A Study of Remanufacturing Pricing Decisions Considering Recycling Quality and Retailer CSR Inputs

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Abstract: In order to improve the sales and production of recycled products, a closed-loop supply chain model of manufacturer recycling is constructed based on the differences in retailers' CSR inputs and the quality level of recycled products, and the optimal pricing of the remanufacturing supply chain is investigated through a Stackelberg game. The results show that supply chain revenue increases when consumers' willingness to pay for remanufactured products approaches that of new products. From the perspective of expanding the market demand for remanufactured products and increasing the supply chain revenue, the higher quality of returned products and consumer CSR sensitivity are better, while the quality of recyclable products also affects the retailer CSR input level, and the efficiency of CSR input and the quality of recycled waste products can be considered to enhance the economic and environmental benefits.

Keywords: Recycling Quality, Consumer Preference, Corporate Social Responsibility, Stackelberg Game.

1 INTRODUCTION

In recent years, due to a series of problems such as epidemic, shortage of production raw materials and environmental pollution, enterprises pay more attention to the recycling and reuse of used products, and scholars gradually regard the study of remanufacturing closed-loop supply chain as one of the research hotspots. In reality, due to the different usage habits and degrees of use in the recycling process, there is uncertainty about the participation value of recycled products, and consumers are more inclined to purchase new products than remanufactured products. Therefore, in order to increase consumers' attention to recycled products and alleviate the shortage of production resources, it is important to study the closed-loop supply chain with the difference in CSR input and recycling quality of retailers under the consumer preference.

Based on the above problems, the review of relevant literature shows that even if the quality of new products and remanufactured products is the same, consumers will have different pricing for new products and remanufactured products due to different consumer cognition. Zhao et al. introduced consumer environmental preferences to study the pricing decisions of supply chain members and the joint decision problem of subsidy shares between remanufacturers and consumers [11]. Hong et al. concluded from their study that the degree of consumer preference

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for remanufactured products affects the price of remanufactured products at wholesale, retail and recycling, and that the recycling price increases with the increase in wholesale and retail prices[3]. Sun et al. develop but-channel and dual-channel closed-loop supply chain models based on consumer preferences and consumer equity concerns to discuss the impact of consumer acceptance of remanufactured goods and equity concerns on members' decisions and profits[9]. For the quality of raw materials in the recycling process, Feng et al. construct a multi-level competitive recycling and remanufacturing supply chain game model with two manufacturers and multiple recyclers to analyze the pricing coordination problem[2]. Taleizadeh et al. analyzed the dynamic pricing and recycling strategies of remanufacturers using a modal interval algorithm considering the uncertainty of scrap product quality [10].

Some scholars believe that donating a certain amount of money for public welfare is also a way to make CSR investment, Muller et al. showed that when consumers are philanthropically socially conscious, an increase in the size of donations can increase consumer demand [7]. Dey et al. considered the sustainability of remanufacturing and competition in the retail market, added socially responsible influences to the market demand, and found that remanufacturing is not only beneficial to the overall supply chain in terms of economic benefits, but also in terms of environmental sustainability [1].

In summary, this study differs from previous work in several ways. Firstly, in order to increase the sales volume of remanufactured products, the influences of consumer preference and CSR input for remanufactured products, namely social donation, on the pricing of remanufactured products and supply chain profits were considered. Secondly, the study found that there was a certain relationship between the quality of recycled products and CSR input. Finally, combining the three aspects of consumer preference, CSR input of enterprises and the quality of recycled products, it provided a certain theoretical reference for alleviating the plight of raw materials and increasing the sales volume of remanufactured products.

2 SYMBOL DEFINITION AND HYPOTHESES

This section examines a closed-loop supply chain system for remanufacturing, taking into account differential pricing of retailers' socially responsible inputs based on quality differences in recycled goods. as shown in Figure 1.

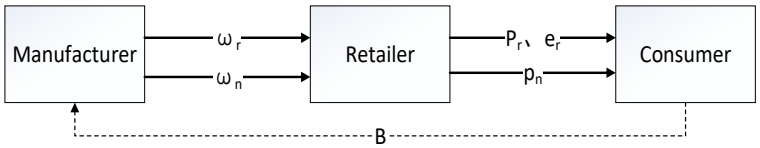


Figure 1 Closed loop supply chain structure diagram.

Based on the actual situation and relevant literature, the following assumptions are made:

Hypothesis 1: In the closed-loop supply chain, each member has completely symmetrical information and neutral preference for market risk. The Stackelberg game is dominated by the manufacturer, and the decision-making goal is to maximize their respective profits [5-6].

Hypothesis 2: Assume that only a single product category is considered, and the market is relatively mature, with enough old products available for recycling and remanufacturing, and consumers buy only one new product or remanufactured product[4].

Hypothesis 3: Assumed that the new product and the remanufactured product have the same specifications, quality and function, but the manufacturing materials are different, so the consumer preferences for the new product and the remanufactured product are different[6].

Hypothesis 4: Assumed that the quality of the recycled products can be remanufactured, the manufacturer passes the quality assessment, and the consumers have different recycling subsidies.

The meanings of relevant parameters of the model are shown in Table 1.

Table 1 Explanation of related variables.

Symbols	Definition
p_n, p_r	The unit retail price of new/remanufactured products
Cn	Unit production cost of new products
Cr	Unit production cost of remanufactured products, $C_r = C_n - C_s q$, C_s is the remanufacturing cost factor, expressed as the degree of influence of the quality of recycled goods on the remanufacturing cost
ϖ_n, ϖ_r	The unit wholesale price of new/ remanufactured products
e_r	Retailer CSR investment level
q	Quality level of recycled waste product $q \in (0,1)$,
B	Recycling price for manufacturers to recycle waste products $B = \sigma q, \sigma > 0$ indicates the maximum recovery price per unit that the manufacturer is willing to pay
G	Number of discarded products recycled by the manufacturer, $G = h + kB$, h Indicates the number of waste products that consumers participate in recycling without compensation, $k > 0$ Indicates the recovery price sensitivity factor
Π_i^j	Profit of closed-loop supply chain member i in model j, $i = M, R$; $j = C, D$

Assuming that the total market size is Q, The willingness to pay for new products is θ, $\theta \epsilon [0.1]$, and the willingness to pay for remanufactured products is $\alpha\theta$. $\alpha \epsilon (0,1]$ is the degree of consumer preference for remanufactured products. Due to consumers' concerns about the quality of remanufactured products, their recognition is low. In order to improve consumers' recognition of remanufactured products, retailers will assume corresponding corporate social responsibility for the sales of remanufactured products, and the corporate social responsibility input conducted is e_r, The reference[8] points out that when the CSR of the retailer's investment level of remanufactured product is e_r, the willingness of consumers to pay for remanufactured product will increase by $\beta\alpha^2 e_r$, $\beta > 0$ refers to the level of consumer sensitivity to corporate social responsibility. Consumers' willingness to pay for recycled goods increased to $\alpha\theta + \beta\alpha^2 e_r$.

At this point, the utility functions of consumers to purchase the unit of new products and remanufactured products are $U_n = \theta - p_n, U_r = \alpha\theta - p_r + \beta\alpha^2 e_r$. The demand for new and remanufactured products is $D_n = Q - \frac{p_n - p_r + \beta\alpha^2 e_r}{1-\alpha}, D_r = \frac{\alpha p_n - p_r + \beta\alpha^2 e_r}{\alpha(1-\alpha)}$. When retailers make

CSR investments, the additional costs to be borne are $C(e_r) = \frac{1}{2}\mu e_r^2$,$\mu$ indicates the cost scale parameter of the retailer's CSR.

In order to ensure that recycling is economically viable for manufacturers,$B \leq C_n - C_r$, That is, $\sigma \leq C_s$ manufacturer will remanufacturing the production.

3 MODEL FORMULATION

3.1 Centralized Pricing Decision Model

Considering the connection between the upstream and downstream enterprises of the closed-loop supply chain, the income function of the whole closed-loop supply chain system considered by the system is:

$$\Pi^C = (p_n - C_n)D_n + (p_r - C_r)D_r - C(e_r) \tag{1}$$

The optimal solution under the centralized decision model can be derived by the inverse recursive method, as shown in Table 2.

3.2 Decentralized Pricing Decision Model

Under the decentralized decision-making mode, the profits of all participants in the closed-loop supply chain are:

$$\Pi_m^D = (\varpi_n - C_n)D_n + (\varpi_r - C_r)D_r \tag{2}$$

$$\Pi_r^D = (p_n - \varpi_n)D_n + (p_r - \varpi_r)D_r - C(e_r) \tag{3}$$

The equilibrium optimal solution is shown in Table 2.When $\mu > \frac{\alpha^3\beta^2}{2(1-\alpha)}$, It can be decided that Π_r^R is a strictly concave function with respect to p_n,p_r,e_r,and Π_m^R is a strictly concave function with respect to ϖ_n,ϖ_r, and there exists a unique optimal solution.

Table 2 Optimal decision of each participating system in closed-loop supply chain.

	Decentralized decision-making（*）	Centralized decision-making（**）
ϖ_n^*	$\frac{Q + C_n}{2}$	-
ϖ_r^*	$\frac{\alpha Q + C_n - C_s q}{2}$	-
p_n^*	$\frac{3Q + C_n}{4}$	$\frac{Q + C_n}{2}$

p_r^*	$\frac{3\alpha Q}{4}+\frac{\alpha^3\beta^2(2C_sq-(2-\alpha)C_n)}{4(2\mu-(\alpha^3\beta^2+2\mu\alpha))}$ $+\frac{\mu(C_n-C_sq)(1-\alpha)}{2(2\mu-(\alpha^3\beta^2+2\mu\alpha))}$	$\frac{(C_n-C_sq)(\mu-\alpha\mu-\alpha^3\beta^2)}{2\mu-(\alpha^3\beta^2+2\mu\alpha)}$ $+\frac{\alpha\mu Q(1-\alpha)}{2\mu-(\alpha^3\beta^2+2\mu\alpha)}$ $-\frac{\alpha^4\beta^2(Q-C_n)}{2(2\mu-(\alpha^3\beta^2+2\mu\alpha))}$
e_r^*	$\frac{\alpha\beta(\alpha C_n-(C_n-C_sq))}{2(2\mu-(\alpha^3\beta^2+2\mu\alpha))}$	$\frac{\alpha\beta(\alpha C_n-(C_n-C_sq))}{2\mu-(\alpha^3\beta^2+2\mu\alpha)}$
D_n^*	$\frac{Q}{4}+\frac{\alpha^3\beta^2C_n-2\mu C_sq}{4(2\mu-(\alpha^3\beta^2+2\mu\alpha))}$	$\frac{Q}{2}+\frac{\alpha^3\beta^2C_n-2\mu C_sq}{2(2\mu-(\alpha^3\beta^2+2\mu\alpha))}$
D_r^*	$\frac{\mu(C_sq-(1-\alpha)C_n)}{2\alpha(2\mu-(\alpha^3\beta^2+2\mu\alpha))}$	$\frac{\mu((\alpha C_n-(C_n-C_sq))}{\alpha(2\mu-(\alpha^3\beta^2+2\mu\alpha))}$
Π_r^*	$\frac{Q(Q-2C_n)}{8}$ $+\frac{C_n(4\mu C_sq-C_n(2\mu+\alpha^3\beta^2))}{16(2\mu-(\alpha^3\beta^2+2\mu\alpha))}$ $+\frac{\mu(C_n-C_sq)^2}{16\alpha(2\mu-(\alpha^3\beta^2+2\mu\alpha))}$	-
Π_m^*	$\frac{Q(Q-2C_n)}{8}$ $+\frac{\mu C_n(1-\alpha)(C_n-2C_sq)}{4\alpha\left(2\mu-(\alpha^3\beta^2+2\mu\alpha)\right)}$ $-\frac{\alpha^4\beta^2C_n^2-C_s^2q^2}{8\alpha\left(2\mu-(\alpha^3\beta^2+2\mu\alpha)\right)}$ $-\sigma q(h+k\sigma q)$	-
Π_s^*	$\frac{3Q(Q-2C_n)}{16}-\frac{3\alpha^3\beta^2C_n^2}{16\left(2\mu-(\alpha^3\beta^2+2\mu\alpha)\right)}$ $+\frac{3\mu\left(C_s^2q^2+C_n(1-\alpha)(C_n-2C_sq)\right)}{8\left(2\mu-(\alpha^3\beta^2+2\mu\alpha)\right)}$ $-\sigma q(h+k\sigma q)$	$\frac{Q(Q-2C_n)}{4}-\frac{\alpha^3\beta^2C_n^2}{4\alpha\left(2\mu-(\alpha^3\beta^2+2\mu\alpha)\right)}$ $+\frac{\mu\left(C_s^2q^2+C_n(1-\alpha)(C_n-2C_sq)\right)}{2\alpha\left(2\mu-(\alpha^3\beta^2+2\mu\alpha)\right)}$ $-\sigma q(h+k\sigma q)$

4 MODEL ANALYSIS

Conclusion 1: Compared with decentralized decision-making, the selling price of new products and remanufactured products under centralized decision-making is lower, the market demand for new products and remanufactured products is higher, and the profit of the whole supply chain is higher, promoting the maximization of overall benefits and achieving win-win cooperation for both sides of the supply chain.

Proof: $p_n^{**}<p_n^*,\ p_r^{**}<p_r^*,\ D_n^{**}>D_n^*,\ D_r^{**}>D_r^*,\ \Pi_s^{**}>\Pi_s^*$.

Conclusion 2: The wholesale and retail prices of recycled products and the market demand for new products are negatively correlated with the quality of recycled products, while the social responsibility input of retailers, the market demand for remanufactured products, and the income

of retailers and manufacturers are positively correlated with the quality of recycled products.

Proof:$\frac{\partial \varpi_r^*}{\partial q} < 0,\ \frac{\partial p_r^*}{\partial q} < 0,\ \frac{\partial e_r^*}{\partial q} > 0,\ \frac{\partial D_n^*}{\partial q} < 0,\ \frac{\partial D_r^*}{\partial q} > 0,$

$\frac{\partial \Pi_r^*}{\partial q} > 0,\ \frac{\partial \Pi_m^*}{\partial q} > 0.$

Conclusion 3: Wholesale price of remanufactured goods, retail price, CSR input of retailers, market demand for remanufactured goods and remanufactured goods preference are positively correlated, while market demand for new products and remanufacturing preference are negatively correlated.

Proof:$\frac{\partial \varpi_r^*}{\partial \alpha} > 0,\ \frac{\partial p_r^*}{\partial \alpha} > 0, \frac{\partial e_r^*}{\partial \alpha} > 0, \frac{\partial D_n^*}{\partial \alpha} < 0, \frac{\partial D_r^*}{\partial \alpha} > 0.$

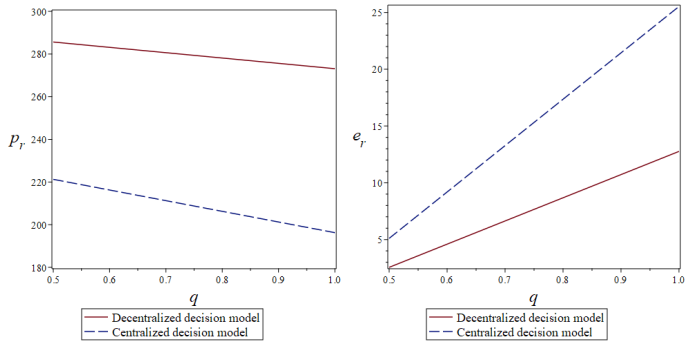
Conclusion 4: The wholesale price of new and remanufactured products and the retail price of new products are not related to consumer sensitivity to CSR, while the retail price of remanufactured products, retailer CSR input, market demand for remanufactured products, and retailer and manufacturer revenue are all positively related to consumer sensitivity to CSR, and market demand for new products is negatively related to consumer sensitivity to CSR.

Proof:$\frac{\partial p_r^*}{\partial \beta} > 0, \frac{\partial e_r^*}{\partial \beta} > 0, \frac{\partial D_r^*}{\partial \beta} > 0, \frac{\partial D_n^*}{\partial \beta} < 0, \frac{\partial \Pi_m^*}{\partial \beta} > 0,$

$\frac{\partial \Pi_r^*}{\partial \beta} > 0.$

5 NUMERICAL STUDIES

In order to verify the rationality and validity of the above findings, numerical analysis is conducted in this section, focusing on the impact of the quality of recycled products and consumer preferences for recycled products as well as the sensitivity of CSR on the equilibrium results of the supply chain. According to the relevant literature and the constraint assumptions $\alpha = 0.5, \beta = 3, C_n = 150, Q = 1000, C_s = 120, \mu = 10$,Numerical simulations were conducted using maple software to analyze the trend of the effect of recycled product quality on the retail price of recycled products, CSR inputs, product demand and supply chain revenue of the firm under the two decision models. q∈[0.5,1] in order to ensure that the variables were meaningful, as shown below.



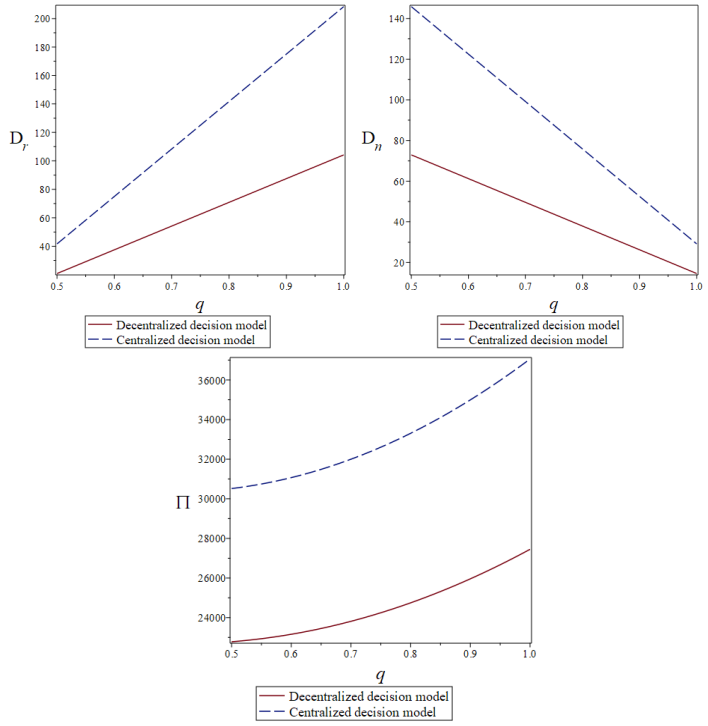


Figure 2 Impact on quality of recycled products q.

According to Figure 2, with the increase in the quality level of recycled products, consumers' enthusiasm to participate in recycling activities increases with the incentive of recycled product subsidies, saving the remanufacturing cost of the remanufacturing process, thus promoting the reduction of the price of remanufactured products and increasing the market share of remanufactured products, while retailers' CSR investment in recycled products, i.e. charity level, also increases, which has a positive impact on increasing the overall profit of the supply chain without affecting the price of new products.

When studying the influence trend of consumers' preference for the remanufactured product on the retail price of the remanufactured product, CSR input, product demand and supply chain income, in order to ensure that the variables have a meaningful $\alpha \in (0.6,0.8)$, as shown in the figure below.

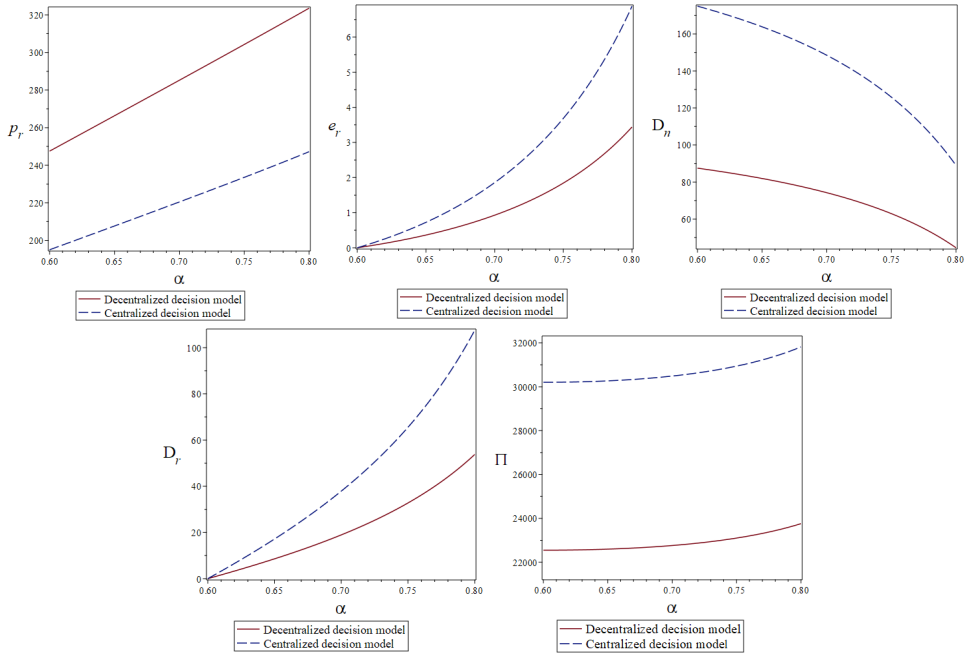
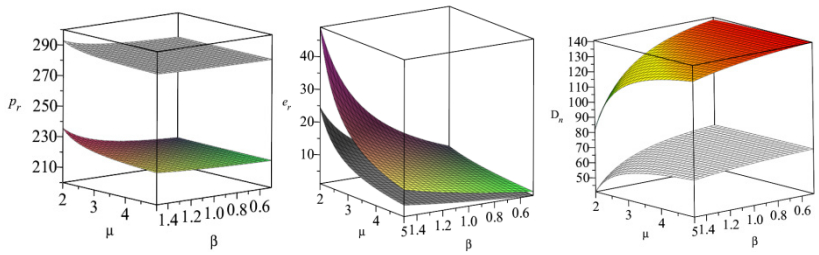


Figure 3 Consumers' preference for remanufactured products α impact.

As can be seen from Figure 3, under the two decision modes, with the increase of consumers' preference for the remanufactured product, the retail price of the remanufactured product and the CSR input of retailers will increase, and consumers' demand for the remanufactured product will also increase gradually. When consumers have the same preference for recycled goods, the retail price of centralized decision-making is lower, and retailers can gain a larger market share through the lower retail price, which has a positive impact on promoting the sales of remanufactured goods and the overall income of the supply chain.

In analyzing the trends of the effects of retailers' CSR input costs and consumer sensitivity on firms' retail prices of remanufactured products, CSR inputs, product demand, and supply chain revenue under the two decision models, in order to ensure that the variables are meaningful,$\beta \in [0.5,1.5]$,$\mu \in [2,5]$ As shown in the figure below：



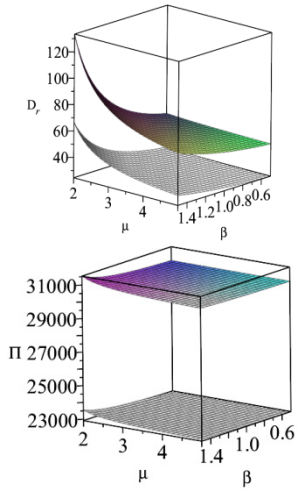


Figure 4 Retailer CSR input cost μ and consumer sensitivity coefficient β impact.

According to Figure 4, the retail price of recycled goods, the level of CSR input by retailers and the profit of the overall supply chain increase with the increase of consumer sensitivity, then the cost of CSR input will also increase accordingly, because consumers are willing to actively bear the CSR input by retailers, so the price increase does not affect the demand of recycled goods, while the increase of cost in the process of CSR input will reduce the corresponding enterprise The increase in the cost of CSR input process will reduce the corresponding CSR input of enterprises, resulting in a corresponding decrease in the market demand for recycled products, thus leading to a reduction in the overall profit of the closed-loop supply chain. Therefore, enterprises should focus on the innovation ability of member companies, reduce the cost consumption in the process of CSR input, and improve the efficiency of CSR input level, so that they can actively perform CSR behavior and improve their own profit at the same time.

From the simulation diagram and the above analysis, we can see that the centralized decision pricing model is better than the decentralized decision model.

6 CONCLUSION

Based on the consumer preferences of different products, this paper studies the impact of different recovery quality and retailers' CSR investment on the pricing of remanufactured products and the revenue of remanufactured supply chain. By building centralized and decentralized decision-making models, it provides reference for enterprises to make decisions. Through the analysis, the following conclusions are drawn:

Firstly, enterprises should pay attention to the efficiency of CSR inputs to reduce input costs while increasing consumer attention; secondly, the government and enterprises can conduct publicity to improve consumer awareness of recycled products and enhance consumer recognition and preference for recycled products; thirdly, since there is a relationship between retailers' social donations and the quality of recycled products, enterprises and the government

can make efforts to introduce relevant subsidies and welfare policies to encourage consumers to provide high-quality recycled goods, thereby improving retailers' CSR donation levels and closed-loop supply chain profits, forming a virtuous cycle.

In the research process, the comparison found that the centralized decision model is still the optimal decision, so the coordination mechanism of the supply chain can be further discussed in the subsequent research; at the same time, we only focused on the forward pricing study of recycled goods in the study, and the next step can be based on this to consider the optimal pricing study of recycled goods in the reverse recycling process.

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