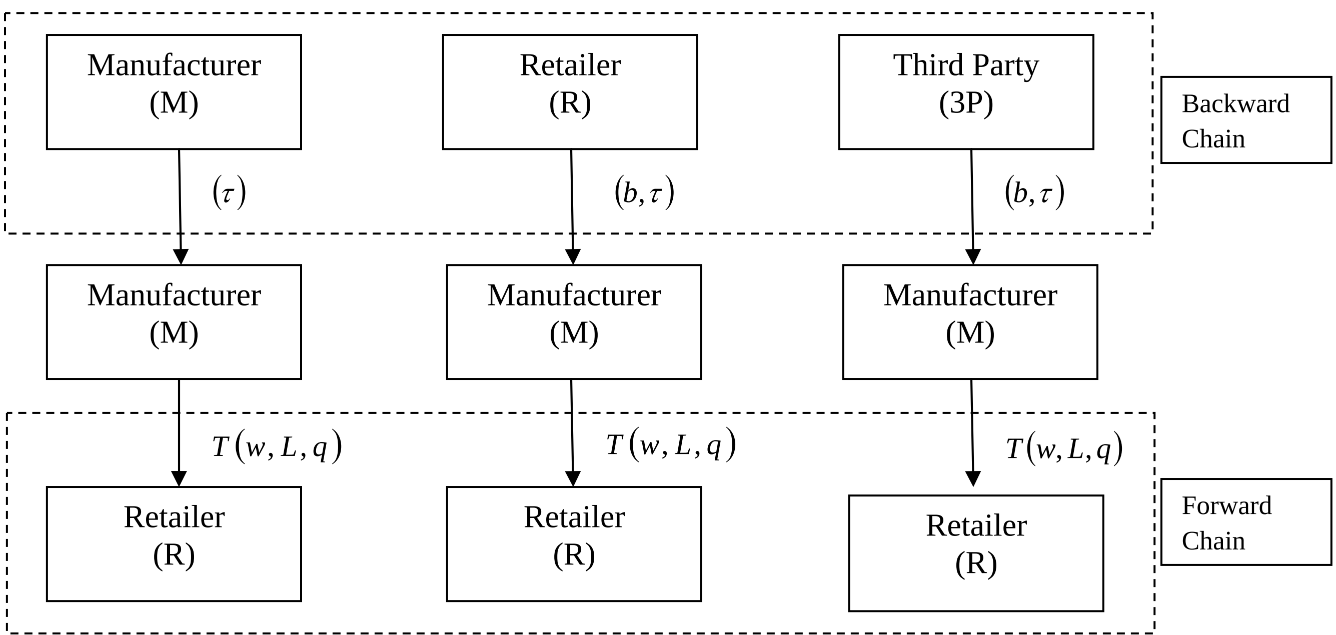

Figure 1. Three Cases of Recollection Strategies

sensitivity of the product. In the forward supply chain, c_m is the unit cost of manufacturing a brand new product from raw materials and in the backward chain, c_r is the unit cost of remanufacturing a product from the returned items. In the reverse supply chain, either the retailer or the manufacturer or a third-party (3P) vendor collects the used products from the consumers. In the case of outsourcing the recollection activity, manufacturer pays either the retailer or the 3P vendoran exogenously decided per unit buyback price $b(< \Delta)$. In either of the cases, $\tau \in [0, 1]$ represents the return rate of the used products, this can also be interpreted as the fraction of the currentgeneration products remanufactured from returned units, and θ is the cost type of the collection agent. Here we assume the same cost type for the different recollection agents. The total cost of recollection is expressed as $\theta\tau^2$. The average unit cost of manufacturing is: $c = (1-\tau)c_m + \tau c_r = c_m - \Delta\tau$.We have made the following assumptions which are consistent with the existing models of closed loop supply chain (Savaskan et al., 2004; Zhang et al., 2014).

(i) $\Delta = c_m - c_r > 0$

(ii) $\phi > \beta c_m$

(iii) There exists perfect substitution between the brand new product and the remanufactured product.

(iv) Retailer's marginal cost is zero.

Assumption 1 shows that the manufacturer obtains economic benefits from the remanufacturing process where as assumption 2 signifies that the market demand of the product cannot be negative for the forward supply chain. Rest of the notations that we adopt for this paper is presented in Table 1.

Table 1: Notations

Notations	**Meaning/ Explanation**
p	Retail Price
q	Order Quantity
w	Per unit Price
m	Per unit margin of the retailer
L	Franchise Fee/ Side-payment Term
π	Profit Level
	Super-script
WP	Wholesale Price Contract

LTT	Linear Two-part Tariff Contract
	Sub-script
R	Retailer
M	Manufacturer
3P	Third Party Vendor
$i-j$, $i \in \{R, M, 3P\}$, $j \in \{R, M, 3P\}$	i: Supply chain agent whose parameter is being determined, j : Supply chain agent who is driving the recollection
C	Centralized Supply Chain
SC	Decentralized Supply Chain

Centralized Supply chain

Analysis of the centralized closed loop supply chain (index: C) provides us with the benchmark solution. In this case, the central planner solves the following problem:

$$\max_{p,\tau}(\pi_C) = (\phi - \beta p)(p - c_m + \tau\Delta) - \theta\tau^2 \quad (1)$$

From the argument of the Hessian matrix, we observe that the central planner's profit function π_C is jointly concave in $p$and τ , when the following condition holds: $\theta > \beta\Delta^2/4$.The optimal retail price, order quantity, return rate along with the feasibility conditions, and optimal profit of the supply chain can be calculated from simultaneous solution of the first order conditions. These are provided in Table 2:

Table 2: Optimal solutions for different parameters of centralized supply chain

Parameter	Decentralized Supply Chain Structure Retailer Driven Recollection
Retail Price	$\frac{(2\theta - \beta\Delta^2)\phi + 2\theta\beta c_m}{\beta(4\theta - \beta\Delta^2)}$
Order Quantity	$\frac{2\theta(\phi - \beta c_m)}{4\theta - \beta\Delta^2}$
Return rate	$\frac{\Delta(\phi - \beta c_m)}{4\theta - \beta\Delta^2}$
Supply Chain Profit	$\frac{\theta(\phi - \beta c_m)^2}{4\beta(4\theta - \beta\Delta^2)}$

Decentralized Supply Chain

Next, we consider three types of decentralized structures for the closed loop supply chain.In the decentralized setting, the manufacturer and the retailer are different entities. The difference in the supply chain structure is based upon the choice of the recollection agent. In the reverse supply chain, the manufacturer can drive the recollection effort through either the retailer (index: R) or a third-party (index: 3P) vendor or she may decide to collect the used products from the consumers herself (index: S). We analyze these three recollection strategiesfrom the perspective of coordination through simple contracts, namely wholesale price (index: WP) and linear two-part tariff contracts (index: LTT). Next, we discuss formulations of the different contractual arguments.

In the decentralized setting most often the manufacturer is the stronger player and would offer contract term(s) to the retailer or the 3P vendor, therefore each contract formulation is done from the perspective of the manufacturer moving first. It is evident that the manufacturer acts as a leader and the retailer or the 3P vendor acts as a follower in a Stakelberg game setting.In each contract type (WP or LTT), the manufacturer tries to maximize her own profit subject to incentive compatibility constraint(s) of the retailer or the vendor or both. Incentive compatibility constraint ensures that the other agents (retailer or vendor) can also maximize their individual profit levels.

Wholesale price contract

In case of the wholesale price contract, the manufacturer offers a wholesale price to the retailer and the contract term for the retailer is derivedbased on it. In this context, we analyze three sub-problems, as mentioned earlier.

Retailer Driven Recollection (R): The manufacturer outsources recollection through the retailer and offers unit buyback price b for the used product. The manufacturer chooses the contract term w; the retailer chooses the retail price, p, and the rate of return, τ. The optimization problem can be formulated as follows:

Problem 1(P1)

$$\max_{w}(\pi_M) = (\phi - \beta p)\{w - c_m + (\Delta - b)\tau\}$$

$$s.t. \quad p^* = \arg\max_{p}(\pi_R)$$

$$\tau^* = \arg\max_{\tau}(\pi_R)$$

$$\pi_R = (\phi - \beta p)(p - w + b\tau) - \theta\tau^2$$

Third-Party Vendor Driven Recollection (3P): The manufacturer outsources recollection through a 3P vendor and the unit buyback price for the used product is b. The manufacturer chooses the contract term, w; the retailer chooses the retail price, p; and the vendor chooses herrate of return for the used products, τ. The manufacturer's profit maximization problem can be expressed as:

Problem 2 (P2)

$$\max_{w,\tau}(\pi_M) = (\phi - \beta p)(w - c_m + \tau\Delta) - \theta\tau^2$$
$$s.t. \quad p^* = \arg\max_p(\pi_R)$$
$$\pi_R = (\phi - \beta p)(p - w)$$

Manufacturer Driven Recollection (M): The manufacturer decides to recollect the used products herself. The manufacturer chooses the contract term, w, and her rate of return, τ; the retailer chooses the retail price, p.The manufacturer's profit maximization problem is given by:

Problem 3 (P3)

$$\max_{w}(\pi_M) = (\phi - \beta p)\{w - c_m + (\Delta - b)\tau\}$$
$$s.t. \quad p^* = \arg\max_p(\pi_R)$$
$$\tau^* = \arg\max_\tau(\pi_{3P})$$
$$\pi_R = (\phi - \beta p)(p - w)$$
$$\pi_{3P} = b\tau(\phi - \beta p) - \theta\tau^2$$

The corresponding optimal solutions of all the sub-problems related to the wholesale price contract are given in Table 3.

Table 3: Optimal solutions of different parameters using wholesale price for Decentralized Supply Chain Structures

Parameter	Decentralized Supply Chain Structure		
	Retailer Driven Recollection	Manufacturer Driven Recollection	Third Party Driven Recollection
Retail Price	$\frac{(3\theta - \beta\Delta^2)\phi + \theta\beta c_m}{\beta(4\theta - \beta\Delta^2)}$	$\frac{(6\theta - \beta\Delta^2)\phi + 2\theta\beta c_m}{\beta(8\theta - \beta\Delta^2)}$	$\frac{(12\theta - \beta\Delta^2)\phi + 4\theta\beta c_m}{\beta(16\theta - \beta\Delta^2)}$
Order Quantity	$\frac{\theta(\phi - \beta c_m)}{4\theta - \beta\Delta^2}$	$\frac{2\theta(\phi - \beta c_m)}{8\theta - \beta\Delta^2}$	$\frac{4\theta(\phi - \beta c_m)}{16\theta - \beta\Delta^2}$
Wholesale Price	$\frac{\phi + \beta c_m}{2\beta}$	$\frac{(4\theta - \beta\Delta^2)\phi + 4\theta\beta c_m}{\beta(8\theta - \beta\Delta^2)}$	$\frac{(8\theta - \beta\Delta^2)\phi + 8\theta\beta c_m}{\beta(16\theta - \beta\Delta^2)}$

Buyback Price	Δ	–	$\frac{\Delta}{2}$
Return Rate	$\frac{\Delta(\phi - \beta c_m)}{2(4\theta - \beta\Delta^2)}$	$\frac{\Delta(\phi - \beta c_m)}{8\theta - \beta\Delta^2}$	$\frac{\Delta(\phi - \beta c_m)}{16\theta - \beta\Delta^2}$
Manufacturer Profit	$\frac{\theta(\phi - \beta c_m)^2}{2\beta(4\theta - \beta\Delta^2)}$	$\frac{\theta(\phi - \beta c_m)^2}{\beta(8\theta - \beta\Delta^2)}$	$\frac{2\theta(\phi - \beta c_m)^2}{\beta(16\theta - \beta\Delta^2)}$
Retailer Profit	$\frac{\theta(\phi - \beta c_m)^2}{4\beta(4\theta - \beta\Delta^2)}$	$\frac{4\theta^2(\phi - \beta c_m)^2}{\beta(8\theta - \beta\Delta^2)^2}$	$\frac{16\theta^2(\phi - \beta c_m)^2}{\beta(16\theta - \beta\Delta^2)^2}$
Third Party Vendor Profit	–	–	$\frac{\theta\Delta^2(\phi - \beta c_m)^2}{(16\theta - \beta\Delta^2)^2}$
Supply Chain Coordination	No	No	No

As the wholesale price (index: WP) contract is widely used across industries, analysis of the same provides us with benchmark solutions for different reverse supply chain mechanisms. However, in the deterministic demand set up the WP contract cannot coordinate the supply chain. Extant literature shows that linear two-part tariff (index: LTT) contract can coordinate a dyadic supply chain (Corbett et al., 2004). We extend this idea in the context of closed loop supply chain to show how theLTT contract can coordinate a supply chain with different recollection modes.

Linear Two-part Tariff contract

In case of the linear two-part tariff contract, the manufacturer offers the contract term (w, L_R) to the retailer, where the price per unit and the lump-sum side payment term are denoted by $w$and L_R, respectively. In this context, we analyze three sub-problems, as mentioned earlier.

Retailer Driven Recollection (R): The manufacturer outsources recollection through the retailer and offers unit buyback price b for the used product. The manufacturer chooses the contract term (w, L_R); the retailer chooses the retail price, p, and herrate of return, τ. The manufacturer's profit maximization problem can be designated as:

Problem 4 (P4)

$$\max_{w, L_R}(\pi_M) = (\phi - \beta p)\{w - c_m + (\Delta - b)\tau\} - L_R$$
$$s.t. \quad p^* = \arg\max_p(\pi_R)$$

$$\tau^* = \arg\max_{\tau}(\pi_R)$$

$$\pi_R = (\phi - \beta p)(p - w + b\tau) - \theta\tau^2 + L_R \geq \bar{\pi}_R$$

Third-Party Vendor Driven Recollection (3P): The manufacturer outsources recollection through a third-party vendor and offers her the contract term: (b, L_{3P}), where the unit buyback price and the lump-sum side payment term for the vendor are b and L_{3P}, respectively. The manufacturer chooses the contract terms: (w, L_R) and (b, L_{3P}); the retailer chooses the retail price, p; and the vendor chooses her effort for recollection, τ. In this sub-problem, we have assumed that the manufacturer offers simple coordinating contract to both retailer and the third-party vendor.The manufacturer's optimization problem can be formulated in the following manner:

Problem 5 (P5)

$$\max_{w,\tau,L_R}(\pi_M) = (\phi - \beta p)(w - c_m + \Delta\tau) - \theta\tau^2 - L_R$$

$$s.t. \quad p^* = \arg\max_{p}(\pi_R)$$

$$\pi_R = (\phi - \beta p)(p - w) + L_R \geq \bar{\pi}_R$$

Manufacturer Driven Recollection (M): The manufacturer decides to recollect the used products herself. The manufacturer chooses the contract term: (w, L_R), and her rate of return, τ; the retailer chooses the retail price, p.The manufacturer's profit maximization problem is:

Problem 6 (P6)

$$\max_{w,L_R,L_{3P}}(\pi_M) = (\phi - \beta p)\{w - c_m + (\Delta - b)\tau\} - L_R - L_{3P}$$

$$s.t. \quad p^* = \arg\max_{p}(\pi_R)$$

$$\tau^* = \arg\max_{\tau}(\pi_{3P})$$

$$\pi_R = (\phi - \beta p)(p - w) + L_R \geq \bar{\pi}_R$$

$$\pi_{3P} = b\tau(\phi - \beta p) - \theta\tau^2 + L_{3P} \geq \bar{\pi}_{3P}$$

For the purpose of expositional simplicity, we assume the buyback price to be exogenously given for all the sub-problems. For the purpose of consistency with contract parameters, we further assume that the manufacturer offers the lump-sum side payment(s) (L_R and L_{3P}) to the retailer and the vendor. $L_x < 0$ ($x = R$ or $3P$) indicates a franchise fee charged by the manufacturer and $L_x > 0$ signifies that the manufacturer is providing x with a subsidy. The reservation profit level(s) of the retailer and the third-party vendor are represented by $\bar{\pi}_R$ and $\bar{\pi}_{3P}$, respectively. Table 4 presents the respectiveoptimal solutions of all the sub-problems related to the linear two-part tariff contract.

Table 4: Optimal solutions of different parameters using two part tariff contract for Decentralized Supply Chain Structures

Parameter	Decentralized Supply Chain Structure: Retailer Driven Recollection	Decentralized Supply Chain Structure: Manufacturer Driven Recollection	Decentralized Supply Chain Structure: Third Party Driven Recollection
Retail Price	$\frac{(2\theta-\beta\Delta^2)\phi+2\theta\beta c_m}{\beta(4\theta-\beta\Delta^2)}$	$\frac{(2\theta-\beta\Delta^2)\phi+2\theta\beta c_m}{\beta(4\theta-\beta\Delta^2)}$	$\frac{(2\theta-\beta\Delta^2)\phi+2\theta\beta c_m}{\beta(4\theta-\beta\Delta^2)}$
Order Quantity	$\frac{2\theta(\phi-\beta c_m)}{4\theta-\beta\Delta^2}$	$\frac{2\theta(\phi-\beta c_m)}{4\theta-\beta\Delta^2}$	$\frac{2\theta(\phi-\beta c_m)}{4\theta-\beta\Delta^2}$
Per unit Price	c_m	$\frac{4\theta c_m-\phi\Delta^2}{4\theta-\beta\Delta^2}$	$\frac{4\theta c_m-\phi\Delta^2}{4\theta-\beta\Delta^2}$
Buyback Price	Δ	–	Δ
Return Rate	$\frac{\Delta(\phi-\beta c_m)}{4\theta-\beta\Delta^2}$	$\frac{\Delta(\phi-\beta c_m)}{4\theta-\beta\Delta^2}$	$\frac{\Delta(\phi-\beta c_m)}{4\theta-\beta\Delta^2}$
Retailer's Side Payment	$-\frac{\theta(\phi-\beta c_m)^2}{\beta(4\theta-\beta\Delta^2)^2}+\bar{\pi}_R$	$-\frac{4\theta^2(\phi-\beta c_m)^2}{\beta(4\theta-\beta\Delta^2)^2}+\bar{\pi}_R$	$-\frac{4\theta^2(\phi-\beta c_m)^2}{\beta(4\theta-\beta\Delta^2)^2}+\bar{\pi}_R$
Third Party Vendor's Side Payment	–	–	$-\frac{\theta\Delta^2(\phi-\beta c_m)^2}{(4\theta-\beta\Delta^2)^2}+\bar{\pi}_{3P}$
Manufacturer Profit	$\frac{\theta(\phi-\beta c_m)^2}{\beta(4\theta-\beta\Delta^2)}-\bar{\pi}_R$	$\frac{\theta(\phi-\beta c_m)^2}{\beta(4\theta-\beta\Delta^2)}-\bar{\pi}_R$	$\frac{\theta(\phi-\beta c_m)^2}{\beta(4\theta-\beta\Delta^2)}-(\bar{\pi}_R+\bar{\pi}_{3P})$
Retailer Profit	$\bar{\pi}_R$	$\bar{\pi}_R$	$\bar{\pi}_R$
Third Party Vendor Profit	–	–	$\bar{\pi}_{3P}$
Supply Chain Coordination	Yes	Yes	Yes

3. Discussion and Managerial Implications

In this section we discuss the implications of the optimal solutions of all the six problems discussed in last section. The optimal results are presented in Table 3 and 4. We compare the retail prices, order quantities, recollection efforts, and per unit prices across all problems.

a. Per Unit Price, Retail Price, and Order Quantity Decisions

PROPOSITION 1: *In case of the WP contract, per unit prices are in the order:* $w_R^{*WP} > w_{3P}^{*WP} > w_M^{*WP}$ *; in case of the LTT contract, per unit prices are in the order:* $w_R^{*LTT} > w_{3P}^{*LTT} = w_M^{*LTT}$.

Algebraic comparison of the optimal wholesale prices gives the above result. In case of retailer driven recollection, the manufacturer can charge maximum wholesale price. In the context of the WP contract, this particular mode of recollection is most desirable from the manufacturer's perspective. Large remanufacturerssuch as Caterpillar Inc. depend on their own dealer network for recollection. We can further observe that: (i) w_R^{*WP} is independent of both the cost type of the retailer (θ) and the economic gain from remanufacturing (Δ); (ii) w_M^{*WP} and w_{3P}^{*WP} are increasing in θ and decreasing in Δ; (iii) w_R^{*WP}, w_M^{*WP}, and w_{3P}^{*WP} all are increasing in c_m and ϕ.

PROPOSITION 2: *In case of the WP contract, the retail prices follow the order:* $p_R^{*WP} < p_M^{*WP} < p_{3P}^{*WP}$ *; in case of the LTT contract, the retail prices follow the order:* $p_R^{*LTT} = p_{3P}^{*LTT} = p_M^{*LTT} = p_C^*$.

Algebraic comparison of the optimal retail prices gives the above result. In the context of the WP contract, retailer driven recollection results in minimum retail price and thus this particular recollection mode is desirable from the retailer's and the end customer's perspective. Outsourcing the recollection through 3P vendor yields the highest retail price and thus drives the entire supply chain furthest from the channel coordinating decisions. As the order quantity follows the relation: $q(p) = \phi - \beta p$, from proposition 2 we observe in the case of the WP contract, the optimal order quantities are in the order: $q_R^{*WP} > q_M^{*WP} > q_{3P}^{*WP}$; and in the case of the

LTT contract, the optimal order quantities are in the order: $q_R^{*LTT} = q_{3P}^{*LTT} = q_M^{*LTT} = q_C^*$.The retail prices are increasing in c_m, ϕ, and θ; and decreasing in Δ.

PROPOSITION 3:*The retailer's margin follows the order:* $m_M^{*WP} > m_{3P}^{*WP} > m_R^{*WP}$ *;* $m_M^{*LTT} = m_{3P}^{*LTT} > m_R^{*LTT} = p_C^* - c_m$.

Algebraic comparison shows that the retailer's margins are: (i) decreasing in c_m, (ii) increasing in ϕ. m_R^{*WP} is increasing in θ and decreasing in Δ. m_M^{*WP} and m_{3P}^{*WP} are decreasing in θ and increasing in Δ. In case of the manufacturer driven or vendor driven recollection, the increase in the economic benefit of remanufacturing (Δ) results in decrease in the average cost of production increasing the corresponding per unit profit margin. In case of the retailer driven recollection, the wholesale price is independent of Δ. Therefore the characteristics of m_R^{*WP} follows from p_R^{*WP}.

In the context of the WP contract, retailer's margin is largest when the manufacturer is recollecting the used products herself. Clearly from a per unit margin perspective retailer would prefer the recollection effort to be taken up by the manufacturer.However, we shall see subsequently in the profitability analysis that the retailer makes maximum profit through her own recollection drive.

b. Profitability Analysis

In this section we compare the profits of the manufacturer, retailer, and the supply chain under different recollection strategies and contract forms.

PROPOSITION 4:*In case of the WP contract, the manufacturer profit levels are in the order:* $\pi_{M-R}^{*WP} > \pi_{M-M}^{*WP} > \pi_{M-3P}^{*WP}$*; in case of the LTT contract, the manufacturer profit levels are in the order:* $\pi_C^* - \bar{\pi}_R = \pi_{M-R}^{*LTT} = \pi_{M-M}^{*LTT} > \pi_{M-3P}^{*LTT} = \pi_C^* - \left(\bar{\pi}_R + \bar{\pi}_{3P}\right)$.

This proposition indicates that the manufacturer makes minimum profit if she outsources the recollection to a third-party vendor under both the WP as well as the LTT contract. She makes maximum profit through retailer recollection channel in the case of the WP contract. In the case of the LTT contract, she is indifferent between the retailer and the manufacturerdriven recollection. This proposition establishes that the manufacturer would always prefer retailer driven recollection under the assumption of similar cost types of the recollection agents.

PROPOSITION 5:*In case of the WP contract, the profits of the retailer follow the order:* $\pi_{R-R}^{*WP} > \pi_{R-M}^{*WP} > \pi_{R-3P}^{*WP}$*; in case of the LTT contract, the profits of the retailer follow the order:* $\pi_{R-R}^{*LTT} = \pi_{R-M}^{*LTT} = \pi_{R-3P}^{*LTT} = \overline{\pi}_R$.

Retailer driven recollection is beneficial not only from a manufacturer's standpoint but also from the retailer's perspective. In case of the WP contract, retailer can earn maximum profit by driving the recollection effort herself and she makes minimum profit if the recollection is outsourced to third party vendor. Thus a retailer would be naturally motivated to take up recollection effort as it allows her to make higher profit. However, in case of the LTT contract the retailer would not be motivated to exert recollection effort, as irrespective of the recollection channel she can only make her reservation profit.

PROPOSITION 6:*The supply chain profits follow the order:* $\frac{3}{4}\pi_C^* = \pi_{SC-R}^{*WP} > \pi_{SC-M}^{*WP} > \pi_{SC-3P}^{*WP}$; $\pi_{SC-R}^{*LTT} = \pi_{SC-M}^{*LTT} = \pi_{SC-3P}^{*LTT} = \pi_C^*$.

From the supply chain profit perspective we observe that, in case of the WP contract the entire supply chain profit is maximum when the retailer drives recollection. As we have seen earlier that in case of the WP contract 3P vendor driven recollection moves the entire system furthest from the channel coordinating parameters and thus the overall system profit is lowest in this case. In case of the LTT contract, irrespective of the recollection agency, the overall supply chain achieves the benchmark profit level.

c. Channel Coordinating Contract Mechanism

PROPOSITION 7:*For* $\theta > \beta\Delta^2/4$*, LTT contract can always coordinate the decentralized closed loop supply chain irrespective of the recollection agent. In case of the retailer driven recollection, the manufacturer offers the contract* $\left(w_R^{*LTT}, L_R^{*LTT}\right) = \left(c_m, -\frac{\theta(\phi - \beta c_m)^2}{\beta\left(4\theta - \beta\Delta^2\right)^2} + \overline{\pi}_R\right)$ *and per unit buyback price* $b = \Delta$ *to the retailer; in case of the manufacturer driven recollection, the* *manufacturer offers the contract* $\left(w_M^{*LTT}, L_R^{*LTT}\right) = \left(\frac{4\theta c_m - \phi\Delta^2}{4\theta - \beta\Delta^2}, -\frac{4\theta^2(\phi - \beta c_m)^2}{\beta(4\theta - \beta\Delta^2)^2} + \bar{\pi}_R\right)$ *to the retailer; in case of the 3P vendor driven recollection, the manufacturer offers the contract forms* $\left(w_{3P}^{*LTT}, L_R^{*LTT}\right) = \left(\frac{4\theta c_m - \phi\Delta^2}{4\theta - \beta\Delta^2}, -\frac{4\theta^2(\phi - \beta c_m)^2}{\beta(4\theta - \beta\Delta^2)^2} + \bar{\pi}_R\right)$ *to the retailer and*

$\left(b, L_{3P}^{*LTT}\right) = \left(\Delta, -\frac{\theta\Delta^2(\phi - \beta c_m)^2}{(4\theta - \beta\Delta^2)^2} + \bar{\pi}_{3P}\right)$ *to the 3P vendor.*

Though LTT contract coordinates a closed loop supply chain, per unit prices do not exactly follow the marginal cost transfer policy in case of the retailer driven recollection. We have seen that the average marginal cost of production for the manufacturer is, $c = c_m - \Delta\tau$; but the manufacturer charges a per unit price $w_R^{*LTT} = c_m$ from the retailer. This result can be physically interpreted in the following way: the manufacturer considers the forward supply chain as equivalent to a new product line and accordingly transfers the products to the retailer at the marginal cost of producing new products. Subsequently through the reverse supply chain whatever economic benefit the manufacturer earns, that adjusts the retailer's side-payment term so that the retailer can retain her reservation profit level. However in manufacturer and vendor driven recollection, the manufacturer transfers products to the retailer at her own average marginal cost of production and makes profit through side-payment terms. It can be verified from the relation: $w_M^{*LTT} = w_{3P}^{*LTT} = \frac{4\theta c_m - \phi\Delta^2}{4\theta - \beta\Delta^2} = c_m - \tau_C^*$.

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