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ADVERTISING AND PRICING STRATEGIES FOR REMANUFACTURING CLOSED-LOOP SUPPLY CHAIN OF ELECTRONIC ENTERPRISES

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Abstract. *The closed-loop supply chain game models with remanufacturing are studied under four market structures: Nash equilibrium game existing between a manufacturer and a retailer, the Stackelberg game led by the manufacturer, the Stackelberg game led by the retailer, and the joint decision. Advertising expense and pricing decision are analyzed under the four market structures. The results show that the retail price, wholesale price, manufacturer's profit and retailer's profit are the highest in market structure of their respective leadership. The advertising expense is the highest in the joint decision, and lowest in the Stackelberg game led by the retailer. The total profit of supply chain is the highest in the joint decision, and lowest when the leader is retailer. The whole industry as well as consumers benefit from the joint decision market structure. However, an individual member has an incentive to play the leader's role.*
Keywords: Electronic enterprise, Closed-loop supply chain, Advertising and pricing strategy, Game theory

1. **Introduction.** With the rapid development of electrical industry, the functions of electrical and electronic equipment are more diverse. Though these equipment enrich our life, they also lead to a large of waste electrical and electronic equipment (WEEE) [1]. Containing harmful substances, more than 90% of the WEEE are not appropriately buried, burned or recycled when abandoned, which becomes one of the biggest sources of pollution. To solve this problem, the EU released the WEEE directive officially in 2002 [2]. The directive requires that WEEE should be recycled in a systematic and environmental way to promote the recycling of resources, future to prevent the improper disposal of WEEE impacting on the environment and human. China promulgated the "waste electrical and electronic products recycling management regulation" in February 25, 2009, namely Chinese version of WEEE, which regulates the recycling processing of WEEE [3]. With the introduction of relevant laws and regulations, HP, Haier and other industries' leading enterprises carried out the closed-loop supply chain (CLSC) management to recycle the WEEE. At the same time, the academic scholars all over the world have paid more attention to the CLSC management [4-6].

Advertising as well as pricing strategies are very important in marketing programs of enterprises in a supply chain [7]. The total advertising expenditures of enterprises range from $900 million in 1970 to more than $50 billion in 2012, indicating the growing significance of the advertising [8,9]. Related studies have been paid more attention in recent years. Zhou et al. consider the level of advertising effort devoted by the retailer as a factor to analyze the enterprise advertising contract impacting on the supply chain's optimal decision [10]. Hong et al. take the advertising investment of the retailer as an important influencing factor of linear demand function. Then they construct Stackelberg game models to investigate the optimal decisions of advertising and pricing [11]. Giri and Sharma consider a supply chain comprising one manufacturer and two retailers with advertising cost dependent demand. Both retailers have their advertising expenses. These two parts of advertising expenses affect the demand in the meantime. And the demand function is linear [12]. These studies all consider advertising expense as an important variable in the demand and profit functions when enterprise makes a decision. However, most of them see advertising expense and demand function is a linear relationship. However, this paper considers the advertising expense affecting the total demand directly to study the optimal advertising spending and pricing of recycled products. The market structures contain three decentralized market structures and one joint market structure. The CLSC system consists of a manufacturer and a retailer. From a different perspective, enrich the research of CLSC.

2. **Basic Assumptions and Description of Models.** Market demand function is $D(P) = \alpha - \beta P$, P is the retail price of a remanufactured product, α is the biggest market demand, and β is price sensitive coefficient. The wholesale price of the manufacturer to the retailer is W, so the profit of retailer is $m = P - W$. The unit cost of new product made by manufacturer is C_m, and the unit cost of remanufacturing using recycled materials is C_r. Let $C_r < C_m$ incent the manufacturer to remanufacture. Let $\Delta = C_m - C_r$ be the saved unit cost due to remanufacture. Recycling subsidy is b, namely, the recycling price of manufacturer to retailer. The price paid from a retailer to a consumer is A. $b \geq A$ ensures the profit of retailer, and $b \leq C_m - C_r$ ensures the profit of manufacturer. And $\Delta = C_m - C_r$, so $b \in [A, \Delta]$. Advertising expense of recycling products is undertaken by retailer. From [13], the impact of advertising on the recycling of waste products is $r\sqrt{a}$, where r is a positive constant, $\left[r^2\beta(\Delta - A)^2\right]/2 < 1$, the amount of recycling is $r\sqrt{a} \cdot D(P) = r\sqrt{a}(\alpha - \beta P)$.

Based on the above assumptions, the profit functions of retailer and manufacturer are

$$\pi_R = \left[P - W + r\sqrt{a}(b - A)\right](\alpha - \beta P) - a \tag{1}$$

$$\pi_M = \left[W - C_m + r\sqrt{a}(\Delta - b)\right](\alpha - \beta P) \tag{2}$$

3. **Closed-Loop Supply Chain Models.**

3.1. **Nash equilibrium game.** In the process of Nash equilibrium, the manufacturer and retailer are all not leaders. They make decisions respectively: the manufacturer determines the wholesale price of product W, the retailer determines the retail price P and advertising expense a. This model represents the market consisting of medium-sized manufacturers and retailers.

From the first order condition of π_R in Equation (1), we get

$$\partial\pi_R/\partial p = \alpha - 2\beta P + \beta W - r\beta\sqrt{a}(b - A) = 0 \tag{3}$$

$$\partial\pi_R/\partial a = r(b - A)(\alpha - \beta P) - 2\sqrt{a} = 0 \tag{4}$$

From the first order condition of π_M in Equation (2), we get

$$\partial\pi_M/\partial W = \alpha - \beta P - \beta W + \beta C_m - \beta r\sqrt{a}(\Delta - b) = 0 \tag{5}$$

Solving simultaneously Equations (3), (4) and (5), we get the optimal wholesale price, retail price and advertising expense as follows.

$$W^{N^*} = \frac{\alpha\big(2 - r^2\beta(b - A)(\Delta - b)\big) + \beta\big(4 - r^2\beta(b - A)^2\big)C_m}{\beta(6 - r^2\beta(b - A)(\Delta - A))} \tag{6}$$

$$P^{N^*} = \frac{\big(4 - r^2\beta(b - A)(\Delta - A)\big)\alpha + 2\beta C_m}{\beta(6 - r^2\beta(b - A)(\Delta - A))} \tag{7}$$

$$a^{N^*} = \left(\frac{r(b - A)(\alpha - \beta C_m)}{6 - r^2\beta(b - A)(\Delta - A)}\right)^2 \tag{8}$$

Lemma 3.1. *In a market structure without a leader, with recycling subsidy b increasing, we have ① the retail price P reduces; ② the advertising expense a increases; ③ the wholesale price W (when $b > (2A + 4\Delta)/6$) increases.*

Proof:

(1) $\dfrac{\partial P^{N^*}}{\partial b} = \dfrac{2r^2(\Delta - A)(\beta C_m - \alpha)}{[6 - r^2\beta(b - A)(\Delta - A)]^2}$

$\because r > 0,\ \Delta - A > 0,\ D(P) = \alpha - \beta P > 0,\ P > C_m,$

$\therefore \beta C_m - \alpha < 0,\ \therefore \partial P^{N^*}/\partial b < 0$

(2) $\dfrac{\partial a^{N^*}}{\partial b} = \dfrac{12r^2(\alpha - \beta C_m)^2(b - A)}{(6 - r^2\beta(b - A)(\Delta - A))^3}$

$\because \alpha - \beta C_m > 0,\ b \geq A,\ 6 - r^2\beta(b - A)(\Delta - A) > 0$

$\therefore \partial a^{N^*}/\partial b > 0$

(3) $\dfrac{\partial W^{N^*}}{\partial b} = \dfrac{\left(r^2(\alpha - \beta)(b - A)\right)^2 + r^2(\alpha - \beta C_m)(6b - 2A - 4\Delta)}{(6 - r^2\beta(b - A)(\Delta - A))^2}$

When $6b - 2A - 4\Delta > 0,\ b > (2A + 4\Delta)/6$

$\therefore \partial W^{N^*}/\partial b > 0$

Substituting Equations (6), (7) and (8) into Equations (1) and (2), we get retailer's profit

$$\pi_R^{N^*} = \frac{(\alpha - \beta C_m)^2\left(4 - r^2\beta(b - A)^2\right)}{\beta(6 - r^2\beta(b - A)(\Delta - A))^2} \tag{9}$$

manufacturer's profit

$$\pi_M^{N^*} = \frac{4(\alpha - \beta C_m)^2}{\beta(6 - r^2\beta(b - A)(\Delta - A))^2} \tag{10}$$

and total profit

$$\pi_T^{N^*} = \pi_R^{N^*} + \pi_M^{N^*} = \frac{(\alpha - \beta C_m)^2\left(8 - r^2\beta(b - A)^2\right)}{\beta(6 - r^2\beta(b - A)(\Delta - A))^2} \tag{11}$$

Lemma 3.2. *In a market structure without a leader, the optimal recycling subsidy of a manufacturer is $b = \Delta$.*

Proof: From the manufacturer's profit expression (10), when recycling subsidy b is close to Δ, the profit of a manufacturer is high. So Lemma 3.2 holds.

Lemma 3.2 shows because the manufacturer gives all the cost saved from remanufacturing to the retailer, it does not seem to be a benefit to the manufacturer. However, an increased subsidy leads to a decreased retail price, and then results in an increased sale. The wholesale price also rises, so the manufacturer still gets a profit. Further, with the subsidy increasing, the advertising investment increased which increases the number of recycled products, therefore reduces the average production cost of the manufacturer and improves the profit.

3.2. **Stackelberg game led by the manufacturer.** In the market led by the manufacturer, a manufacturer makes the wholesale price W get the maximum profit on the basis of the speculation that a retailer responds to the wholesale price. In order to get the maximum profit, the retailer makes a decision to determine the retail price P and the advertising expense a depending on the manufacturer's W. This model represents the market consisting of a handful of large manufacturers and many small retailers. Backward induction is used to solve the equations.

Solving simultaneously Equations (3) and (4), we get the retail price and advertising expense

$$P^Z = \frac{2(\beta W + \alpha) - \alpha r^2\beta(b - A)^2}{\beta(4 - r^2\beta(b - A)^2)} \tag{12}$$

$$a^Z = \left(\frac{r(b-A)(\alpha-\beta W)}{4-r^2\beta(b-A)^2}\right)^2 \tag{13}$$

Lemma 3.3. *In the market led by the manufacturer, the retail price P and the wholesale price W are positive correlation; the advertising expense a and the wholesale price W are negative correlation.*

Lemma 3.3 shows when the wholesale price rises, the retailer has to increase the retail price to ensure profit, and vice versa. With the rise of wholesale price, the retailer should reduce the cost of investment in advertising in order to ensure profit.

Substituting Equations (12) and (13) into Equation (2), from the first order condition of π_M, we get the optimal wholesale price W as

$$W^{Z^*} = \frac{\alpha+\beta C_m}{2\beta} - \frac{r^2(b-A)(\Delta-b)(\alpha-\beta C_m)}{8-2r^2\beta(b-A)(\Delta-A)} \tag{14}$$

Substituting Equation (14) into Equations (12) and (13), we get the optimal retail price and advertising expense as follows.

$$P^{Z^*} = \frac{\alpha\big(3-r^2\beta(b-A)(\Delta-A)\big)+\beta C_m}{\beta(4-r^2\beta(b-A)(\Delta-A))} \tag{15}$$

$$a^{Z^*} = \left(\frac{r(b-A)(\alpha-\beta C_m)}{8-2r^2\beta(b-A)(\Delta-A)}\right)^2 \tag{16}$$

Lemma 3.4. *In the market led by the manufacturer, with recycling subsidy b increasing, we have ① the retail price P reduces; ② the advertising expense a increases; ③ the wholesale price W (when $A \le b < (\Delta+A)/2$) decreases.*

Proof:

(1) $\dfrac{\partial P^{Z^*}}{\partial b} = \dfrac{r^2(\Delta-A)(\beta C_m-\alpha)}{(4-r^2\beta(b-A)(\Delta-A))^2} < 0$

(2) $\dfrac{\partial a^{Z^*}}{\partial b} = \dfrac{16r^2(b-A)(\alpha-\beta C_m)^2}{(8-2r^2\beta(b-A)(\Delta-A))^3} > 0$

(3) $\dfrac{\partial W^{Z^*}}{\partial b} = \dfrac{8r^2(2b-A-\Delta)-2r^4\beta(b-A)^2(\Delta-A)}{[8-2r^2\beta(b-A)(\Delta-A)]^2}(\alpha-\beta C_m)$

When $2b-A-\Delta<0$, $A \le b < (\Delta+A)/2$, therefore, $\partial W^{Z^*}/\partial b < 0$.

Substituting W^{Z^*}, P^{Z^*} and a^{Z^*} into Equations (1) and (2), we get

$$\pi_R^{Z^*} = \frac{\big(4-r^2\beta(b-A)^2\big)(\alpha-\beta C_m)^2}{4\beta(4-r^2\beta(b-A)(\Delta-A))^2} \tag{17}$$

$$\pi_M^{Z^*} = \frac{(\alpha-\beta C_m)^2}{2\beta(4-r^2\beta(b-A)(\Delta-A))} \tag{18}$$

$$\pi_T^{Z^*} = \pi_R^{Z^*} + \pi_M^{Z^*} = \frac{\big(12-r^2\beta(b-A)(b+2\Delta-3A)\big)(\alpha-\beta C_m)^2}{4\beta(4-r^2\beta(b-A)(\Delta-A))^2} \tag{19}$$

Lemma 3.5. *In the market led by the manufacture, the optimal recycling subsidy is $b=\Delta$.*

Proof: From the profit expression (18), when recycling subsidy b is close to Δ, the profit value of a manufacturer is high. So Lemma 3.5 holds.

Lemma 3.5 shows in the market led by the manufacturer, the manufacturer does not get the cost saved from remanufacturing. However, subsidy drives the retail price to reduce and advertising expense to increase. Then more products are recycled. These all cause an increase in demand for remanufactured products and a decrease in average cost. Further, the manufacturer gets the profit.

3.3. **Stackelberg game led by the retailer.** In the market led by the retailer, retailer makes the retail price P and the advertising expense a get the maximum profit on the basis of a reaction to the price of the manufacturer. Then manufacturer determines the wholesale price W relying on the price P to maximize the profit. This model represents the market consisting of a number of influential large retailers and manufacturers. Backward induction is used to solve the equations.

From Equation (5), we get the wholesale price as:

$$W^L = \left[\alpha - \beta P + \beta C_m - \beta r\sqrt{a}(\Delta - b)\right]/\beta \tag{20}$$

Lemma 3.6. *The wholesale price has negative correlation to the retail price and advertising expense, and has positive correlation to the manufacturing cost.*

Lemma 3.6 shows an increase in manufacturing cost leads to the wholesale price rising. An increase in the wholesale price causes the retailer to reduce the advertising expense. The increasing retail price results in the decreasing of the market demand. In order to expand market demand, manufacturer encourages retailer to lower the retail price by reducing the wholesale price.

Substituting Equation (20) into Equation (1), we get the profit function of the retailer.

$$\pi_R = \left[2P - C_m - \alpha/\beta + r\sqrt{a}(\Delta - A)\right](\alpha - \beta P) - a \tag{21}$$

From the first order condition of π_R in Equation (21), we get

$$\partial\pi_R/\partial P = 3\alpha - 4\beta P + \beta C_m - \beta r\sqrt{a}(\Delta - A) = 0 \tag{22}$$

$$\partial\pi_R/\partial a = 2\sqrt{a} - r(\alpha - \beta P)(\Delta - A) = 0 \tag{23}$$

Solving simultaneously Equations (22) and (23), we get the optimal retail price and advertising expense as follows

$$P^{L^*} = \frac{\left(6 - \beta r^2(\Delta - A)^2\right)\alpha + 2\beta C_m}{\beta(8 - \beta r^2(\Delta - A)^2)} \tag{24}$$

$$a^{L^*} = \left(\frac{r(\Delta - A)(\alpha - \beta C_m)}{8 - \beta r^2(\Delta - A)^2}\right)^2 \tag{25}$$

Substituting Equations (24) and (25) into Equation (20), the optimal wholesale price is

$$W^{L^*} = \frac{\left(2 - \beta r^2(\Delta - A)(\Delta - b)\right)\alpha + \left(6 - \beta r^2(\Delta - A)(b - A)\right)\beta C_m}{\beta(8 - \beta r^2(\Delta - A)^2)} \tag{26}$$

Lemma 3.7. *In the market led by the retailer, with recycling subsidy b increasing, we have ① the retail price P unchanged; ② the advertising expense a unchanged; ③ the wholesale price W rises.*

Lemma 3.7 shows in the market led by the retailer, the retail price and the advertising expense are not affected by the subsidy. This is because that retailer's decision is not affected by the manufacturer. However, the wholesale price of the manufacturer increases with the subsidy increasing.

Proof: we have

(1) $\dfrac{\partial P^{L^*}}{\partial b} = 0$;

(2) $\dfrac{\partial a^{L^*}}{\partial b} = 0$;

(3) $\dfrac{\partial W^{L^*}}{\partial b} = \dfrac{r^2(\Delta - A)(\alpha - \beta C_m)}{8 - r^2\beta(\Delta - A)^2} > 0$

Substituting W^{L^*}, P^{L^*} and a^{L^*} into Equations (1) and (2), we get

$$\pi_R^{L^*} = \frac{(\alpha - \beta C_m)^2}{\beta(8 - r^2\beta(\Delta - A)^2)} \tag{27}$$

$$\pi_M^{L^*} = \frac{4(\alpha - \beta C_m)^2}{\beta(8 - r^2\beta(\Delta - A)^2)^2} \tag{28}$$

$$\pi_T^{L^*} = \pi_R^{L^*} + \pi_M^{L^*} = \frac{\big(12 - r^2\beta(\Delta - A)^2\big)(\alpha - \beta C_m)^2}{\beta(8 - r^2\beta(\Delta - A)^2)^2} \tag{29}$$

Lemma 3.8. *In the market led by the retailer, the recycling subsidy of manufacturer is* $b \in [A, \Delta]$.

Lemma 3.8 shows in the market led by the retailer, the manufacturer's profit is not affected by the subsidy. This is because that the increased profit caused by subsidy equals the profit from the high wholesale price. The recycling subsidy does not play a role.

3.4. **Joint decision between the manufacturer and the retailer.** The goal of joint decision is to maximize the profit of supply chain system. The profit function is

$$\pi = \pi_R + \pi_M = \left[P + r\sqrt{a}(\Delta - A) - C_m\right](\alpha - \beta P) - a \tag{30}$$

From the first order condition of π in Equation (30), we get

$$\partial\pi/\partial P = \alpha - 2\beta P - \beta r\sqrt{a}(\Delta - A) + \beta C_m = 0 \tag{31}$$

$$\partial\pi/\partial a = 2\sqrt{a} - r(\alpha - \beta P)(\Delta - A) = 0 \tag{32}$$

Solving simultaneously Equations (31) and (32), we get the optimal retail price and advertising expense

$$P^{C^*} = \frac{\big(2 - \beta r^2(\Delta - A)^2\big)\alpha + 2\beta C_m}{\beta(4 - \beta r^2(\Delta - A)^2)} \tag{33}$$

$$a^{C^*} = \left(\frac{r(\alpha - \beta C_m)(\Delta - A)}{4 - \beta r^2(\Delta - A)^2}\right)^2 \tag{34}$$

Lemma 3.9. *In the market structure of joint decision with increasing of subsidy* b*, we have ① the retail price* P *unchanged; ② the advertising expense* a *unchanged.*

Proof:

(1) $\partial P^{C^*}/\partial b = 0$;
(2) $\partial a^{C^*}/\partial b = 0$

Lemma 3.9 shows in the market structure of joint decision, due to the fact that the subsidy internalizes on the supply chain system, the retail price and advertising expense have not been affected by the subsidy.

Substituting Equations (33) and (34) into Equation (30), we get the optimal profit of CLSC as

$$\pi_T^{C^*} = \frac{(\alpha - \beta C_m)^2}{\beta(4 - r^2\beta(\Delta - A)^2)} \tag{35}$$

Lemma 3.10. *In the market of joint decision, the recycling subsidy of manufacturer is* $b \in [A, \Delta]$.

Lemma 3.10 shows in the market of joint decision between a manufacturer and a retailer, we only consider the profit of CLSC but not the profits of manufacturer and retailer. So the subsidy is just an internal factor, which has no effect on the system.

TABLE 1. Comparison of four types of closed-loop supply chain models

Decision Variables	Nash Equilibrium	Manufacturer's Stackelberg Game	Retailer's Stackelberg Game	Joint Decision
P^*	$\frac{\left(4-r^2\beta(\Delta-A)^2\right)\alpha+2\beta C_m}{\beta\left(6-r^2\beta(\Delta-A)^2\right)}$	$\frac{\alpha\left(3-r^2\beta(\Delta-A)^2\right)+\beta C_m}{\beta\left(4-r^2\beta(\Delta-A)^2\right)}$	$\frac{\left(6-r^2\beta(\Delta-A)^2\right)\alpha+2\beta C_m}{\beta\left(8-r^2\beta(\Delta-A)^2\right)}$	$\frac{\alpha\left(2-r^2\beta(\Delta-A)^2\right)+2\beta C_m}{\beta\left(4-r^2\beta(\Delta-A)^2\right)}$
W^*	$\frac{2\alpha+\beta\left(4-r^2\beta(\Delta-A)^2\right)C_m}{\beta(6-r^2\beta(\Delta-A)^2)}$	$\frac{\alpha+\beta C_m}{2\beta}$	$\frac{2\alpha+\left(6-r^2\beta(\Delta-A)^2\right)\beta C_m}{\beta\left(8-r^2\beta(\Delta-A)^2\right)}$	N/A
$\sqrt{a^*}$	$\frac{r(\Delta-A)(\alpha-\beta C_m)}{6-r^2\beta(\Delta-A)^2}$	$\frac{r(\Delta-A)(\alpha-\beta C_m)}{8-2r^2\beta(\Delta-A)^2}$	$\frac{r(\Delta-A)(\alpha-\beta C_m)}{8-r^2\beta(\Delta-A)^2}$	$\frac{r(\alpha-\beta C_m)(\Delta-A)}{4-r^2\beta(\Delta-A)^2}$
π_M^*	$\frac{4(\alpha-\beta C_m)^2}{\beta\left(6-r^2\beta(\Delta-A)^2\right)^2}$	$\frac{(\alpha-\beta C_m)^2}{2\beta\left(4-r^2\beta(\Delta-A)^2\right)}$	$\frac{4(\alpha-\beta C_m)^2}{\beta\left(8-r^2\beta(\Delta-A)^2\right)^2}$	N/A
π_R^*	$\frac{\left(4-r^2\beta(\Delta-A)^2\right)(\alpha-\beta C_m)^2}{\beta\left(6-r^2\beta(\Delta-A)^2\right)^2}$	$\frac{\left(4-r^2\beta(\Delta-A)^2\right)(\alpha-\beta C_m)^2}{4\beta\left(4-r^2\beta(\Delta-A)^2\right)^2}$	$\frac{(\alpha-\beta C_m)^2}{\beta\left(8-r^2\beta(\Delta-A)^2\right)}$	N/A
π_T^*	$\frac{\left(8-r^2\beta(\Delta-A)^2\right)(\alpha-\beta C_m)^2}{\beta\left(6-r^2\beta(\Delta-A)^2\right)^2}$	$\frac{\left(12-3r^2\beta(\Delta-A)^2\right)(\alpha-\beta C_m)^2}{4\beta\left(4-r^2\beta(\Delta-A)^2\right)^2}$	$\frac{\left(12-r^2\beta(\Delta-A)^2\right)(\alpha-\beta C_m)^2}{\beta\left(8-r^2\beta(\Delta-A)^2\right)^2}$	$\frac{(\alpha-\beta C_m)^2}{\beta\left(4-r^2\beta(\Delta-A)^2\right)}$

4. **Comparative Analysis for Four Types of Closed-Loop Supply Chain Models.** In order to facilitate comparative analysis, let $b = \Delta$, and the above results are summarized in Table 1.

From Table 1, we get the following results.

Lemma 4.1. *The optimal retail price* $P^{C^*} < P^{N^*} < P^{Z^*} < P^{L^*}$. *Accordingly, the market demand* $D\left(P^{L^*}\right) < D\left(P^{Z^*}\right) < D\left(P^{N^*}\right) < D\left(P^{C^*}\right)$.

Proof:

$$P^{L^*} - P^{Z^*} = \frac{r^2\beta(\Delta - A)^2(\alpha - \beta C_m)}{\beta(4 - r^2\beta(\Delta - A)^2)(8 - r^2\beta(\Delta - A)^2)} > 0$$

$$P^{Z^*} - P^{N^*} = \frac{\left(2 - r^2\beta(\Delta - A)^2\right)(\alpha - \beta C_m)}{\beta(4 - r^2\beta(\Delta - A)^2)(6 - r^2\beta(\Delta - A)^2)} > 0$$

$$P^{N^*} - P^{C^*} = \frac{4(\alpha - \beta C_m)}{\beta(6 - r^2\beta(\Delta - A)^2)(4 - r^2\beta(\Delta - A)^2)} > 0$$

Due to the equation market demand $D(P) = \alpha - \beta P$, the relation $D\left(P^{L^*}\right) < D\left(P^{Z^*}\right) < D\left(P^{N^*}\right) < D\left(P^{C^*}\right)$ holds.

Lemma 4.2. *The optimal wholesale price* $W^{L^*} < W^{N^*} < W^{Z^*}$.

Proof:

$$W^{Z^*} - W^{N^*} = \frac{\left(2 - r^2\beta(\Delta - A)^2\right)(\alpha - \beta C_m)}{2\beta(6 - r^2\beta(\Delta - A)^2)} > 0$$

$$W^{N^*} - W^{L^*} = \frac{4(\alpha - \beta C_m)}{\beta(6 - r^2\beta(\Delta - A)^2)(8 - r^2\beta(\Delta - A)^2)} > 0$$

Lemma 4.3. *The optimal advertising expense* $a^{L^*} < a^{Z^*} < a^{N^*} < a^{C^*}$.

Proof:

$$\sqrt{a^{C^*}} - \sqrt{a^{N^*}} = \frac{2r(\Delta - A)(\alpha - \beta C_m)}{(4 - r^2\beta(\Delta - A)^2)(6 - r^2\beta(\Delta - A)^2)} > 0$$

$$\sqrt{a^{N^*}} - \sqrt{a^{Z^*}} = \frac{r\left(2 - r^2\beta(\Delta - A)^2\right)(\Delta - A)(\alpha - \beta C_m)}{(6 - r^2\beta(\Delta - A)^2)(8 - 2r^2\beta(\Delta - A)^2)} > 0$$

$$\sqrt{a^{Z^*}} - \sqrt{a^{L^*}} = \frac{r^3\beta(\Delta - A)^3(\alpha - \beta C_m)}{(6 - r^2\beta(\Delta - A)^2)(8 - 2r^2\beta(\Delta - A)^2)} > 0$$

Lemma 4.4. *The optimal profit of the manufacturer* $\pi_R^{L^*} < \pi_R^{N^*} < \pi_R^{Z^*}$.

Proof:

$$\pi_M^{Z^*} - \pi_M^{N^*} = \frac{\left(2 - r^2\beta(\Delta - A)^2\right)^2(\alpha - \beta C_m)^2}{2\beta(4 - r^2\beta(\Delta - A)^2)(6 - r^2\beta(\Delta - A)^2)^2} > 0$$

$$\pi_M^{N^*} - \pi_M^{L^*} = \frac{16\left(7 - r^2\beta(\Delta - A)^2\right)(\alpha - \beta C_m)^2}{\beta(6 - r^2\beta(\Delta - A)^2)^2(8 - r^2\beta(\Delta - A)^2)^2} > 0$$

Lemma 4.5. *The optimal profit of the retailer* $\pi_R^{Z^*} < \pi_R^{N^*} < \pi_R^{L^*}$.

Proof:

$$\pi_R^{L^*} - \pi_R^{N^*} = \frac{4(\alpha - \beta C_m)^2}{\beta(8 - r^2\beta(\Delta - A)^2)(6 - r^2\beta(\Delta - A)^2)^2} > 0$$

$$\pi_R^{N^*} - \pi_R^{Z^*} = \frac{\left(14 - 3r^2\beta(\Delta - A)^2\right)\left(2 - r^2\beta(\Delta - A)^2\right)(\alpha - \beta C_m)^2}{4\beta(6 - r^2\beta(\Delta - A)^2)^2(4 - r^2\beta(\Delta - A)^2)} > 0$$

Lemma 4.6. *The optimal profit of CLSC* $\pi_T^{L^*} < \pi_T^{Z^*} < \pi_T^{N^*} < \pi_T^{C^*}$.

Proof:

$$\pi_T^{C^*} - \pi_T^{N^*} = \frac{4(\alpha - \beta C_m)^2}{\beta(4 - r^2\beta(\Delta - A)^2)(6 - r^2\beta(\Delta - A)^2)^2} > 0$$

$$\pi_T^{N^*} - \pi_T^{Z^*} = \frac{\left(10 - r^2\beta(\Delta - A)^2\right)\left(2 - r^2\beta(\Delta - A)^2\right)(\alpha - \beta C_m)^2}{4\beta(6 - r^2\beta(\Delta - A)^2)^2(4 - r^2\beta(\Delta - A)^2)} > 0$$

$$\pi_T^{Z^*} - \pi_T^{L^*} = \frac{r^2(\Delta - A)^2\left(16 - r^2\beta(\Delta - A)^2\right)(\alpha - \beta C_m)^2}{4(4 - r^2\beta(\Delta - A)^2)(8 - r^2\beta(\Delta - A)^2)^2} > 0$$

From the above lemmas, we find: (1) Retail price is the highest in the market structure led by retailer, and the lowest in the joint decision; (2) The wholesale price is the highest in the market structure led by manufacturer and the lowest when the retailer is the leader; (3) Advertising expense is the highest in the market structure of joint decision, and the lowest in the market structure led by retailer; (4) The manufacturer's profit is the highest in the market structure led by manufacturer and the lowest when the retailer is the leader; (5) The retailer's profit is the highest in the market structure led by retailer, and the lowest when the manufacturer is the leader; (6) The profit of total CLSC is the highest in the market structure of the joint decision, and the lowest in the market structure led by retailer.

5. **Conclusion.** In this paper, we study the problem of advertising and pricing decision making in remanufacturing CLSC under different types of market structures. We analyze the retail price, wholesale price, advertising expense, and the profit of manufacture, retailer and total CLSC under these market structures. From the results we can see that the industry's profit is the largest in the market structure of joint decision. Consumers and the industry benefit from the low price and high profit due to joint. However, becoming a leader can make their profits maximize. Thus, manufacturer and retailer have the motivation to be a leader. On the basis of this study, we can further study how to introduce other factors into the decision of CLSC.

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