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Research on the Complexity of the Dual-Channel Recycling Closed Loop Supply Chain

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Abstract: **The model of dual-channel recycling is builded, which is based on the closed loop supply chain (CLSC) of manufacturer and retailer. Under the decentralized decision-making, the Sterberg model is investigated. And then the optimal pricing and profit in different power-dominated rules are obtained. Meanwhile, under the same dominant model, the optimal price and profit of manufacturer and retailer based on the model are studied. The results show that under the dual-channel recycling model, when some parameters meet certain conditions, the collection rate of the manufacturer is always greater than that of the retailer under different dominant model.**

Keywords: **CLSC; Dual-channel recycling; Sterberg model; optimal pricing.**

1. INTRODUCTION

The significance of remanufacturing in achieving both economical and environmentally sustainable development goals has been self-evident. In recent years, relative legislations have been introduced in China and European countries to protect the ecological environment and save resources. Given the pressure, numerous firms are prompted to bound up in investing on the construction of reverse channels [1], and more companies take part in the closed-loop supply chain (CLSC) [2-4].

CLSC has been widely studied in the past years, and there are large numbers of available literatures on it. Savaskan et al.[5] investigated the problem of choosing the appropriate reverse channel structure for collecting used products from customers. The study proposed the incentive to the customers to improve the collection of used product. T.Maiti et al. [6-10] considered a closed loop supply chain under retail price and product quality dependent demand, and compared with the optimal results, finding out the best decentralized scenario out of the four mentioned. Studies about CLSC under single channel for recycling are reported in the references mentioned above.

However, to the best of our knowledge, little studies about CLSC under dual channel for recycling are found so far. ChengTang Zhang et al. [11] addressed pricing and coordination strategy of closed-loop supply chain under dual channel recovery. The study shown that Stackelberg game pricing caused a loss of system efficiency, by contrast, joint decision making pricing could acquired more used products, lowest product price and maximum profits. XianPei Hong et al. [12] considered about the closed-loop supply chain pricing, recycling and profits based on the direct and indirect recycling channels. The rest of the paper is organized as follows. Section 2 presents the problem description and notations. The dual-channel recycling CLSC model is developed in section 3. Comparative analysis is presented in section 5. Finally, conclusions and future scope of study are presented in section 6.

2. THE MODEL

2.1 Description of the problem:

Consider a closed-loop supply chain composed of a manufacturer and a retailer with dual recycling channel (see Fig. 1). In the system, manufacturers and retailers recycle a product simultaneously. In the forward supply chain, it is assumed that the manufacturer possesses manufacturing or remanufacturing production lines which can manufacture new products directly from original materials or collected products. The manufacturer sells the products to the retailers with unit wholesale price w, then the retailer sells them to consumers with unit retail price P ,which is a decision variable for the retailer. In the reverse supply chain, and the manufacturer takes charge of deciding the recycling rate that denoted as τ_1 of the remanufactured products directly, at the same time, the retailer is in charge of deciding the collection rate (denoted as τ_2). Under the decentralized decision-making, the manufacturer-managed model and retailer-managed model are considered in this paper.

2.2 Assumptions of the model:

The following assumptions are made to develop the model:

Assumption 1. The remanufactured products can be sold at the same price as the manufactured ones from the raw materials in the market.

Assumption 2. Demand function becomes the classic linear demand function that used to characterize consumer demand and widely used in closed-loop supply chain.

Assumption 3.The production cost of a new product from returns is lower than a new one from raw materials. i.e., $C_r < C_m$ .Let $\Delta = C_m - C_r$, which denotes unit cost saving.

Assumption 4. $\tau_i (i=1,2)$ is the used-product collection rate of manufacturer or retailer, which indicates the reverse channel property. The investment of returning used products satisfies: $\tau_i = \sqrt{I/B}$, where I denotes the investment of collection and B denotes the scale parameter[13].

2.3 Notations:

The following notations in Table 1 will be used throughout this paper:

Table 1 .Notations of the CLSC system

P	Unit retail price
w	Unit wholesale price
C_m	Unit cost of manufacturing a new product from original materials
C_r	Unit cost of manufacturing a new product from returns
Δ	Unit cost saving, $\Delta = C_m - C_r$
τ_1	Collection rate of manufacturer
τ_2	Collection rate of retailer
b	Unit transfer price paid to retailer by the manufacturer
A_1	Unit cost of manufacturers handle a returned product
A_2	Unit cost of retailers handle a returned product
ϕ	Market size
β	Sensitivity of consumers to the retail price
D	Demand function
B Π	Scale parameter The profit of the manufacturer or the retailer
I	Investment of collection

It is considered that the demand for products in the market as a linear function of product price, i.e., $D = \phi - \beta P$, where ϕ denotes the market size ,and β denotes the sensitivity of consumers to the retail price.

Table 2. The optimal solutions among CLSC with the dual-channel recycling

Channel performance	M-manage	R-manage	NASH
The wholesale price	$\frac{\beta[b^2(C_m\beta-\phi)-2\Delta\phi(A_2-b)+\phi(A_1-\Delta)^2-2A_2b\beta C_m]+(A_2^2-4B)(C_m\beta+\phi)}{\beta(-8B+\beta[2(A_2-\Delta)(A_2-b)+(A_1-\Delta)^2])}$	$\frac{[-2B(3C_m\beta+\phi)+(C_m\beta+\phi)(A_1-\Delta)^2-(A_2-\Delta)[C_m\beta(b-A_2)-b\phi)]+\phi\Delta^2]}{\beta(-8B+\beta[(A_2-\Delta)^2+2(A_1-\Delta)^2])}$	$\frac{-2B(2C_m\beta+\phi)+\beta(A_2-b)[C_m\beta(A_2-b)^2+[(b-\Delta)(A_2-b)+(A_1-\Delta)^2]\phi]}{\beta(-6B+\beta[(A_2-\Delta)(A_2-b)+(A_1-\Delta)^2])}$
The retail price	$\frac{\beta\phi[2(A_2-\Delta)(A_2-b)+(A_1-\Delta)^2]-2B(C_m\beta+3\phi)}{\beta(-8B+\beta[2(A_2-\Delta)(A_2-b)+(A_1-\Delta)^2])}$	$\frac{\beta\phi[(A_2-\Delta)^2+2(A_1-\Delta)^2]-2B(C_m\beta+3\phi)}{\beta(-8B+\beta[(A_2-\Delta)^2+2(A_1-\Delta)^2])}$	$\frac{\beta\phi[(A_2-\Delta)(A_2-b)+(A_1-\Delta)^2]-2B(C_m\beta+2\phi)}{\beta(-6B+\beta[(A_2-\Delta)(A_2-b)+(A_1-\Delta)^2])}$
The collectio n rate of	$\frac{-(C_m\beta-\phi)(A_1-\Delta)}{-8B+\beta[2(A_2-\Delta)(A_2-b)+(A_1-\Delta)^2]}$	$\frac{-(C_m\beta-\phi)(A_1-\Delta)}{-8B+\beta[(A_2-\Delta)^2+2(A_1-\Delta)^2]}$	$\frac{-(C_m\beta-\phi)(A_1-\Delta)}{(6B-\beta[(A_2-\Delta)(A_2-b)+(A_1-\Delta)^2])}$
The collection rate of the	$\frac{-(C_m\beta-\phi)(A_2-b)}{-8B+\beta[2(A_2-\Delta)(A_2-b)+(A_1-\Delta)^2]}$	$\frac{-(C_m\beta-\phi)(A_2-\Delta)}{-8B+\beta[(A_2-\Delta)^2+2(A_1-\Delta)^2]}$	$\frac{-(C_m\beta-\phi)(A_2-b)}{(6B-\beta[(A_2-\Delta)(A_2-b)+(A_1-\Delta)^2])}$
The profit of the	$\frac{B[4B-\beta(A_2-b)^2](C_m\beta-\phi)^2}{\beta(-8B+\beta[2(A_2-\Delta)(A_2-b)+(A_1-\Delta)^2])^2}$	$\frac{-B(C_m\beta-\phi)^2}{\beta(-8B+\beta[(A_2-\Delta)^2+2(A_1-\Delta)^2])}$	$\frac{B[4B-\beta(A_2-b)^2](C_m\beta-\phi)^2}{\beta(-6B+\beta[(A_2-\Delta)(A_2-b)+(A_1-\Delta)^2])^2}$
The profit of the	$\frac{-B(C_m\beta-\phi)^2}{\beta(-8B+\beta[2(A_2-\Delta)(A_2-b)+(A_1-\Delta)^2])}$	$\frac{B[4B-\beta(A_2-\Delta)^2](C_m\beta-\phi)^2}{\beta(-8B+\beta[(A_2-\Delta)^2+2(A_1-\Delta)^2])^2}$	$\frac{B[4B-\beta(A_1-\Delta)^2](C_m\beta-\phi)^2}{\beta(-6B+\beta[(A_2-\Delta)(A_2-b)+(A_1-\Delta)^2])^2}$

3. THE DUAL-CHANNEL RECYCLING CLSC MODEL

The decentralized supply chain contained a manufacturer and a retailer with dual recycling channel is studied in this section, (see Fig. 1).

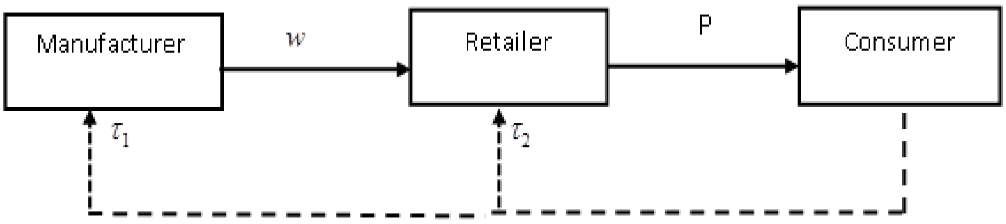

Fig.1 Closed Loop Supply Chain with Dual Recycling Channel Systems.

Under the dual recycling channel, the profit function Π_M^2 of manufacturer can be described as follows:

$$\Pi_M^2 = D[w-c_m+(\Delta-b)\tau_2+(\Delta-A_1)\tau_1]-B\tau_1^2 \qquad (1)$$

The profit function Π_R^2 for retailer can be expressed as follows:

$$\Pi_R^2 = D[P-w+(b-A_2)\tau_2]-B\tau_2^2 \qquad (2)$$

3.1 MD-managed model:

It is supposed that the manufacturer is the leader, and the retailer is the follower. In the game, the manufacturer makes decisions of the wholesale price w and the collection rate τ_1 according to the market information firstly, then the retailer makes decisions of the retail price P and the collection rate τ_2.

3.1.1 The retailer's reaction:

We have

$$\begin{cases} \frac{\partial \Pi_R^1}{\partial P} = -\beta[2P - w + (b - A_2)\tau_2] + \phi = 0 \\ \frac{\partial \Pi_R^1}{\partial \tau_2} = (\phi - \beta P)(b - A_2) - 2B\tau_2 = 0 \end{cases} \quad (3)$$

When $4B > (A_2 - b)^2 \beta$, the Hessian matrix is negative definite, the retailer's profit function is concave and has a unique maximum solution. The retail's best reply functions are as follows by solving Eq.(3).

$$\begin{cases} P(w,\tau_1) = \frac{(A_2 - b)(-w\beta + \phi)}{-4B + (A_2 - b)^2 \beta} \\ \tau_2(w,\tau_1) = \frac{\beta\phi(A_2 - b)^2 - 2B(w\beta + \phi)}{-4B\beta + (A_2 - b)^2 \beta^2} \end{cases} \quad (4)$$

3.1.2 The manufacturer's reaction:

Similarly, we can get the manufacturer's marginal profit and best reply functions as follows:

$$\begin{cases} \frac{\partial \Pi_M^1}{\partial w} = -\frac{2B[k_1[-4B + A_2\beta(A_2 - b)] + \beta(A_2 - b)[2\Delta(w\beta - \phi) - b(k_1 + 2w\beta - 2\phi)]]}{(-4B + (A_2 - b)^2 \beta)^2} \\ \frac{\partial \Pi_M^1}{\partial \tau_1} = -\frac{2B\beta(A_1 - \Delta)[-4B + \beta(A_2 - b)(A_1 - b)]}{(-4B + (A_2 - b)^2 \beta)^2} \end{cases} \quad (5)$$

Where $k_1 = C_m\beta - 2w\beta + \beta\tau_1(A_1 - \Delta) + \phi,$

When $4B > \beta(A_2 - b)(A_2 - \Delta)$, the Hessian matrix is negative definite, the manufacturer's profit function is concave and has a unique maximum solution. From (4) to (5), we yield the optimal solutions.

Results are presented in Table 2 in "Appendix".

3.2 RD-managed model:

In this section, the retailer is the leader and the manufacturer is the follower. In the retailer-managed dual- channel recycling model, the retailer makes decisions of the retail price P and the collection rate τ_2, then the manufacturer makes decisions of the wholesale price w and the collection rate τ_1. Similar to the assumption of section 3.2, the retailer's unit profit margin function can be expressed as $P = w + t$.

3.2.1 The manufacturer's reaction:

We have

$$\begin{cases} \frac{\partial \Pi_M^1}{\partial w} = -\beta[-P - C_m + w + (\Delta - A_1)\tau_1 + (\Delta - b)\tau_2] + \phi = 0 \\ \frac{\partial \Pi_M^1}{\partial \tau_1} = (\phi - \beta P)(\Delta - A_1) - 2B\tau_2 = 0 \end{cases} \quad (6)$$

When $4B > (A_1 - \Delta)^2 \beta,$ the Hessian matrix is negative definite, the manufacturer's profit function is concave and has a unique maximum solution. The manufacturer's best reply functions are as follows by solving Eq. (6).

$$\begin{cases} w(P,\tau_2)=\dfrac{(P\beta-\phi)[2B+\beta(A_1-\Delta)^2]-2B[\phi+(b-\Delta)\beta\tau_2]}{2B\beta} \\ \tau_1(P,\tau_2)=\dfrac{(A_1-\Delta)(P\beta-\phi)}{2B} \end{cases} \quad (7)$$

3.2.2 The retailer's reaction

Similarly, the retailer's marginal profit and best reply functions can be calculated as follows:

$$\begin{cases} \dfrac{\partial \Pi_R^1}{\partial P}=\dfrac{\beta(A_1-\Delta)^2(P\beta-\phi)+B[\beta(C_m-4P)+\beta\tau_2(A_2-\Delta)+3\phi]}{B} \\ \dfrac{\partial \Pi_R^1}{\partial \tau_2}=-2B\tau_2+(A_2-\Delta)(P\beta-\phi) \end{cases} \quad (8)$$

When $8B>\beta[2(A_1-\Delta)^2+(A_2-\Delta)^2]$, the Hessian matrix is negative definite, the retailer's profit function is concave and has a unique maximum solution. The optimal decision of the system can be obtained by solving Eqs. (7) and (8).

Results are presented in Table 2in "Appendix".

4. COMPARISON OF THE SUPPLY CHAIN WITH DUAL RECYCLING CHANNEL

In this section, comparing with the relationship of the collection rate in the same channel, then analyzing the optimal wholesale price, the retail price, the collection rate and the profit of the manufacturer and the retailer based on the M-managed model , last we analysis the profit of the manufacturer and the retailer under the different models.

Proposition1. Under dual recycling channel, when $\Delta-b>A_1-A_2$, the optimal collection rate of the manufacturer is all higher than that of the retailer based on three decentralized supply chain. i.e., $\tau_D^{MM}>\tau_D^{MR},\tau_D^{RM}>\tau_D^{RR}$, and in the M-managed model, the profit of the manufacturer is lower than that of the retailer. i.e., $\Pi_D^{MR}>\Pi_D^{MM}$

Proposition2. The retailer's and manufacturer's profits with dual recycling channel across the three different reverse channels are related as follows:

$\Pi_D^{MR}<\Pi_D^{RR},\Pi_D^{RM}<\Pi_D^{MM}$.

5. CONCLUSIONS

The models of dual-channel recycling is builded, which is based on the closed loop supply chain (CLSC) of manufacturer and retailer. the Sterberg model is investigated in the model of dual-channel recycling. And then the optimal pricing and profit in different power-dominated rules are obtained. Meanwhile, under the same dominant model, the optimal price and profit of manufacturer and retailer under the single-channel recycling and the dual-channel recycling are studied. The main results are shown as follows: 1. under the dual channel recycling model, when some parameters meet certain conditions, the collection rate of the manufacturer is always greater than that of the retailer under different dominant model; 2. under the dual channel recycling model, the manufacturer and the retail can obtain the optimal profits under their own dominant model; under the retail-managed (manufacturer- managed) model, the manufacturer (the retailer) can obtain the minimum profit.

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