Universe Scientific Publishing

Consider the Remanufactured Product Pricing Decisions of Green Preference Consumers

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Abstract: We consider the case that consumers have strong green preference, that is, consumers value remanufactured products more than new products. With the goal of maximizing the profit and social welfare of the original product manufacturer and the remanufacturer respectively, this paper study the impact of consumer green preference degree, optimal profit and maximum social welfare value were investigated by using two-stage Stackelberg game analysis and backward induction. The results show that: (1) With the increase of consumers' green preference, the optimal price of stage 2 products increases, and the price of remanufactured products increases significantly; However, the price of new products in stage 2 gradually decreases. In addition, with the increase of consumers' green preference, the profit value of the original product manufacturer decreases gradually, while the profit of the remanufacturer increases gradually. In addition, consumer surplus increases with the increase of green preference, but the growth rate is slow. 2) With the increase of consumers' green preference, the optimal pricing of new products shows a decreasing trend. However, there is a unique threshold to distinguish the influence of green preference coefficient on the optimal price of remanufactured products. When consumers' green preference is greater than the threshold, the optimal price of remanufactured products is positively correlated with it. Overall, the Original Product Manufacturer's profit decreases with the increase of consumers' green preference, while the remanufacturer's profit increases first and then decreases. When the goal is to maximize social welfare, the pricing of new products is the cost of new products, and the optimal pricing of remanufactured products increases gradually with the increase of consumers' green preference. When pursuing the maximization of social welfare, only the existence of external incentives can achieve the maximization of social welfare. Therefore, the accurate positioning of remanufactured products, the comprehensive understanding of consumers' preference for remanufactured products and appropriate government incentives have a significant impact on the optimal pricing decision of products and the profit of remanufacturers.

Keywords: Remanufacturing; Pricing Decision; Green Preference; Game Theory; Closed-Loop Supply Chain

Introduction

Environmental and resource issues have become the common concern of all mankind. Improving the green production of manufacturing industry and vigorously developing green remanufacturing industry are important ways to solve this problem. According to foreign statistics, green remanufacturing can reduce energy consumption by 50%, consumables by 85% and labor value by 33% on average. How to realize the harmonious development of nature and society is a severe challenge faced by human society. Therefore, the development strategy of sustainable development has been paid more and more attention by governments and enterprises. Thus, a closed-loop supply chain of "resource-production-consumption-resource regeneration" has been formed [1]. Effective closed-loop supply chain operation can better save resources, improve resource utilization, protect the environment, and achieve the strategic goal of sustainable development [2].

With the economic development and social progress, people's awareness of environmental protection is gradually enhanced. When consumers buy products, they not only consider the price, but also pay attention to the environmental protection concept of products. Wan Xiaoming et al. [3] believe that the use of remanufacturing technology is conducive to the construction of closed-loop system for natural ecological development. Shi Chunlai [4] studied the cooperative strategy selection of each member in the closed-loop supply chain system, and the results show that the cooperative mode is always beneficial to the increase of consumer surplus. Considering the government subsidy mechanism and supply interruption, Guo et al. [5] studied the optimal production and recycling strategies of enterprises in closed-loop supply chain. Aiming at the closed-loop supply chain system with market competition, Zhang and Zhou [6] studied the optimal pricing decisions of each member under decentralized and centralized decision-making, and realized the coordination of the closed-loop supply chain system composed of one manufacturer and two retailers through revenue sharing contract. For the green and sustainable supply chain, Cao et al. [7] studied the pricing decisions and supply chain system optimization of enterprises in competitive and cooperative environments. Alamdar et al. [8] used game theory and fuzzy theory to construct and compare six models, and found that the cooperative recycling model between original product manufacturers and remanufacturers was the most effective, and the cooperative relationship between enterprises was the most beneficial to consumers and the supply chain as a whole. Zheng Kejun [9] proposed a franchise fee contract that can support "double marginalization" and coordinate closed-loop supply chain, considering the price difference between new products and remanufactured products as well as the cost difference in the process of product recycling.

With the development of economy, consumers' demands are also diversified and differentiated, resulting in different purchase behaviors. Consumers' purchasing decisions are not only related to the product itself, but also influenced by consumer preferences. Based on consumers' preference for green brands, Tao Yuhong et al. [10] established a BP model and conducted quantitative analysis to study the formation and changing trend of green preference. Li Hong and Chen Jun [11] showed that consumers' awareness of green consumption affects the development of green operation of food enterprises. Conrad[12] constructed a duopoly competition game model to study how consumers' awareness of green environmental protection affects product prices and enterprises' market shares. Fanelli[13] extended this model by dividing consumers into two types: the common type and the green type, and established a two-stage heterogeneous duopoly game model for analysis. Liu et al. [14] divided three supply chain structure models according to whether there is alternative product competition and retailer competition, explored the alternative relationship between products and the impact of public's overall green preference on different enterprises, and found that the increase of public's green preference benefits retailers and environmentally friendly manufacturers, and as the competition among alternative products increases, As the degree of competition among alternative products increases, the profits of environmentally unfriendly enterprises gradually decline.

In today's information age, consumers in the market are no longer simple price takers, but active and active purchase decision makers. Therefore, in the market where new products and remanufactured products coexist, consumers will not only choose the ideal products, but also strategically choose the right time to buy, so as to maximize their own benefits. Based on the above background, this study uses Stackelberg game analysis method and backward induction method to study the closed-loop supply chain with remanufacturing activities. Faced with consumers with green preferences, Original product manufacturer (OPM) seeking profit maximization, and remanufacturer's optimal pricing decision, this paper analyzes the impact of consumers' green preferences on manufacturer's pricing decision and optimal profit.

1. Model establishment

This study constructs a basic model to describe the existence of an Original Product Manufacturer (OPM), a remanufacturer, and a large number of consumers with intertemporal purchase choice behavior and green preferences. The model consists of a two-stage decision. In a limited two-stage selling period, in the first stage, only OPM sells new products to consumers at a price p_1. Because remanufactured products are recycled and reprocessed, there are no remanufactured products in stage 1 market; In the second stage, OPM provides new products to consumers at a price p_2 that satisfies $p_2 < p_1$ [15-17], while the remanufacturer sells remanufactured products to consumers at a price p_r that satisfies $p_r < p_1$ [18]. It is assumed that each consumer buys at most one product and the market capacity is one.

The basic model focus on the situations where consumers value the remanufactured product higher than the new product ($\alpha > 1$). The symbols and definitions of the model are summarized in Table 1 below.

Table 1 Model symbols and definitions

p_1	Sales price of new products in the stage
p_2	Stage 2 Sales price of new products
p_r	Sales price of remanufactured products in stage 2
v	Consumers' valuation of the new product
U_1	The utility value of the new product at the purchase stage
U_2	The utility value of a consumer purchasing a new product in stage 2
U_r	The utility value of the consumer purchasing the stage 2 remanufactured product
α	Degree of green preference of consumers (intensity of environmental awareness)
δ	Consumers' cross-stage utility loss coefficient
C	consumer surplus

2. Consumer purchase and choice behavior and market demand analysis

2.1 Strong green preference

When the consumer's green preference coefficient $\alpha > 1$is satisfied, the customer group shows a strong green preference, and the valuation of environmental protection-related goods is higher than the valuation of ordinary new products. In this case, it is assumed $\alpha + \delta < 2$ that the coefficient of green preference is only slightly greater than 1 to meet the realistic situation.

Stage 1: Only OPM sells the new product in the market. If satisfied with$U_1 \geq 0$,$U_1 \geq U_2$ and $U_1 \geq U_r$, the customer chooses to immediately purchase the product offered in the current market, i.e

$$\begin{cases} v - p_1 \geq 0 \\ v - p_1 \geq \delta(v - p_2) \\ v - p_1 \geq \delta(\alpha v - p_r) \end{cases} \quad (2\text{-}1)$$

Let $v_1 = p_1$, $v_2 = \frac{p_1 - \delta p_2}{1-\delta}$ and $v_3 = \frac{p_1 - \delta p_r}{1-\alpha\delta}$, obtain:$v \geq v_1$, $v \geq v_2$and$v \geq v_3$, because $p_1 \geq p_2$, so $v_2 - v_1 = \frac{\delta(p_1 - p_2)}{1-\delta} \geq 0$. The relationship $v_2$and $v_3$determines the valuation range of consumers who immediately buy the new product in stage 1, which can be divided into the following two cases:

When $v_2 \geq v_3$,then$v_2 - v_3 = \frac{\delta((1-\delta)p_r - (1-\alpha\delta)p_2 - (\alpha-1)p_r)}{(1-\delta)(1-\alpha\delta)} \geq 0$.The customers whose valuation is in the range $[v_2,1]$ choose to purchase the products provided in the market immediately, while other customers at the end of the market delay their purchase decision. In stage 2, the market not only provides new products, but also introduces remanufactured products with environmental value. If satisfied $U_2 \geq 0$, $U_2 \geq U_r$,the first choice of the customer group is still the new product, i.e

$$\begin{cases} \delta(v - p_2) \geq 0 \\ \delta(v - p_2) \geq \delta(\alpha v - p_r) \end{cases} \quad (2\text{-}2)$$

Let $v_4 = p_2$,$v_5 = \frac{p_r - p_2}{\alpha - 1}$, can obtain: $v_4 \leq v \leq v_5$. If $v_5 - v_4 < 0$ then $p_r < \alpha p_2$, there is no consumer who chooses to buy new products in stage 2, that is the sales volume of new products in stage 2 OPM is 0 . If $v_5 - v_4 \geq 0$, i.e. $p_r > \alpha p_2$, the consumers whose valuation is in the range $[v_4,v_2]$ choose to buy the new product in stage 2 because $v_2 - v_5 = \frac{(\alpha-1)p_1 + (1-\alpha\delta)p_2 - (1-\delta)p_r}{(1-\delta)(\alpha-1)} \leq 0$.

Similarly, if satisfied with $U_r \geq 0$and $U_r \geq U_2$, the consumer chooses to remanufacture the product, i.e

$$\begin{cases} \delta(\alpha v - p_r) \geq 0 \\ \delta(\alpha v - p_r) \geq \delta(v - p_2) \end{cases} \quad (2\text{-}3)$$

Let $v_6 = \frac{p_r}{\alpha}$ then we can get that $v \geq v_5$ and $v \geq v_6$. If $v_5 - v_6 < 0$, i.e. $p_r < \alpha p_2$, we know that there are no consumers who choose to buy the new product in stage 2, that is, the sales volume of the new product in stage 2 OPM is 0. And because $v_6 > v_5 \geq v_2$, the sales volume of remanufactured products in stage 2 is also 0; If $v_5 - v_6 \geq 0$, i.e.$p_r \geq \alpha p_2$, the sales volume of the remanufactured product is still 0, and the consumer with valuation in the range $[v_4, v_2]$ chooses to buy the new product in stage 2 because $v_2 - v_5 \leq 0$.

Therefore, when the green preference coefficient α of consumers is greater than 1, and $v_2 \geq v_3$, if the remanufacturer adopts the high-price strategy ($p_r \geq \alpha p_2$), the customers with valuation in the range $[v_2,1]$ prefer the new products currently provided in the market, and the customers with valuation in the range $[v_4, v_2]$ think it is best to delay the purchase of new products, and the sales volume of remanufactured products with environmental protection functions is 0; If the remanufacturer adopts the low-price strategy ($p_r < \alpha p_2$), the customers with the valuation in the range $[v_2,1]$ still prefer the new products currently offered in the market, and the sales volume of any product in stage 2 is 0. Therefore, no matter the remanufacturer adopts the strategy of high price or low price, there is no demand for the remanufactured products. In this case, the remanufacturer exits the market.

When $v_2 < v_3$, namely $v_2 - v_3 = \frac{\delta((1-\delta)p_r-(1-\alpha\delta)p_2-(\alpha-1)p_1)}{(1-\delta)(1-\alpha\delta)} < 0$, consumers with valuation in the range $[v_3,1]$ choose to purchase the new product immediately in stage 1, while consumers with valuation in the range $[0, v_3]$ postpone their purchase decision to stage 2.

In stage 2, the market not only provides new products, but also introduces remanufactured products with environmental value. If satisfied $U_2 \geq 0$ and $U_2 \geq U_r$, customers take the new product as the best option. Solve (2-2) to obtain $v_4 \leq v \leq v_5$. If $v_5 - v_4 < 0$, namely $p_r < \alpha p_2$, there are no consumers who choose to buy new products in stage 2, that is, the sales volume of new products in stage 2 OPM is 0; If $v_5 - v_4 > 0$, that is $p_r > \alpha p_2$, the consumers whose valuation is in the range $[v_4, v_5]$ choose to buy the new product in stage 2, because.$v_3 - v_5 = \frac{((\alpha-1)p_1-(1-\delta)p_r+(1-\alpha\delta)p_2)}{(1-\alpha\delta)(\alpha-1)} > 0$.

Similarly, the remanufactured product becomes the customer's first choice if it satisfies $U_r \geq 0$ and $U_r \geq U_2$. Solving (2-3) yields that $v \geq v_5$ and $v \geq v_6$. If . $v_5 - v_6 < 0$, i.e.$p_r < \alpha p_2$, we know that there are no customers who choose stage 2, that is $v_5 < v_6 < v_3$, the sales volume of new products of OPM in Stage 2 is 0, since, the consumers whose valuation is in the range $[v_6, v_3]$ choose to purchase remanufactured products in stage 2. If $p_r > \alpha p_2$, the consumers with valuation in the range $[v_4, v_5]$ choose the new product, the consumers with valuation in the range $[v_5, v_3]$ choose the remanufactured product with environmental significance.

Therefore, when the green preference coefficient of consumers is greater than 1 and $v_2 < v_3$, if the remanufacturer adopts the high-price strategy ($p_r > \alpha p_2$), the customers with valuation in the range $[v_3, 1]$ choose the current product, the customers with valuation in the range $[v_4, v_5]$ postpone purchasing the new product, and the customers with valuation in the range $[v_5, v_3]$ choose the remanufactured product as the best choice; If the remanufacturer adopts the low-price strategy ($p_r < \alpha p_2$), the customer with valuation in the range $[v_3, 1]$ still chooses the current product, and the customer with valuation in the range $[v_6, v_3]$ chooses the remanufactured product with significance, and the sales volume of the new product in stage 2 is 0. Only when $v_2 < v_3$ and the remanufacturer adopts the high-price strategy, the demand for the new product will be generated in each stage, and the demand for the remanufactured product will also be generated in stage 2.

The profit of the original product manufacturer comes from the new products sold in stage 1 and stage 2, while the profit of the remanufacturer comes from the remanufactured products sold in stage 2. Therefore, the respective profit equation can be written as follows:

OPM:

$$\pi_M = (p_1 - c_n)D_{M1}(p_1, p_2) + (p_2 - c_n)D_{M2}(p_1, p_2) \quad (2\text{-}4)$$

Remanufacturer:

$$\pi_R = (p_r - c_r)D_{R2}(p_r) \quad (2\text{-}5)$$

According to the assumptions of the basic model, the remanufactured products in stage 2 come from the recycling and reprocessing of the sold products in Stage 1, and only part of the used products meet the recycling and remanufacturing conditions, so the demand for remanufactured products meets the restrictive conditions $D_{R2}(p_r) < D_{M1}(p_1, p_2)$.

2.2 Consumer surplus

By analyzing the utility values generated in different stages and consumers' choice behaviors, consumer surplus is expressed as:

$$C = \int_{v_3}^{1} (v - p_1)\, dv + \int_{v_5}^{v_3} \delta(\alpha v - p_r)\, dv + \int_{v_4}^{v_5} \delta(v - p_2)\, dv = \frac{1}{2} - p_1 + \frac{(p_1-\delta p_r)^2}{2(1-\alpha\delta)} + \frac{\delta(\alpha p_2^2-2p_2 p_r+p_r^2)}{2(\alpha-1)} \quad (2\text{-}6)$$

Of which $v_3 = \frac{p_1-\delta p_r}{1-\alpha\delta}, v_4 = p_2 v_5 = \frac{p_r-p_2}{\alpha-1}$. The optimal prices of the two-stage products p_1^*, p_2^* and p_r^* are substituted into Equations (2-3) to obtain consumer surplus C^*. We can also obtain the social welfare value when enterprises pursue their own profit maximization, that is the sum of consumer surplus and the profit of OPM and remanufacturer:

$$SW = C^* + \pi_M^* + \pi_R^* \qquad (2\text{-}7)$$

2.3 Maximize social welfare

When consumers and enterprises as a whole , the goal equation of pursuing maximum social welfare is expressed as follows:

$$\max_{p_1,p_2,p_r} \pi_{SW} = C + \pi_M + \pi_R = \frac{1}{2} - c_n + \frac{2p_1p_r - p_1^2 - \delta(2-\delta)p_r^2}{2(1-\alpha\delta)} + \frac{(p_1-\delta p_r)(c_n-c_r)}{1-\alpha\delta} + (\delta-2)\frac{p_2^2+p_r^2-2p_2p_r}{2(\alpha-1)} + \frac{(\delta-2)p_2^2+2c_np_2}{2} - (c_n-c_r)\frac{p_r-p_2}{\alpha-1}$$

(2-8)

Proposition: The social welfare equation is a joint concave function of the price of new products and the price of remanufactured products in stage 1 and stage 2. The optimal product pricing with the maximum value of social welfare is:

$$SW_{p_1}^* = \frac{(2-\alpha\delta-\delta)c_n - (1-\delta)c_n}{2-\alpha-\delta}$$

$$SW_{p_2}^* = \frac{(4\delta-4-\delta^2+\alpha)c_n + (1-\delta)c_r}{(2-\alpha-\delta)(\delta-2)}$$

$$SW_{p_r}^* = \frac{\alpha(1-\delta)c_n + (1-\alpha)c_r}{2-\alpha-\delta}$$

Proof: Solve the second derivative of the social welfare equation with respect to the price of new products and the price of remanufactured products in stage 1 and stage 2, and obtain:

$$|H_1| = \frac{\partial^2\pi}{\partial p_1^2} = -\frac{1}{1-\alpha\delta} < 0$$

$$|H_2| = \begin{vmatrix} \frac{\partial^2\pi}{\partial p_1^2} & \frac{\partial^2\pi}{\partial p_1 p_2} \\ \frac{\partial^2\pi}{\partial p_2 p_1} & \frac{\partial^2\pi}{\partial p_2^2} \end{vmatrix} = \frac{\alpha(2-\delta)}{(1-\alpha\delta)(\alpha-1)} > 0$$

$$|H_3| = \begin{vmatrix} \frac{\partial^2\pi}{\partial p_1^2} & \frac{\partial^2\pi}{\partial p_1 p_2} & \frac{\partial^2\pi}{\partial p_1 p_r} \\ \frac{\partial^2\pi}{\partial p_2 p_1} & \frac{\partial^2\pi}{\partial p_2^2} & \frac{\partial^2\pi}{\partial p_2 p_r} \\ \frac{\partial^2\pi}{\partial p_r p_1} & \frac{\partial^2\pi}{\partial p_r p_2} & \frac{\partial^2\pi}{\partial p_r^2} \end{vmatrix} = \frac{(2-\delta)(\alpha+\delta-2)}{(\alpha-1)(1-\alpha\delta)^2} < 0$$

Since $|H_1| < 0, |H_2| > 0$ and $|H_3| < 0$, there is an optimal solution and the social welfare can be maximized $SW_{p_1}^* SW_{p_2}^* SW_{p_r}^*$.

Let $\frac{\partial\pi_{SW}}{\partial p_1} = 0$, $\frac{\partial\pi_{SW}}{\partial p_2} = 0$ and $\frac{\partial\pi_{SW}}{\partial p_r} = 0$, i.e

$$\begin{cases} p_r - p_1 + c_n - c_r = 0 \\ \alpha(\delta-2)p_2 - (\delta-2)p_r + \alpha c_n - c_r = 0 \\ (\alpha-1)p_1 - (1-\alpha\delta)(\delta-2)p_2 + (\delta-2)(1-\delta)p_r - (1-\delta)(c_n-c_r) = 0 \end{cases}$$

Solving the above equation, the optimal product price that maximizes social welfare can be obtained as follows:

$$SW_{p_1}^* = \frac{(2-\alpha\delta-\delta)c_n - (1-\delta)c_n}{2-\alpha-\delta}$$

$$SW_{p_2}^* = \frac{(4\delta-4-\delta^2+\alpha)c_n + (1-\delta)c_r}{(2-\alpha-\delta)(\delta-2)}$$

$$SW_{p_r}^* = \frac{\alpha(1-\delta)c_n + (1-\alpha)c_r}{2-\alpha-\delta}$$

The certificate is completed.

Observing the above optimal solution, it can be found that when the maximization of social welfare is pursued, if the optimal solution satisfies $\alpha c_n > c_r$, then the maximization of social welfare can only be achieved in the presence of external incentives $SW_{p_1}^* > SW_{p_2}^* > c_n, SW_{p_r}^* > c_r$.

3. Conclusion and prospect

Product recycling is one of the effective ways to achieve sustainable economic, social and environmental development, which not only has obvious economic benefits, but also can meet the increasing awareness of environmental protection and differentiated needs of consumers. This paper focuses on the core decision-making problems of original product manufacturers (OPM) and remanufacturers based on the unique problems of remanufacturing industry and the multiple purchasing behaviors of consumers. The results show that the strengthening of consumers' green preference is beneficial for remanufacturers to increase product prices and obtain higher profits. However, considering the competition among alternative products, when consumers' green preference is high, remanufacturers should take measures to reduce prices to maintain their price advantage. In most cases, the strengthening of green consumer preference leads OPM to adopt a price reduction strategy to stimulate consumers to buy immediately. Due to the price reduction of new products, the price advantage of remanufactured products is not obvious, so it also reduces the price. In general, the influence of consumers' green preference behavior on OPM is greater than that on remanufacturers, and the change degree of the optimal price of new products is greater than that of remanufactured products. Therefore, OPM need to be fully considered the impact of consumer behavior and the impact of government incentives.

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