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Complexity Analysis of Pricing Policies in the Dual-Channel and Single-Channel Recycling

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Abstract: **The models of single-channel recycling and dual-channel recycling are builded respectively, which are based on the closed loop supply chain (CLSC) of manufacturer and retailer. Under the decentralized decision-making, the Sterberg model is investigated in the models of single-channel recycling and dual-channel recycling, respectively. 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 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; 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. It's found that whether it is the manufacturer-managed or retailer-managed, the profits of retailers under the dual-channel recycle are higher than that under the single-channel recycle. Dual-channel recycling model is more advantageous to benign development and stable operation of closed-loop supply chain.**

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

1. INTRODUCTION

Closed loop supply chain (CLSC) can be defined as an integration of the reward supply chain and the reverse supply chain[1,2]. The forward supply chain is regarded as the process of manufacturing new products from original materials, the reverse supply chain is the process where some components of the used products are disassembled, cleaned, reprocessed, inspected, and reassembled to be used again.

CLSC has been widely studied in the past years, and there are large numbers of available literatures on it. Xianpei Hong et al. [3] addressed joint advertising, pricing and collection decisions in a closed-loop supply chain. The study shown that it is optimal for manufacturer to authorize the retailer for collecting the used products, and the examined cooperative advertising can not coordinate the ClSC. Mitra et al. [4] developed the price competition between remanufactured and new product in the market based on the effect of government subsidies. Yu Xiong et al. [5] analyzed the performance of manufacturer remanufacturing and supplier- remanufacturing in a closed loop supply chain, the study examined their desirability from different stakeholder perspectives. Sarat Kumar Jena et al. [6] considered price competition and co-operation issues a duopoly closed loop supply chain. A numerical studies have been carried out global-co-operative system is the best among all the three cases considered.

It is different from the results reported in the literatures mentioned above[7,8,9], in this paper the analysis and comparison of the optimal decision problem under the single-channel recycling and the dual-channel recycling are investigated. It's found that whether it is the manufacturer-managed, retailer-managed or Nash model, the retail price of the dual-channel recovery CLSC is always lower than that of the single-channel recycling CLSC, and the profits of retailers under the dual-channel recycle are higher than that under the single-channel recycle.

2. THE SINGLE-CHANNEL RECYCLING CLSC MODEL

In this subsection, we consider three decentralized closed-loop supply chain on the basis of retailer recycle the used products, i.e., the manufacturer-managed, retailer-managed and Nash model.

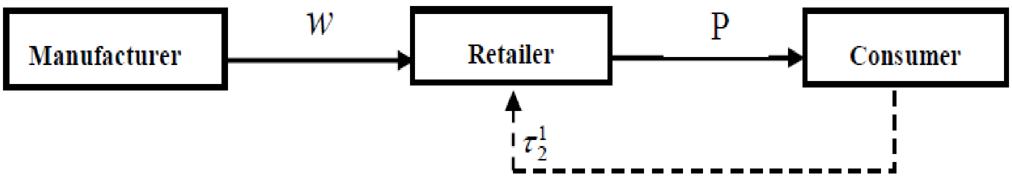

Fig.1 Closed Loop Supply Chain with Retailer Recycling Channel Systems

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. Based on the assumptions we introduced, under the single-channel recycling systems, the profit function Π^1_M of Manufacturer and the profit function Π^1_R for Retailer can be written as follows respectively:

$$\Pi^1_M = D[w - c_m + (\Delta - b)\tau^1_2] \quad (1)$$

$$\Pi^1_R = D[P - w + (b - A_2)\tau^1_2] - B\tau^1_2 \quad (2)$$

2.1 MS-managed model:

In the M model, suppose that in the CLSC the manufacturer is the leader and the retailer is the follower and this relationship implies that the manufacturer command the market over the retailer, then form a Stackelberg game, and the game equilibrium is called Stackelberg Equilibrium[].In this game, the manufacturer makes decisions of the wholesale price w according to the market information firstly, then the retailer makes decisions of the retail price P and the collection rate τ_2 according to the decision-making of the manufacturer.

2.1.1 The retailer's decision:

The retailer's pricing decisions are decided by solving the following optimization problem:

$$(P, \tau_2) = \arg\max \Pi^1_R ; \quad (3)$$

then the optimal marginal utility of the retailer can be obtained as follows:

$$\begin{cases} \dfrac{\partial \Pi^1_R}{\partial P} = -2\beta P + \beta[w + (A_2 - b)\tau_2] + \phi \\ \dfrac{\partial \Pi^1_R}{\partial \tau^1_2} = -2B\tau_2 + (A_2 - b)(\beta P - \phi) \end{cases} \quad (4)$$

When parameter B is defined in the collection cost function satisfies: $4B > (A_2 - b)^2 \beta$ .The retailer's profit function is concave and has a unique maximum solution because the Hessian matrix associated with the profit function Π^1_R

$$H^M_1 = \begin{pmatrix} -2\beta & (A_2 - b)\beta \\ (A_2 - b)\beta & -2B \end{pmatrix}$$

is negative definite.

Solving formula (), the retailer's best reaction function is as follows, and this is the retailer's optimal pricing decisions according to the manufacturers' pricing decision.

$$\begin{cases} P = -\dfrac{(A_2 - b)^2 \beta\phi - 2B(\beta w + \phi)}{(4B - (A_2 - b)^2 \beta)\beta} \\ \tau_2^1 = -\dfrac{(A_2 - b)(-\beta w + \phi)}{4B - (A_2 - b)^2 \beta} \end{cases} \tag{5}$$

2.1.2 The manufacturer's decision:

Use (5) in (1), the manufacture's marginal utility function and the best reply function can be obtained by the first-order conditions .

$$\frac{\partial \Pi_M^1}{\partial w} = -\frac{2B[-4B(C_m\beta - 2\beta w + \phi) + \beta(A_2 - b)[C_m\beta(A_2 - b) + 2\beta w(\Delta - A_2) + \phi(A_2 + b - 2\Delta)]]}{(4B - (A_2 - b)^2 \beta)^2} \tag{6}$$

Taking the second-order derivatives of $\partial \Pi_M^1$ with respect to w, we have

$$\frac{\partial^2 \Pi_M^1}{\partial w^2} = \frac{4B\beta[4B - \beta(A_2 - b)(A_2 - \Delta)]}{(4B - (A_2 - b)^2 \beta)^2} \tag{7}$$

When $4B > \beta(A_2 - b)(A_2 - \Delta)$, the manufacturer's profit function is concave and has a unique maximum solution because the second-order derivatives of $\partial \Pi_M^1$ with respect to w is negative definite. The concavity for models and can be derided in a similar manner. The optimal decisions (w^*, P^*, τ_2^*) of the system can be obtained by solving Eqs. (4) and (6).

2.2 Retailer-managed model:

In this Stackelberg model, the retailer is the leader, and the manufacturer is the follower. In the game, 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. Since $P > w$, therefore, w can't be equal to the retail price P. We assume that the manufacturer's unit profit margin satisfies the relational expression:

$P = w + t$.

2.2.1 The manufacturer's reaction:

We have

$$\frac{\partial \Pi_M^1}{\partial w} = -\beta[P + w - C_m + (\Delta - b)\tau_2] + \phi \tag{8}$$

$$\frac{\partial^2 \Pi_M^1}{\partial w^2} = -2\beta < 0 \tag{9}$$

The unique wholesale price w follows from the first order conditions:

$$w(P, \tau_2) = \frac{\beta[(C_m - P) + \tau_2(b - \Delta)] + \phi}{\beta} \tag{10}$$

2.2.2 The Retailer's reaction:

Substituting expression (11) into (2), and take the first-order derivatives of $\partial \Pi_R^1$ with respect to P and τ_2, we have

$$\begin{cases} \dfrac{\partial \Pi_R^1}{\partial P} = C_m\beta - 4\beta P + \beta(A_2 - \Delta)\tau_2 + 3\phi = 0 \\ \dfrac{\partial \Pi_R^1}{\partial \tau_2^1} = -2B\tau_2 + \dfrac{\beta(A_2 - \Delta)(\beta P - \phi)}{\beta} = 0 \end{cases} \tag{11}$$

Taking the second-order derivatives, we can get the Hessian matrix

$$H = \begin{vmatrix} -4\beta & \beta(A_2-\Delta) \\ \beta(A_2-\Delta) & 2B \end{vmatrix}$$

When $8B > \beta(A_2-\Delta)^2$， the retailer's profit function is concave and has a unique maximum solution .

Results are presented in Table 1 in "Appendix".

3. COMPARISON OF THE SUPPLY CHAIN BETWEEN DUAL RECYCLING CHANNEL AND SINGLE RECYCLING CHANNEL

Proposition 1. Under the manufacturer-managed model, the unit wholesale price and the retail price with dual recycling channel, are lower than the scenario with single recycling channel. By contrast, the optimal collection rate, as well as and the profits of the retailer and manufacturer with dual recycling channel are higher than that with single recycling channel. i.e. $P_D^R < P_S^R, w_D^M < w_S^M, \tau_D^{MR} > \tau_S^{MR}, \Pi_D^{MR} > \Pi_S^{MR}, \Pi_D^{MM} > \Pi_S^{MM}$.

Proposition 2. Under the retailer-managed model, the retail price with dual-channel recycling , is lower than the scenario with single recycling channel. By contrast, the optimal collection rate and the profits of the retailer with dual recycling channel are higher than that with single recycling channel. i.e., $P_D^R < P_S^R, \tau_D^{RR} > \tau_S^{RR}, \Pi_D^{RR} > \Pi_S^{RR}$.

4. CONCLUSIONS

The models of single-channel recycling and dual-channel recycling are builded respectively, which are based on the closed loop supply chain (CLSC) of manufacturer and retailer. the Sterberg model and NASH model are investigated in the models of single-channel recycling and dual-channel recycling, respectively. 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. Dual-channel recycling model is more advantageous to benign development and stable operation of closed-loop supply chain.

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APPENDIX - A

Table 1. The optimal solutions among CLSC with the single-channel recycling

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