Research on Decision-making of Closed-loop Supply Chain Considering Consumption Preference under Different Power Structures

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Abstract. In a dual-channel closed-loop supply chain, consumers have different preferences for purchasing from manufacturers' direct channels and traditional retailers' channels. The dual-channel closed-loop supply chain structure is constituted with single manufacturer and single retailer. Considering Stackelberg game, a centralized decision-making game model is established, and a decentralized decision-making game model dominated by manufacturers and retailers respectively. According to the inverse solution method, the equilibrium solutions of the decision-making model under three different power structures is obtained. According to the difference of consumer preferences for different channels, this paper analyzes the pricing decisions and the impact of profit distribution on closed loop supply chain under different power structure. It is found, the optimal prices, market demand, and profits of manufacturer and retailer in a closed-loop supply chain under centralized and decentralized decision-making are affected by consumer preference.

Keywords: consumer preference; closed-loop supply chain; different power structure; decision-making.

1. Introduction

China has gradually entered the era of post-industrialization. The problem of reducing environmental pollution and improving the efficiency of resource utilization needs to be solved urgently. Therefore, the government proposes to strongly support enterprises to recycle used products for remanufacturing. Compared with traditional supply chain systems, closed-loop supply chain systems for recycling and remanufacturing production are more complex and affected by various uncertainties easily. Considering that manufacturers and retailers aim to maximize the total profits or respective profit of them in the closed-loop supply chain, there are different modes of closed-loop supply chain decision-making under the several power structures. Additionally, With the popularity of online stores, the choices of consumers' purchase channels have increased. The consumption preference of different channels will affect the policy decision in the closed loop supply chain.

The articles about closed-loop supply chain decision-making mostly focused on supply chain pricing strategies, benefit distribution in the supply chain members, and supply chain stability. Closed-loop supply chain policy decision-making is affected by factors such as the recovery channels, sales channels, logistics service, and leading companies. According to the ability of remanufacture or recycle, the closed-loop supply chain is mostly dominated by manufacturers or retailers [1]. Different main-subsidiary The closed-loop supply chains which are dominated by different companies need different channels of distribution or recycle, then decide whether to adopt logistics outsourcing or self-logistics[2]. Savaskan et al. [3] conducted a study on the closed-loop supply chain of different recycling channels established by manufacturers, sellers, and third parties respectively. It is found that recycling in charge of retailers is more effectively than manufacturers and third parties.

Han Xiaohua [4] and Gao Peng, etc. [5] studied the three recovery channel strategies of seller-led, closed-loop supply chain, vendor recycling, manufacturer recycling, and third-party recycling. Yokohide [6] designs four supply chain models based on cross-combination of manufacturers or sellers leading models and recycling methods, and analyzes the relationship among sales price, sales volume, recycling rate, and profit relationship under different models to determine the stability of four types of supply chains.

Karakayali et al. [7] studied the pricing service decisions of the reverse supply chain from the perspective of different channels of power structure. Ma et al. [8] studied the existence of two closed-loop supply chains under government subsidies and explored the benefits to consumers. Gao et al. [9] studied the pricing of products in the closed-loop supply chain under the three conditions of manufacturer-leader, retailer-leader, and manufacturer-retailer power parity, and the profit distribution of the member companies. They believe that retailers' profits are greatest when they are led by retailers, and they are best for consumers in the context of power parity. At this moment, the sales price of products is the lowest. Liu Guangfu et al. [10] analyzed the dual-channel closed-loop supply chain system where the original manufacturer and third-party remanufacturing coexist, and used the game model to analyze the differential pricing models for new products and remanufactured products, and obtained the best pricing strategies under different models. Sun Jiawei and others [11] constructed three closed-loop supply chain structures based on the impact of sales volume and recycling prices. Lin Jie et al. [12], based on the closed-loop supply chain structure in which dual sales and dual-recovery channels coexist, explores a closed-loop supply chain pricing strategy model that considers manufacturers and retailers as the lead players. Xie Jiaping [13] believes that the revenue-sharing contract can provide support for cooperation in the supply chain and proposes a closed-loop supply chain based on contract theory that distributes the positive sales revenue and the reverse recovery revenue at the same time, which helps single manufacturer to cooperate with single retailer. The profits of the two are maximized in the system. Ding Bin et al. [14] conducted a comparative analysis of the pricing decisions and benefits of the two closed-loop supply chain models in which suppliers choose to participate in component recycling and remanufacturing under vendor-led circumstances. Zhang Fuan et al. [15] divided the supply chain leading model into positive manufacturer-led and reverse-seller- dominated models, and studied the stability of closed-loop supply chains from the forward logistics strategy and reverse logistics strategy.

To sum up, closed-loop supply chain decisions are influenced by different power structures, and consumption preference for channels also influences closed-loop supply chain decisions. Therefore, this paper discusses closed-loop supply chain decision-making problems based on different power structures while considering the influence factors of consumer preferences. Currently, closed-loop supply chain research is more based on the product's reverse recycling process, and does not consider product remanufacturing sales. Therefore, this paper focuses on manufacturers' direct sales and traditional retail channels, and considers consumers' different preferences for different channels, based on the Stackelberg game theory. To build a closed-loop supply chain decision model under different power structures, and then analyze the influence of consumers' preferences for different channels on the entire closed-loop supply chain decision.

2. Model Description and Basic Assumptions

This paper studies closed-loop supply chain based on a two-level closed-loop supply chain constructed by single manufacturer and single traditional retailer,and only consider a complete cycle of supply chain and single recycling and remanufacturing reverse supply chain for single production and sales. The cycle, as shown in Figure 1.At the same time , the research closed-loop supply chain is based on two channels: traditional retail channels and manufacturers direct sales channels. Among them, the reverse recycling is entrusted to the retailer by the manufacturer, and then the recycled product is obtained from the retailer at a certain transfer price for remanufacturing.

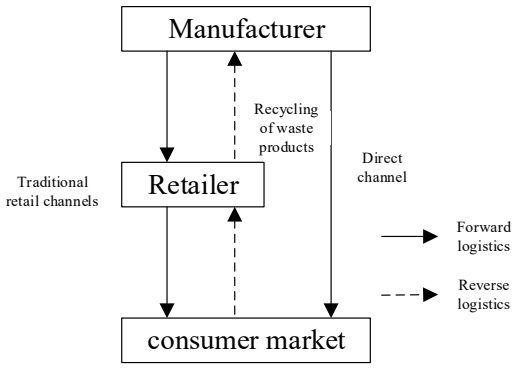

Fig. 1 Two-channel closed-loop supply chain decision model

According to the above model background description, in order to deal with issues such as conflict of sales channels and interest distribution in closed-loop supply chain, and control the complexity of the model research, this paper simplifies practical problems, so the following specific assumptions and parameter descriptions are made.

(1) Hypothetical manufacturer m Product production marginal cost c_m The remanufactured marginal cost of recycled used products is $\overline{c}_m$, remanufacturing cost savings $\Delta=c_m-\overline{c}_m$ ($c_m>\overline{c}_m$)[6].

(2) The manufacturer's direct sales product unit price is p_m, Or manufacturers at wholesale prices ω Wholesale to retailers r, retailers use retail prices p_r Sales to consumers, and there are $p_m>c_m$, $p_r>\omega>c_m$.

(3) The level of consumer preference purchased by consumers in retail channels is α The market's maximum possible demand is the market size a, the sales volume of retail channels and direct sales channels are respectively $Q_r=\alpha a-\beta p_r$, $Q_m=(1-\alpha)a-\beta p_m$,among them: $0\le\alpha\le1$; β For consumer sensitivity to price, φ_1 versus φ_2 Refers to the number of product impacts in the cross-channel.

(4) The retailer's unit cost price for recycling used products from consumers is h_r And transfer prices h_{mr} Handed over to the manufacturer for remanufacturing and $h_r<h_{mr}<\Delta$; Assume an effective recovery rate for used products k, that is, the number of products that can be recycled is $k(Q_m+Q_r)$ [6].

(5) The theoretically recovered waste products can be fully utilized. The remanufactured products and raw material production products are almost identical in performance and quality, and enter the sales market with the same channels.

Based on the above basic assumptions, the manufacturer, retailer, and the entire closed-loop supply chain profit function that considers consumer preferences are:

$$\Pi_m=(p_m-c_m)Q_m+(\omega-c_m)Q_r+k(Q_m+Q_r)(\Delta-h_{mr}) \tag{1}$$

$$\Pi_r=(p_r-\omega)Q_r+k(h_{mr}-h_r)(Q_m+Q_r) \tag{2}$$

$$\Pi_{\text{Total}}=(p_m-c_m)Q_m+(p_r-c_m)Q_r+k(Q_m+Q_r)(\Delta-h_r) \tag{3}$$

Π is expressed as profit, Π_M, Π_R and Π_{Total} represent manufacturer's profits, retailer's profits, and overall profits in closed-loop supply chain, respectively; Manufacturer-leader model and retailer-lead model are used M and R, separately.

3. Model Analysis

3.1 Centralized Decision Model

The centralized decision-making model means that manufacturers and retailers seek the maximization of the profits of the dual-channel closed-loop supply chain system from the overall interests of the closed-loop supply chain, and the two determine their optimal pricing decisions through cooperation. Using the Stackelberg game theory, the inverse induction method is used to solve, in which manufacturers and retailers will jointly determine the optimal sales price combination $\left(p_m^{C^*}, p_r^{C^*}\right)$ Combined with optimal market requirements $\left(Q_m^{C^*}, Q_r^{C^*}\right)$.

Proposition 1: In the centralized decision-making mode, the total profit of closed-loop supply chain Π_{Total}^{C} Is about direct selling prices p_m And retail prices p_r The strict concave function has unique optimal solution.

Under the centralized decision, there are the following optimal solutions:

$$p_m^{C^*} = \frac{(1-\alpha)a + \beta c_m - k\beta(\Delta - h_r)}{2\beta},\ p_r^{C^*} = \frac{\alpha a + \beta c_m - k\beta(\Delta - h_r)}{2\beta};$$

$$Q_m^{C^*} = \frac{(1-\alpha)a - \beta c_m + k\beta(\Delta - h_r)}{2};\ Q_m^{C^*} = \frac{(1-\alpha)a - \beta c_m + k\beta(\Delta - h_r)}{2};\ Q_r^{C^*} = \frac{\alpha a - \beta c_m + k\beta(\Delta - h_r)}{2}.$$

3.2 Decentralized Decision Model

Decentralized decision-making means that manufacturers and retailers use the principle of maximizing their profits to determine the price of closed-loop supply chain products.

3.2.1 Decision Analysis under Manufacturer-led Mode

Under the manufacturer-dominated power structure, it has the price-setting power and can use the retailer's price response as its price decision basis. In this lead mode, the two-stage game order between manufacturer and retailer is: Manufacturer first determines the wholesale price of the product ω And direct selling prices p_m , Retailers determine the retail price of traditional sales channels based on manufacturer pricing p_r. This game belongs to the perfect dynamic game structure. There is a unique subgame-refined Nash equilibrium, which is solved using the inverse induction method [19].

Proposition 2: Retailer profits in manufacturer-led decentralized decision-making $\Pi_R^M\left(p_m, p_r\right)$ its about p_r Strict Concave Function*[Manufacturer Profit] $\Pi_M^M\left(p_m, \omega\right)$ its about p_m with ω The strict concave function has unique optimal solution.

Optimal solution: $p_m^{M^*} = \frac{(1-\alpha)a + \beta c_m - k\beta(\Delta - h_{mr})}{2\beta}$, $p_r^{M^*} = \frac{3\alpha a + \beta c_m - k\beta(\Delta - h_r)}{4\beta}$,

$$\omega^{M^*} = \frac{\alpha a + \beta c_m - k\beta(\Delta + h_r - 2h_{mr})}{2\beta},\ Q_m^{M^*} = \frac{(1-\alpha)a - \beta c_m + k\beta(\Delta - h_{mr})}{2},\ Q_r^{M^*} = \frac{\alpha a - \beta c_m + k\beta(\Delta - h_r)}{4}.$$

3.2.2 Decision Analysis under Retailer-led Model

Under the lead power structure of the retailer, it acts as a decision maker for channel prices and uses the manufacturer's price response as a basis for price decision. In this lead model, the two-stage game order between manufacturers and retailers is: Retailers freely decide the sales price of products in traditional sales channels. p_r, and the manufacturer can only establish the wholesale price of the product based on this decision. ω And direct sales channel sales prices p_m To maximize profits. This game belongs to the perfect dynamic game structure. There is a unique subgame-refined Nash equilibrium. This problem is solved by using inverse induction.

Proposition 3: Retailer profits in retailer-led decentralized decision-making $\Pi_R^R(p_m, p_r)$ its about p_r The strict concave function, $\Pi_M^R(p_m, \omega)$ its about p_m with ω The strict concave function has unique optimal solution.

The following optimal solutions are available under the retailer-led decision:

$$p_m^{R^*} = \frac{(1-\alpha)a + \beta c_m - k\beta(\Delta - h_{mr})}{2\beta}, p_r^{R^*} = \frac{3\alpha a + \beta c_m - k\beta(\Delta - h_r)}{4\beta}, \omega^{R^*} = \frac{\alpha a + 3\beta c_m - k\beta(3\Delta - 4h_{mr} + h_r)}{4\beta},$$

$$Q_m^{R^*} = \frac{(1-\alpha)a - \beta c_m + k\beta(\Delta - h_{mr})}{2}, Q_r^{R^*} = \frac{\alpha a - \beta c_m + k\beta(\Delta - h_r)}{4}.$$

3.3 Influence of Consumer Preferences on Decision-making and Profit of Closed-loop Supply Chain

Conclusion 1: $p_m^{C^*}$, $p_m^{M^*}$, $p_m^{R^*}$, $Q_m^{C^*}$, $Q_m^{M^*}$, $Q_m^{R^*}$ Average consumer preferences α Increase and decrease $p_r^{C^*}$, $p_r^{M^*}$, ω^{M^*}, $p_r^{R^*}$, ω^{R^*}, $Q_r^{C^*}$, $Q_r^{M^*}$, $Q_r^{R^*}$ Average consumer preferences α The increase increases.

Conclusion 2: Centralized decision-making and decentralized decision-making The direct selling price of a closed-loop supply chain satisfies the following relationship: $p_m^{C^*} < p_m^{M^*} = p_m^{R^*}$. Traditional channel sales prices meet the following relationship: $\alpha < \frac{\beta c_m - k\beta(\Delta - h_r)}{a}$ Time $p_r^{C^*} < p_r^{M^*} = p_r^{R^*}$,when $\alpha \geq \frac{\beta c_m - k\beta(\Delta - h_r)}{a}$ There are $p_r^{C^*} \geq p_r^{M^*} = p_r^{R^*}$. The wholesale price meets the following relationship: When consumer preferences are met $\alpha > \frac{\beta c_m - k\beta(\Delta - h_r)}{a}$ Have $\omega^{M^*} > \omega^{R^*}$,when $\alpha \leq \frac{\beta c_m - k\beta(\Delta - h_r)}{a}$ Have $\omega^{M^*} \leq \omega^{R^*}$.

Conclusion 3: Centralized decision-making and decentralized decision-making the optimal market demand under direct sales channels of a closed-loop supply chain satisfies the following relationship: $Q_m^{C^*} > Q_m^{M^*} = Q_m^{R^*}$ The optimal market demand under the traditional channels meets the following relationships: $Q_r^{C^*} > Q_r^{M^*} = Q_r^{R^*}$.

Conclusion 4: Comparison of market demand under direct sales channels under different power structures: consumer preference coefficient under the centralized decision model $0 < \alpha < \frac{1-a}{2}$, $Q_m^{C^*} > Q_r^{C^*}$,when $\alpha \geq \frac{1-a}{2}$ Time, $Q_m^{C^*} \leq Q_r^{C^*}$ Decentralized decision-making under the optimal market demand, when the consumer preference coefficient interval $0 < \alpha < \frac{2a - \beta c_m + k\beta(\Delta + h_r - 2h_{mr})}{3}$ When available $Q_m^{M^*} > Q_r^{M^*}$, $Q_m^{R^*} > Q_r^{R^*}$. when $\frac{2a - \beta c_m + k\beta(\Delta + h_r - 2h_{mr})}{3} \leq \alpha \leq 1$ Time, $Q_m^{M^*} \leq Q_r^{M^*}$, $Q_m^{R^*} \leq Q_r^{R^*}$.

Conclusion 5: When $0 < \alpha < 1$ At the time, in a centralized decision-making supply chain that takes into account consumers' consumer preference behavior, the total profit of the closed-loop supply chain will follow the consumer preference coefficient. α The increase increases. when $\alpha = 1$, indicating that consumers are completely inclined to the consumption patterns of traditional channels when $\alpha = 0$, indicating that consumers are completely inclined to direct product purchases from direct sales channels. At this time, the total profit of the closed-loop supply chain $\Pi_{Total}^{C^*}\big|_{\alpha=0} = \Pi_{Total}^{C^*}\big|_{\alpha=1}$.

Conclusion 6: Under different power structure, the profit relationship of manufacturers under the optimal condition of closed-loop supply chain is: $\Pi_m^{M^*} \geq \Pi_m^{R^*}$ The retailer's profit relationship is:

$\Pi_R^{M^*} \le \Pi_R^{R^*}$ Closed-loop supply chain relations of profit are: $\alpha \ge \frac{3\beta c_m - 2k\beta(3\Delta - 2h_{mr} - h_r)}{a}$ Time, $\Pi_{Total}^{C^*} \ge \Pi^{M^*} = \Pi^{R^*}$ On the contrary $\Pi_{Total}^{C^*} < \Pi^{M^*} = \Pi^{R^*}$.

4. Numerical Analysis

In order to simplify the model to better analyze the equilibrium results of supply chain decisions under different power structures, the model parameters are assigned as follows: The marginal cost of the manufacturer's production unit $c_m = 20$, manufacturer's remanufacturing unit marginal cost $\overline{c}_m = 10$,then $\Delta = c_m - \overline{c}_m = 10$, Market size $a = 1000$, price sensitivity factor $\beta = 10$, Manufacturer's Transfer Prices for Retailers' Scrapped Products $h_{mr} = 5$, retailer unit recovery costs $h_r = 2$, Market recovery rate of used products $k = 0.5$. Consumer preferences for traditional sales channels α For the entry point, we will study the influence of consumer preferences on the overall profit of the closed-loop supply chain under different power structures. At the same time, we compare the profit changes of retailers and manufacturers under different lead entities under the decentralized decision model. The numerical analysis results are shown in Figure 1~ 3 shows.

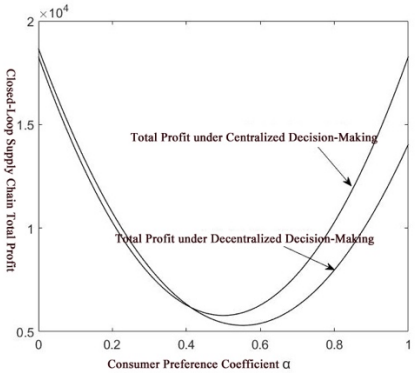

Fig 2. Comparison of total profit of closed-loop supply chains under different power structures

As can be seen from Figure 1, with consumer preferences for traditional retail channels α The changing trend of total profit of closed-loop supply chains under change, centralized decision-making and decentralized decision-making is to first decline and then continue to rise. That is, when consumers prefer to use single direct sales channel or traditional retail channels, the closed-loop supply chain of the two models Profits are relatively high. At this point, due to single consumer preference, consumers are keen on a certain kind of consumer channels. At this time, it will create a market monopoly for the channel, leading to a reduction in competition. Ultimately, the formulation of prices will be dominated by enterprises, and the profits of closed-loop supply chains will increase. Similarly, When the consumer preferences of the two sales channels are the same, due to the need of market competition, it will lead to a decrease in total profits, but this situation is beneficial to consumers. Further analysis of Figure 2, from the intersection point, when $0 \le \alpha \le 0.42$ When the decentralized decision-making, the total profit of closed-loop supply chain is higher than the total profit under centralized decision-making; $0.42 < \alpha \le 1$ At that time, the total profit of the closed-loop supply chain under centralized decision-making was higher than the total profit under decentralized decision-making.

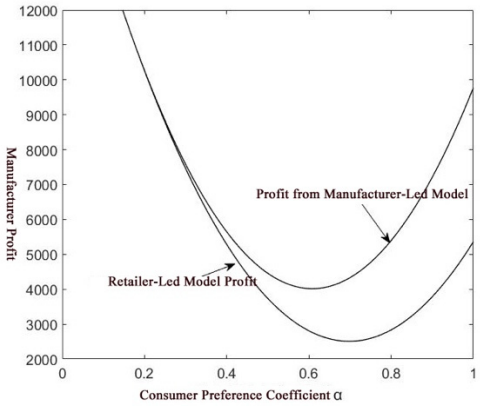

Fig. 3 Comparison of manufacturer's profits under different lead models

From Figure 2, we can see that under the decentralized decision, consumers' preferences for traditional retail channel preferences α With the increase, the profits of manufacturers under different lead models will decrease and then rise again. Which when α The lower the coefficient is, the higher the manufacturer's profit is. At this time, because consumers have a lower preference for traditional retail channels, more direct sales channels are preferred for manufacturers. At the same time, under different lead models, manufacturers' profits in the manufacturer-led model are higher than retailer-dominated profits. $\Pi_m^{M^*} \geq \Pi_m^{R^*}$ .From Figure 3 can be further analyzed, when the consumer preference for traditional retail channels α In the interval $[0.6, 0.7]$ At that time, the manufacturer's profit reached the lowest level. At this time, consumers' preference for traditional retail channels and direct sales channels reached a certain balance. At this time, manufacturers were not in an absolute lead position in the process of profit distribution in the closed-loop supply chain, so the total profit was relatively Lower.

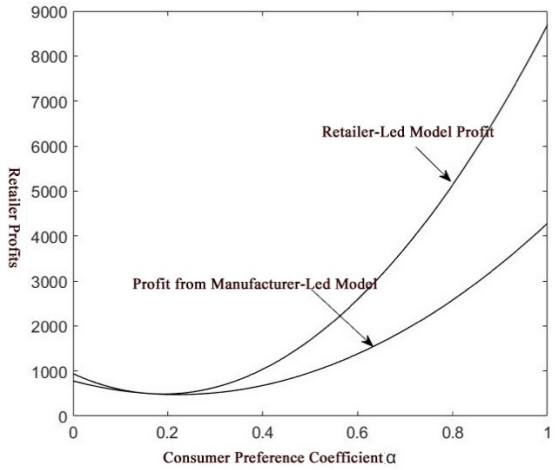

Fig 4. Comparison of retailer profits under different lead models of decentralized decision making

Figure 4 shows that under decentralized decision-making, consumer preferences for traditional retail channels α With the increase, retailers' profits will decrease and then rise again under different lead models. Which when α The higher the coefficient, the higher the retailer's profitability. This is because when the consumer prefers traditional sales channels, the retailer's competitive advantage will be higher; at the same time, the manufacturer has more bargaining power, More favorable. Under different lead models, the retailer's profit in the manufacturer's lead model is lower than the retailer's lead profit. $\Pi_R^{M^*} \leq \Pi_R^{R^*}$ .From Figure 4 can be further analyzed, when the consumer preference for traditional retail channels α In the interval $[0.16, 0.22]$ At the time, the retailer's profits have reached a minimum.

5. Conclusion

This paper introduces the influence of consumer preference behavior on the supply chain decision-making, and builds a dual-channel closed-loop supply chain structure based on single manufacturer and a retailer. A centralized decision-making model and a decision-making model for closed-loop supply chains under three power structures, such as manufacturer-dominated and retailer-dominated, under decentralized decision-making are designed. This paper designs three decision-making models with different power structure, including centralized decision making, manufacturer led and retailer led decentralized decision-making model. Through the solution results, the impact of consumer preferences on the pricing decisions and profits of closed-loop supply chains is analyzed. Numerical examples verify the conclusions. The research results show that the level of consumer preference has a direct impact on the market demand of direct sales channels and traditional retail channels. The higher the consumer preference, the greater the market demand of the channel, and the pricing of products in different channels and consumer preferences. The degree is related; in addition, the profit of the closed-loop supply chain under different power structures also changes with changes in consumer preferences. The research results show that the behavior preference of consumption has a great influence on the decision-making of closed-loop supply chain.

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