Research on Differentiated Rebate Decision-Making Under the Closed-Loop Supply Chain Based on "Trade-Old-for-Remanufactured" and "Trade-Old-for-New"

Junhua Guo* Dan Huang

School of Transportation and Logistics, East China Jiaotong University, Nanchang, China
**Corresponding author. Email: zwx0716@163. com*

ABSTRACT
Aiming at the single-stage closed-loop supply chain system, in the context of the implementation of the "replacement of old" policy, it is analyzed that the same rebate or differential rebate should be provided to consumers under the situation that enterprises simultaneously "replace the old for new (re)". Two models have been designed to explore how companies plan to rebate consumers to achieve the best benefits of the closed-loop supply chain. Use Stackelberg's method to discuss the decisions of manufacturers and retailers. The conclusion shows that companies providing consumers with rebates will increase consumption and expand the company's market share; moreover, setting differential rebates within a certain threshold can optimize the profits and total profits of supply chain members, and the government can give manufacturers corresponding remanufacturing subsidies to promote consumption Participation in the "replacement of old products for reuse" is conducive to the promotion of reproduced products and can increase social welfare

Keywords: *Trade-old-for-new, Trade-old-for-remanufactured, Business rebates, Government subsidy.*

1. INTRODUCTION

Due to the rapid development of social economy, the environmental and resource problems facing human beings are becoming more and more severe. Although the advancement of science and technology has improved people's quality of life, it has also brought many problems. For example, the continuous upgrading of electronic products has led to a sharp increase in the number of waste products. And most of the waste products are directly processed without recycling. How to properly dispose of waste products is an important issue that the country needs to face. The correct recycling and disposal of waste home appliances and reducing electronic pollution require the joint efforts of the government, enterprises and the public [1].

Based on this, the research of closed-loop supply chain has received widespread attention. Closed-loop supply chain plays an important role in saving energy consumption and reducing environmental pollution[2]. It can be realized through the design, control and operation of the system in the entire life cycle. Maximize the value of. Many countries around the world have long been aware of energy shortages and environmental pollution problems, and have long issued policies to implement the recycling of waste products. Japan is currently the country with the highest recycling rate of waste home appliances in the world. As early as 2015, China promulgated the "Remanufactured Products "Replacement of Old for Re" Pilot Implementation Plan" and "Replacement of Old for Renew Policy" [3], and in 2009, it launched the old-for-new activities for used home appliances and scrapped cars. Give certain subsidies to consumers who participate in trade-in, stimulate consumers to actively participate in trade-in, promote the development of the automobile market, facilitate the upgrading of automobile products, and relieve the environmental pressure caused by scrap cars to a certain extent.

Trade-in has brought certain economic benefits to the closed-loop supply chain, but the environmental benefits are relatively weak [4]. Most companies directly treat the recycled waste products in a unified manner and do not reuse them. How to maximize the recycling rate of recycled materials and maximize the economic benefits and social welfare of the closed-loop supply chain. Remanufacturing is the most effective way to recycle and reuse products [5, 6]. Remanufacturing refers to professionally repairing waste products (such as parts and components, mechanical equipment, etc.) to make them the same as new products. The process of quality and performance [7]. Compared with new products, remanufactured products can save materials by 70%, save energy by 60%, save costs by 50%, and reduce pollutant emissions by more than 80% [8]. In May 2015, "Made in China 2025" determined my country’s overall strategy for building a strong manufacturing nation at the national level, proposed to fully implement green manufacturing, vigorously develop the remanufacturing industry, implement high-end remanufacturing, intelligent remanufacturing, and in-service remanufacturing to promote Product certification promotes the sustainable and healthy development of the remanufacturing industry. As an emerging strategic industry in my country, the remanufacturing industry is an important part of green manufacturing and an effective way to achieve energy conservation and emission reduction and promote the development of circular economy. Because the government strongly supports remanufacturing, many companies have joined remanufacturing, but because the acceptance of remanufactured products in the consumer market is low, the marketing of remanufactured products is a very important issue.

Many scholars at home and abroad have systematically studied the trade-in and trade-in. The old trade-in mainly studies pricing decisions and recycling methods. In the form of recycling, Miao Chaowei et al. [9] based on the closed-loop supply chain with the participation of third-party recyclers and discussed three Two-stage consumer purchasing decision behavior in a closed-loop supply chain of this model, and analyzed the most favorable model for the closed-loop supply chain system involving manufacturers and third-party recyclers. Zhu Xiaodong and Wu Bingbing studied the online and offline dual-channel recycling model and found that the product recycling price is proportional to the remanufacturing ratio in the product[10], and it is also proportional to the consumer recycling price sensitivity coefficient. For the pricing decision of trade-in, Yin et al. [11] compared the impact of three trade-in pricing strategies on corporate profits.

The current research on trade-in is mainly about the pricing of remanufactured and new products and the difference in consumers' willingness to pay. Han Xiaohua et al. [12] studied the implementation conditions of the "replacement of old" strategy, and analyzed the pricing and coordination strategies of manufacturers and retailers. Meng Lijun et al. [13] aimed at the manufacturer's only oligopoly market competition structure and introduced recycling risks, and established mathematical models for the closed-loop supply chain of manufacturers (OEMs) recycling waste products by themselves and the closed-loop supply chain of third-party recyclers recycling waste products [14]. Analyze the optimal differential pricing rules of each enterprise.

There have been some studies on the promotion strategy of trade-in (re). Ma Weimin et al. [15] deeply studied the impact of trade-in subsidies on various closed-loop supply chain channels, including consumers, the scale of the closed-loop supply chain and the impact of enterprises, and refined four types The closed-loop supply chain model compares and analyzes the impact of trade-in subsidies on consumers, supply chains and enterprises. Li Xinran, Wu Yibiao et al. [16] based on previous studies on government incentives for recycling and remanufacturing of waste products, and based on the government’s “replacement of old” policy, considering whether there are reproducts with differential pricing between new products and reproducts under government subsidies. For sales promotion, it analyzes the optimal pricing decision of a closed-loop supply chain with or without government subsidies, and discusses the government's “replacement of old” subsidies. Cao Jian et al. [17] analyzed the relationship between manufacturers' remanufacturing rate and other factors and government subsidies and taxes. [18]Gao Pan and Ding Xuefeng subdivided consumers into original consumers and new consumers under the background of “replacement of old” government subsidies, and studied the production and pricing strategies of manufacturers.

Different from previous studies, this article analyzes that under the premise of government subsidies for manufacturers participating in remanufacturing, companies should give the same rebate or difference rebate to consumers who participate in the trade-in (re)consumer. Compare the two models which can bring more to the closed-loop supply chain. Multi-profit and maximum environmental benefits.

2. MODEL DESCRIPTION AND BASIC ASSUMPTIONS

When the initial consumers (who have old products in their hands) have three strategic choices in the new consumption cycle, the article research company has three strategic choices. One is to continue to use the old products in their hands; the other is to participate in the "replacement of old products". The old products get a certain rebate before buying new products. The third is to participate in the "replacement of old", the enterprise provides rebates to consumers, whether the government sets up differentiated rebates under the condition of certain remanufacturing subsidies to manufacturers, and whether the differentiated rebates Can bring more benefits to the closed-loop supply chain, which is the main problem studied in this article. The market structure is shown in Figure 1. For the government, in order to reuse resources and maximize environmental benefits, the government will provide subsidies to remanufacturers to actively participate in the production of remanufactured products; for enterprises, provide consumers with trade-in) Rebates can stimulate consumer demand, promote product upgrading, and expand market share; for consumers, the main purpose of participating in trade-in (re) is to maximize their own interests.

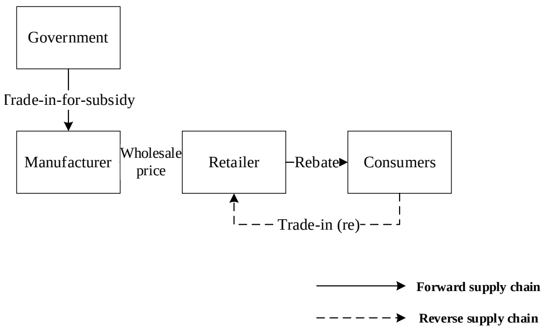

Figure 1 Market structure

The initial consumers in the market have already consumed the product and have an objective evaluation of the effectiveness of the product. Suppose the initial consumer's evaluation of the new product is v, (v obeys the uniform distribution of $[0,1]$, 1 for its greatest value evaluation), And the consumer's discount on the value of the old product is α, Value evaluation is αv; The consumer's discount on the value of the reproduced product is δ, Value evaluation is δv. In a closed-loop supply chain, the costs of new products and re-products are respectively $c_n c_r$, Manufacturers at wholesale prices $w_n w_r$ Wholesale new products and remanufactured products to retailers, Retailers sell to consumers at retail prices $p_n p_r$, And suppose $c_n > c_r > 0$, Reflect the cost-saving advantage of rework. In the reverse supply chain, the manufacturer recycles waste products from the retailer at a unit recycling price A, and the retailer recycles the waste products to consumers in the form of rebates. (To make the retailer profitable, suppose in model S, $A > s_a$; in model D, $A > s_t$ and $A > s_r$), In this article, we use U_u, U_t and U_r to represent the utility of original consumers continuing to use old products and participating in trade-in (re).

The basic assumptions of this article are as follows:

Assumption1: This article only considers a single consumer, and the original consumer already owns an old product and will not give up using the product. The role of the waste product is that the consumer can participate in the trade-in (re)2:

Assumption2: There is a Stackelberg game relationship between the manufacturer and the retailer, and the manufacturer is the market leader and the retailer is the market follower.

Assumption3: The function, quality and utility of the rework are exactly the same as the new product, but the rework needs to be affixed with a unique label for the rework to let consumers know that it is a rework, and the rework and the new product enter the market in the same way.

Assumption4: The utility of remanufactured products to consumers is lower than that of new products, but higher than that of old products. is $0<\alpha<\beta<1$, This assumption has been adopted in many existing literatures [19-21].

Assumption5: In order to encourage manufacturers to actively participate in remanufacturing, it is assumed that the government subsidies to remanufacturers should be greater than the enterprise's rebates for participating in trade-in (re)consumersis $s_g > s_a$, $s_g > s_t$, $s_g > s_r$

Table 1. Description of symbols in this article

Symbol	Symbol Description
U_t, U_r	Consumers continue to use old products and participate in the utility of trade-in (re)
v	Consumers' evaluation of the value of new products
α	Consumer discounts on old products
δ	Consumer discounts on reproductive reviews
q_t, q_r	Trade-in (re)demand
p_n, p_r	New product and remanufactured prices
w_n, w_r	Wholesale prices of new products and remanufactured products
c_n, c_r	New product and reproduct production cost
A	Manufacturer's unit recycling price for recycling waste products
s_a	In Model*S*, the retailer provides consumers with rebates for participating in the trade-in (re)

s_t, s_r	In Model*D*, the retailer provides consumers with rebates for participating in trade-in (re)respectively
s_g	Remanufacturing subsidies provided by the government to manufacturers

3. DECISION, MODEL AND ANALYSIS

This article will set up two different rebate models, Model S is for consumers to participate in the trade-in (re)rebate for s_a, model D shows that the rebate for consumers participating in trade-in is s_t, the rebate obtained by consumers participating in the exchange is s_r. then study the same and difference rebate model, which brings different benefits to the closed-loop supply chain.

3.1. ModelS: The Same Rebate Situation

Suppose the initial consumer's evaluation of the value of the new product is v, then the value utility of consumers buying new products is $U_n = v - p_n$, (v obeys the uniform distribution of [0, 1]), and the effect of continuing to use the old product is $U_u = \alpha v$, (α is the value discount of the consumer to the old product), the utility of initial consumer participation in trade-in is $U_t = v - p_n + s_a$. In order to encourage consumers to participate in trade-in and expand the company's market share, the company will pay certain rebates to consumers who participate in trade-in s_a. Available from $U_n \geq 0$ 、$U_t \geq U_u$ and $U_t \geq U_r$, can know $\begin{cases} v \leq 1 \\ v \geq \dfrac{p_n - s_a}{1-\alpha} \\ v \geq \dfrac{p_n - p_r}{1-\delta} \end{cases}$ due to $U_r > U_u$, So the demand for consumers to participate in trade-in is $q_t^S = \int_{\frac{p_n - p_r}{1-\delta}}^{1} 1dv = 1 - \dfrac{p_n - p_r}{1-\delta}$. The effect of initial consumer participation in trade-in is $U_r = \delta v - p_r + s_a$. ($\delta$ is the value discount of reproducts to new products). Available from $U_r \geq 0$、$U_r \geq U_t, U_r \geq U_u$, due to $\dfrac{p_r - s_a}{\delta - \alpha} \leq v \leq \dfrac{p_n - p_r}{1-\delta}$ and, $q_r^S = \int_{\frac{p_r - s_a}{\delta-\alpha}}^{\frac{p_n - p_r}{1-\delta}} 1dv = \dfrac{p_n - p_r}{1-\delta} - \dfrac{p_r - s_a}{\delta - \alpha}$.

Decentralized decision making

When the company sets the same rebate of s_a for the old trade-in (re), under the decentralized decision-making model, manufacturers and retailers take their profit maximization as their decision goals, and the manufacturer is the stackeberg leader [22]. The decision sequence is that the manufacturer first determines the wholesale price of new products and re-products w_n、w_r, and the retailer determines the selling price p_n、p_r. Using the reverse induction method, first consider the retailer's decision-making problem. The retailer's objective function is:

$$\underset{p_n p_r}{Max}\, \pi_R^S = (p_n - w_n + A - 2s_a)q_t + (p_r - w_r + A - 2s_a)q_r \quad (1)$$

$$s.t. 0 \leq q_t \leq q_n$$

$$\frac{\partial \pi_S^R}{\partial p_r} = \frac{p_n - 2p_r - w_n + w_r}{1-\delta} - \frac{2p_r - w_r - 3s_a + A}{\delta - \alpha}$$

$$\frac{\partial \pi_R^S}{\partial p_n} = \frac{-2p_n + 2p_r + w_n - w_r + 1 - \delta}{1\text{-}\delta} \quad (2)$$

Available retailer's response function:

$$p_n^S = \frac{w_n + 3s_a + 1 - \alpha + A}{2}$$

$$p_r^S = \frac{w_r + 3s_a + \delta - \alpha + A}{2} \quad (3)$$

Proved:

$$H_2 = \begin{vmatrix} \dfrac{-2}{1-\delta} & \dfrac{2}{1-\delta} \\ \dfrac{1}{1-\delta} & \dfrac{-2}{1-\delta} - \dfrac{2}{\delta - \alpha} \end{vmatrix} = \frac{2}{(1-\delta)^2} + \frac{4}{(1-\delta)+(\delta-\alpha)} > 0 \quad (4)$$

and $H_1 = \dfrac{-2}{1-\delta} < 0$, the Hessian matrix is negative definite, The profit function is concave, There is an optimal solution p_n, p_r, The profit of the manufacturer is the sum of the profit of new products and remanufactured products, At the same time, the government will give subsidies to remanufacturers s_g, The profit function is $\underset{w_n w_r}{Max}\, \pi_M^S = (w_n - c_n - A)q_t + (w_r - c_r + s_g - A)q_r$ Substituting the retailer's reaction function into the manufacturer's profit function.

According to its first-order conditions, the optimal wholesale price of the manufacturer's new products and remanufactured products is:

$$w_n^S = \frac{c_n - s_a + (1-\alpha) + 2A}{2}, \quad w_r^S = \frac{c_r - s_a - s_g - \alpha + \delta + 2A}{2}, \quad (5)$$

Similarly, the Hessian matrix can be used to judge that there is an optimal solution w_n、w_r

Substituting the manufacturer's optimal wholesale price into the retailer's response function, calculated by the Hessian matrix, there is an optimal solution, and the optimal retail price of new products and re-products can be obtained:

$$p_n^S = \frac{c_n + 5s_a + 3(1-\alpha)}{4}, \quad p_r^S = \frac{c_r + 5s_a - s_g + 3(\delta - \alpha)}{4} \tag{6}$$

Furthermore, the optimal profit of the manufacturer and retailer can be obtained as

$$\underset{p_n p_r}{Max}\,\pi_M^S = \frac{(1-\alpha)(cr-sg)^2}{8(1-\delta)(\delta-\alpha)} + \frac{s_a{}^2 + 2s_a(c_r - s_g)}{8(\delta-\alpha)} + \frac{c_n{}^2 - 2c_n(1-\delta+c_r-s_g) - 2(1-\delta)s_a}{8(1-\delta)}$$
$$\underset{p_n p_r}{Max}\,\pi_R^S = \frac{(1-\alpha)(cr-sg)^2}{16(1-\delta)(\delta-\alpha)} + \frac{s_a{}^2 + 2s_a(c_r - s_g)}{16(\delta-\alpha)} + \frac{c_n{}^2 - 2c_n(1-\delta+c_r-s_g) - 2(1-\delta)s_a}{16(1-\delta)} \tag{7}$$

Proposition1: Under the model S , The retail price p_n of new products and the retail price p_r of re-products are increasing functions of the rebate s_a , The wholesale price w_n of new products and the wholesale price w_r of re-products are a decreasing function of the rebate s_a .

$$\frac{\partial p_n^S}{\partial s_a} = \frac{\partial p_r^S}{\partial s_a} = \frac{5}{4} > 0, \quad \frac{\partial w_n^s}{\partial s_a} = \frac{\partial w_r^S}{\partial s_a} = -\frac{1}{2} < 0$$

Proposition 1 shows that if companies give appropriate rebates to consumers who participate in trade-in (re)consumers, the retailer's cost will be relatively higher, which will lead to higher wholesale prices and selling prices of new products and re-products. Since appropriate rebates can promote consumer participation in trade-in (re), and stimulate consumption enthusiasm, enterprises can occupy more market shares and promote the upgrading of new products; waste products can be recycled, energy saving and emission reduction can be achieved, and energy consumption can be reduced. Reduce the burden on the environment. Therefore, companies should give appropriate rebates to consumers participating in the trade-in (re)consumption.

As retailers provide consumers with rebates, operating costs will increase, but sales will also increase, and competition among manufacturers increases. Therefore, the wholesale price given to retailers by manufacturers will decrease as the rebates increase. This promotes the virtuous circle of the closed-loop supply chain, both upstream and downstream of the supply chain are profitable, and it promotes product upgrading.

Proposition2: In the case of the same rebate, Both the wholesale price w_n and retail price p_n of new products have nothing to do with the subsidy s_g given to manufacturers by the government. The wholesale price w_r and retail price p_r of re-products are a decreasing function of the government subsidy s_g to manufacturers.

Prove: It can be seen from the expressions of w_n and p_n that both w_n and p_n have nothing to do with s_g ,

$$\frac{\partial p_r^s}{\partial s_g} = -\frac{1}{4} < 0, \quad \frac{\partial w_r^s}{\partial s_g} = -\frac{1}{2} < 0$$

So w_r and p_r decrease as s_g increases.

Proposition 2 explains: When the remanufacturing subsidy granted by the government to the manufacturer increases, the manufacturer's cost of producing remanufactured products will decrease. The manufacturer can wholesale to retailers at a lower price, and the retailer can also sell to consumers at a lower price. Therefore, it stimulates consumers to have more choices of trade-in than trade-in. Since the trade-in activity only encourages consumers to return old products and simply recycle waste products, these waste products are not reused, and remanufacturing can recycle waste products for remanufacturing, so the government should participate in remanufacturing Certain remanufacturing subsidies to expand the market for remanufactured products.

Proposition3: The selling price p_n wholesale price w_n of the new product and the selling price p_r wholesale price w_r of the reproduced product are a decreasing function of the consumer's discount factor α for the old product.

Prove: $\frac{\partial p_n^S}{\partial \alpha} = \frac{\partial p_r^S}{\partial \alpha} = -\frac{3}{4} < 0 \quad \frac{\partial w_n^S}{\partial \alpha} = \frac{\partial w_r^S}{\partial \alpha} = -\frac{1}{2} < 0$

Proposition 3 shows that the higher the use value of the old product, the lower the original consumer's need to participate in trade-in (re)reduction, more consumers will choose to continue to use the old product, and the company will appropriately reduce the price incentives for new products and remanufactured products. Consumers participate in trade-in (re) to gain profits.

Proposition4: The new product's selling price p_n wholesale price w_n has nothing to do with the consumer's discount factor δ for reworked products, while the reworked product selling price p_r wholesale price w_r is an increasing function of the consumer's discount factor for reworked products δ .

Prove: $\frac{\partial p_n^S}{\partial \delta} = 0, \quad \frac{\partial p_r^S}{\partial \delta} = \frac{3}{4} > 0, \quad \frac{\partial w_n^S}{\partial \delta} = 0, \quad \frac{\partial w_r^S}{\partial \delta} = \frac{1}{2} > 0$

Proposition 4 shows that the higher the discount coefficient of re-products, the higher the use value of re-products, the higher the psychological acceptance of re-products by consumers, and the higher the price at which re-products can be sold. However, the wholesale price of new products is not related to the discount factor of reproducts.

Proposition 5: Analyze the impact of rebates and subsidies on the profit of model S

$$\frac{\partial \pi_M^S}{\partial s_a} = \frac{c_r + s_a - s_g - (\delta - \alpha)}{4(\delta - \alpha)} \quad \frac{\partial \pi_R^S}{\partial s_a} = \frac{c_r + s_a - s_g - (\delta - \alpha)}{8(\delta - \alpha)}$$

$$\frac{\partial \pi_M^S}{\partial s_g} = \frac{(1-\alpha)(c_r - s_g)}{4(1-\delta)(\delta-\alpha)} - \frac{c_n}{4(1-\delta)} - \frac{s_a}{4(\delta-\alpha)}$$

$$\frac{\partial \pi_R^S}{\partial s_g} = \frac{(1-\alpha)(c_r - s_g)}{8(1-\delta)(\delta-\alpha)} - \frac{c_n}{8(1-\delta)} - \frac{s_a}{8(\delta-\alpha)}$$

Analysis of Proposition 5: It can be seen from the proof that the effect of rebate on profits is not monotonous, when $s_a > -c_r + s_g + \delta - \alpha$, Manufacturer's profit π_M^S and retailer's profit π_R^S are increasing functions of the rebate, when $s_a < -c_r + s_g + \delta - \alpha$,

Manufacturer's profit π_M^S and retailer's profit π_R^S are a decreasing function of the rebate. Therefore, the enterprise must provide rebates to consumers who participate in the trade-in (re)return within a certain range to bring more profits to the supply chain.

And the remanufacturing subsidy s_g granted by the government to manufacturers is not monotonous. When $s_g > \frac{-(\delta-\alpha)c_n + (1-\delta)s_a + (1-\alpha)c_r}{1-\alpha}$, The profit π_M^S of the manufacturer and the profit π_R^S of the retailer increase with the increase of government subsidies. Therefore, when the government provides subsidies to participating remanufacturers, it must be above this threshold to bring profits to the closed-loop supply chain.

3.2. Model D: Under Different Circumstances

Companies are launching two strategies: old-for-new and old-for-replacement, both of which maximize the overall benefits of the closed-loop supply chain. The rebate for trade-in is s_t, and the rebate for trade-in is s_r. Compare the difference between setting the same rebate and the difference rebate to the profit of the closed-loop supply chain. Finally, it analyzes the impact of trade-in-for-the-old government subsidie s_g to manufacturers on the closed-loop supply chain.

Assuming that the original consumer's evaluation of the value of the new product is v, the value utility of the consumer's purchase of the new product is $U_n = v - p_n$, (v obeys the uniform distribution of [0, 1]), The utility of the original consumer continuing to use the old product is $U_u = \alpha v$, (α is the consumer's discount on the value of the old product), The utility of original consumers participating in trade-in is $U_t = v - p_n + s_t$, due to $U_n \geq 0$, $U_t \geq U_u$ and $U_t \geq U_r$, The price of the new product is p_n, In order to better encourage consumers to participate in trade-in and expand the market share of enterprises, the corresponding enterprises will pay consumers a certain rebate s_t, According to the principle of non-negative utility and the principle of utility maximization, the demand of consumers to participate in trade-in is $q_t^D = \int_{\frac{p_n - p_r}{1-\delta}}^{1} 1 dv = 1 - \frac{p_n - p_r}{1-\delta}$.

The utility of the original consumer's trade-in is $U_r = \delta v - p_r + s_r$, and δ is the value coefficient of the reproduced product to the new product. At this time, suppose the rebate given to the consumer by the trade-in retailer is s_r, (hypothesis $s_r > s_a > s_t$), due to $U_r \geq U_t$ and $U_r \geq U_u$, At this time, consumers' demand for participating in trade-in is:

$$q_r^D = \int_{\frac{p_r - s_r}{\delta-\alpha}}^{\frac{p_n - p_r + s_r - s_t}{1-\delta}} 1 dv = \frac{p_n - p_r + s_r - s_t}{1-\delta} - \frac{p_r - s_r}{\delta-\alpha} \tag{8}$$

Still making decentralized decision-making, the retailer's decision problem is:

$$\underset{p_n, p_r}{Max} \pi_R^D = (p_n - w_n - 2s_t + A)q_t + (p_r - w_r - 2s_r + A)q_r$$

$$\frac{\partial \pi_M^D}{\partial p_n} = \frac{-2p_n + 2p_r + w_n - w_r + 2s_t - 2s_r + 1 - \delta}{1-\delta}$$

$$\frac{\partial \pi_R^D}{\partial p_r} = \frac{2p_n - 2p_r - w_n + w_r - 3s_t + 3s_r}{1-\delta} - \frac{2p_r - w_r - 3s_r + A}{\delta-\alpha} \tag{9}$$

The retailer's response function is:

$$p_r^D = \frac{(1-\delta)(w_r - A + \delta - \alpha) - (\delta-\alpha)s_t + (3 - 2\delta - \alpha)s_r}{2(1-\delta)}$$

$$p_n^D = \frac{(1-\delta)(w_n - A) + (2 + \alpha - 3\delta)s_t + (1-\alpha)(s_r + 1 - \delta)}{2(1-\delta)} \tag{10}$$

The Hessian matrix of the available profit function is:

$$H_2 = \begin{vmatrix} \frac{-2}{1-\delta} & \frac{2}{1-\delta} \\ \frac{2}{1-\delta} & \frac{-2}{1-\delta} + \frac{-2}{\delta-\alpha} \end{vmatrix} = \frac{4}{(\delta-\alpha)(1-\delta)} > 0, \quad H_1 = \frac{-2}{(1-\delta)} < 0.$$

That is, the Hessian matrix is negative definite, the profit function is concave, and there is an optimal solution $p_n p_r$, The profit of the manufacturer is the sum of the profit of trade-in products and remanufactured products, and the government will give the manufacturer subsidies s_g, The profit function is $\underset{w_n, w_r}{Max} \pi_M^D = (w_n - c_n - A)q_t + (w_r - c_r + s_g - A)q_r$ In the same way, the Hessian matrix can be used to judge that there is an optimal solution w_n、w_r:

$$w_n^D = \frac{(c_n + 2A + 1 - \alpha)(1-\delta) + (2 - \delta - \alpha)s_t + (1-\alpha)s_r}{2(1-\delta)}$$

$$w_r^D = \frac{(c_r + 2A + \delta - \alpha - s_g)(1-\delta) - (\delta-\alpha)s_t + (2\delta - 1 - \alpha)s_r}{2(1-\delta)} \tag{11}$$

Substituting the manufacturer's optimal wholesale price into the retailer's response function, it is known from the Hessian matrix calculation that there is an optimal solution that can calculate the retailer's optimal retail prices for new and remanufactured products.

$$p_n^D = \frac{(1-\delta)\left[c_n + 3(1-\alpha)\right] + 3(1-\alpha)s_r + (2+3\alpha-5\delta)s_t}{4(1-\delta)}$$
$$p_r^D = \frac{(1-\delta)\left[c_r - s_g + 3(\delta-\alpha)\right] + (5-\delta-3\alpha)s_r - 3(\delta-\alpha)s_t}{4(1-\delta)} \quad (12)$$

Furthermore, the optimal profit of the manufacturer and the retailer can be obtained respectively as:

$$\underset{p_n p_r}{Max}\, \pi_M^D = \frac{(1-\alpha)^2 s_r^2 - (3\delta^2 - 2\delta\alpha - \alpha^2)s_t^2}{8(1-\delta)^2(\delta-\alpha)} + \frac{4s_t^2 + 2(2\delta+\alpha-3)s_r s_t}{8(1-\delta)^2} + \frac{c_n^2 - 2(2c_n - c_r)s_t + 2s_g(c_n+s_t)}{8(1-\delta)} + \frac{(1-\alpha)\left[(c_r-2s_g) + 2(c_r-s_g)s_r\right]}{8(1-\delta)(\delta-\alpha)} + \frac{(1-\alpha)s_r}{4(1-\delta)} - \frac{c_n(1+s_r)}{4} + \frac{1-\alpha}{8}$$
$$\underset{p_n p_r}{Max}\, \pi_R^D = \frac{(1-\alpha)^2 s_r^2 - (3\delta^2 - 2\delta\alpha - \alpha^2)s_t^2}{16(1-\delta)^2(\delta-\alpha)} + \frac{4s_t^2 + 2(2\delta+\alpha-3)s_r s_t}{16(1-\delta)^2} + \frac{c_n^2 - 2(2c_n - c_r)s_t + 2s_g(c_n+s_t)}{16(1-\delta)} + \frac{(1-\alpha)\left[(c_r-2s_g) + 2(c_r-s_g)s_r\right]}{16(1-\delta)(\delta-\alpha)} + \frac{(1-\alpha)s_r}{8(1-\delta)} - \frac{c_n(1+s_r)}{8} + \frac{1-\alpha}{16} \quad (13)$$

Proposition6: Model D The relationship between the selling price and wholesale price of new products and remanufactured products and the rebate of trade-in (re) is as follows:

Prove:

$$\frac{\partial p_n^D}{\partial s_t} = \frac{1}{2} - \frac{3(\delta-\alpha)}{4(1-\delta)} \quad \frac{\partial p_r^D}{\partial s_t} = \frac{3(\delta-\alpha)}{-4(1-\delta)} < 0$$

$$\frac{\partial p_n^D}{\partial s_r} = \frac{3(1-\alpha)}{4(1-\delta)} > 0 \quad \frac{\partial p_r^D}{\partial s_r} = \frac{1}{2} + \frac{3(1-\alpha)}{4(1-\delta)} > 0$$

$$\frac{\partial w_n^D}{\partial s_t} = \frac{2-(\delta+\alpha)}{-2(1-\delta)} < 0 \quad \frac{\partial w_r^D}{\partial s_t} = \frac{\delta-\alpha}{-2(1-\delta)} < 0$$

$$\frac{\partial w_n^D}{\partial s_r} = \frac{1-\alpha}{2(1-\delta)} > 0 \quad \frac{\partial w_r^D}{\partial s_r} = -\frac{1}{2} + \frac{\delta-\alpha}{1-\delta}$$

Analysis of Proposition 6:

When $\delta < \frac{2+3\alpha}{5}$, the price p_n of new products increases as consumers participate in trade-in rebates s_t; and the price p_r of remanufactured products also increases with the increase in rebates s_r. As retailers provide rebates, their costs increase, so the price will also increase improve. Retailers give consumers rebates to stimulate consumer demand to a certain extent, but the selling price should not be too high, otherwise it will affect sales. Therefore, retailers should balance the relationship between rebates and selling prices when setting prices.

The wholesale price w_n of new products decreases as the consumer participates in the rebate s_t of trade-in. At $\delta < \frac{1+2\alpha}{3}$, the wholesale price w_r of re-products decreases as the consumer participates in the rebate s_r of trade-in. Due to the increase in rebates, consumers are encouraged to participate in the exchange of old (new), and there is a certain degree of competition among upstream manufacturers, so manufacturers will lower the wholesale prices of new products and remanufactured products.

Both the selling price p_r and the wholesale price w_r of re-products decrease with the increase of s_t. As consumers participate in trade-in rebates, the price of new products rises. Consumers will choose to participate in trade-in repurchase of re-products, stimulating re Products gain more market share, so the higher the rebate of the company to consumers, the higher the demand and the lower the price.

Both the selling price p_n and wholesale price w_n of new products increase as consumers participate in trade-in rebates s_r. As remanufactured products not only provide rebates to consumers, the government also provides subsidies to remanufacturers. There will be a certain degree of competition in the old-for-new market, so companies will appropriately increase the prices of new products in order to make profits.

Proposition7: The selling price of new products p_n wholesale price w_n and the selling price p_r wholesale price w_r of remanufactured products decrease as consumers increase the discount factor α of old products.

Prove

$$\frac{\partial p_n^D}{\partial \alpha} = \frac{\partial p_r^D}{\partial \alpha} = -\frac{3}{4}\left(1 + \frac{s_r - s_t}{1-\delta}\right) < 0$$

$$\frac{\partial w_n^D}{\partial \alpha} = \frac{\partial w_r^D}{\partial \alpha} = -\frac{1}{2}\left(1 + \frac{s_r - s_t}{1-\delta}\right) < 0$$

Proposition 7 is consistent with the conclusion of proposition 3, so I will not repeat it.

Proposition8: The selling price of new products p_n wholesale price w_n and the selling price of remanufactured products p_r wholesale price w_r will increase with the increase of the discount factor δ for remanufactured products by consumers.

$$\frac{\partial p_n^D}{\partial \delta} = \frac{3(1-\alpha)(s_r - s_t)}{4(1-\delta)^2} > 0 \quad \frac{\partial p_r^D}{\partial \delta} = \frac{3}{4} + \frac{3(1-\alpha)(s_r - s_t)}{4(1-\delta)^2} > 0$$

$$\frac{\partial w_n^D}{\partial \delta} = \frac{(1-\alpha)(s_r - s_t)}{2(1-\delta)^2} > 0 \quad \frac{\partial w_r^D}{\partial \delta} = \frac{1}{2} + \frac{(1-\alpha)(s_r - s_t)}{2(1-\delta)^2} > 0$$

Analysis of Proposition 8: As the use value of re-products is higher, consumers' acceptance of re-products will become higher and higher, and the market share of re-products will become larger and larger. Enterprises will appropriately increase the price of re-products to obtain more profit. The increase in the use value of reproducts will, to a certain extent, encroach on the market share of trade-in, and enterprises will also increase the price of new products to obtain more profits.

Proposition9: Analyze the impact of rebates and subsidies on the profit of Model S

$$\frac{\partial \pi_M^D}{\partial s_t}=\frac{(1-\delta)(2c_n-c_r+s_g+\alpha-2+\delta)+(-3+2\delta+\alpha)s_r+(4-3\delta-\alpha)s_t}{4(1-\delta)^2}$$

$$\frac{\partial \pi_R^D}{\partial s_t}=\frac{(1-\delta)(2c_n-c_r+s_g+\alpha-2+\delta)+(-3+2\delta+\alpha)s_r+(4-3\delta-\alpha)s_t}{8(1-\delta)^2}$$

$$\frac{\partial \pi_M^D}{\partial s_r}=\frac{(1-\alpha)\left[(1-\alpha)s_r-\alpha\right]}{4(1-\delta)^2(\delta-\alpha)}+\frac{(1-\alpha)(c_r-s_g)+\delta}{4(1-\delta)(\delta-\alpha)}-\frac{3-\delta\alpha-2\delta-\alpha}{4(1-\delta)^2}-\frac{c_n}{2(1-\delta)}$$

$$\frac{\partial \pi_R^D}{\partial s_r}=\frac{(1-\alpha)\left[(1-\alpha)s_r-\alpha\right]}{8(1-\delta)^2(\delta-\alpha)}+\frac{(1-\alpha)(c_r-s_g)+\delta}{8(1-\delta)(\delta-\alpha)}-\frac{3-\delta\alpha-2\delta-\alpha}{8(1-\delta)^2}-\frac{c_n}{4(1-\delta)}$$

$$\frac{\partial \pi_M^D}{\partial s_g}=\frac{c_n+s_t}{4(1-\delta)}-\frac{c_r+s_r-s_g}{4(1-\delta)(\delta-\alpha)}\quad \frac{\partial \pi_R^D}{\partial s_g}=\frac{c_n+s_t}{8(1-\delta)}-\frac{c_r+s_r-s_g}{8(1-\delta)(\delta-\alpha)}$$

Analysis of Proposition 9:

when $s_t>\frac{(1-\delta)(-2c_n+c_r-s_g-\alpha+2-\delta)+(3-2\delta-\alpha)s_r}{(4-3\delta-\delta)}$, manufacturer's profit π_M^D and retailer's profit π_R^D increase with the increase in the company's rebate s_t to consumers participating in trade-in.

when $s_r>\frac{(1-\delta)(2c_n-c_r+3s_t+s_g-2+\delta+\alpha)+(1-\alpha)s_t}{2(1-\delta)+(1-\alpha)}$, Manufacturer's profit π_M^D and retailer's profit π_R^D increase with the increase in the company's rebates s_r to consumers participating in trade-in.

when $s_g>-\frac{(\delta-\alpha)(c_n+s_t)}{1-\alpha}+(c_r+s_r)$, the profit of the manufacturer π_M^D and the profit of the retailer π_R^D increase with the increase in the subsidy s_g of the manufacturer participating in the remanufacturing.

Proposition10: Analyze the relationship between model S and model D demand

$$p_n^S=\frac{c_n+5s_a+3(1-\alpha)}{4}\quad p_r^S=\frac{c_r+5s_a-s_g+3(\delta-\alpha)}{4}$$

$$p_n^D=\frac{(1-\delta)\left[c_n+3(1-\alpha)\right]+3(1-\alpha)s_r+(2+3\alpha-5\delta)s_t}{4(1-\delta)}$$

$$p_r^D=\frac{(1-\delta)\left[c_r-s_g+3(\delta-\alpha)\right]+(5-\delta-3\alpha)s_r-3(\delta-\alpha)s_t}{4(1-\delta)}$$

Compared:

$$p_n^S-p_n^D=\frac{(1-\delta)(-c_n+c_r+5s_a-2s_t)-3(1-\alpha)s_r+3(\delta-\alpha)s_t}{4(1-\delta)}$$

$$p_r^S-p_r^D=\frac{-(5-\delta-3\alpha)s_r+3(\delta-\alpha)s_t+5(1-\delta)s_a}{4(1-\delta)}$$

Analysis of Proposition 11:

when $s_a>\frac{3-3\alpha}{5(1-\delta)}s_r+\frac{2+3\alpha-5\delta}{5(1-\delta)}s_t$, $p_n^S>p_n^D$

when $s_a>\frac{5-\delta-3\alpha}{5(1-\delta)}s_r-\frac{3(\delta-\alpha)}{5(1-\delta)}s_t$, $p_r^S>p_r^D$,

Since the price is determined by other variables, a numerical verification analysis is done in Table 2 below.

4. NUMERICAL SIMULATION AND ANALYSIS

Through numerical simulation, we will further analyze the impact of differentiated rebates on the overall profit of the closed-loop supply chain. At the same time, we can verify the relevant propositions in the previous article. In this section, we will assign certain values to each parameter based on the assumptions of the article, and use Maple19 simulation software to perform numerical simulation.

4.1. Analysis on the Change of Supply Chain Profit with Rebate s_a in Model S (Set the Same Rebate)

The specific parameter settings in this section are as follows:

Hypothesis $c_n=0.5, c_r=0.3, \delta=0.6, \alpha=0.4, s_a\in(0,0.3), s_g\in(0.3,0.5)$ (The value range meets the article's assumptions 4 and 5)

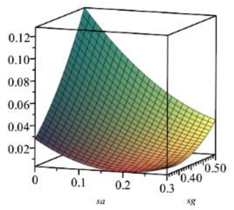

Figure 2 Manufacturer's profit changes with rebate s_a

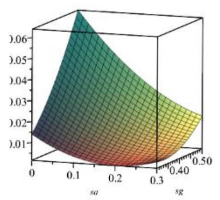

Figure 3 Retailer's profit changes with rebate s_a

Figures 3 and 4 can verify the conclusion of proposition 5 in this article. The impact of the changes in the profits of manufacturers and retailers with the rebate is not monotonous, and they all decrease first and then increase. The existence of rebates will increase the retailer's cost, but it will also increase consumer demand. The upstream manufacturers will have a certain degree of competition, and the wholesale price will decrease accordingly. It can be seen from this that the establishment of rebates for consumers must be combined with the actions of other members in the closed-loop supply chain in order to increase profits in the supply chain.

4.2. Analysis of the Change of Supply Chain Profit with the Rebate s_t, s_r in Model S (Setting the Difference Rebate)

The specific parameter settings in this section are as follows:
$c_n = 0.5, c_r = 0.3, \delta = 0.6, \alpha = 0.4, s_t = 0.5, s_r \subseteq (0.5,1), s_g \subseteq (0,1)$ (The value range meets the article's assumptions 4 and 5)

The profit of supply chain manufacturers and retailers changes with the rebate s_t that retailers give to participate in trade-in, as shown in Figures 4 and 5.

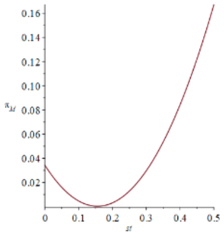

Figure 4 Manufacturer's profit changes with rebate s_t

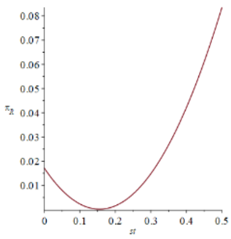

Figure 5 Retailer's profit changes with rebate s_t

Figures 4 and 5 can verify the conclusion of proposition 9 of this article. The analysis is similar to 5. 1, so we won't repeat it.

Figure 6 shows the influence of the total profit of the supply chain, the individual profit of the manufacturer, and the individual profit of the retailer as the retailer gives the participation in exchange for rebates.

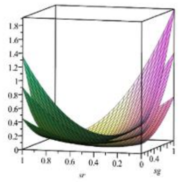

Figure 6 Changes in total supply chain profits, manfacturers profits, and retailer profits with rebates s_r

Figure 6 can verify the conclusion of proposition 9 in this paper. The profit of the supply chain changes with the influence of rebate s_r not monotonous, but all increase with the increase of government subsidy s_g. In the setting of rebates, enterprises must combine the behaviors of other members of the supply chain to obtain profits in coordination, so that consumers can actively participate in the exchange of old products, and the recycling rate and utilization rate of waste products can be greatly improved. Manufacturers' active participation in remanufacturing can reduce the price of remanufactured products and drive demand downstream in the supply chain. The government should also strongly support remanufacturing, grant subsidies to manufacturers participating in remanufacturing, encourage more companies to join remanufacturing, and maximize the economic and environmental benefits of the supply chain.

4.3. Analyze the relationship between model S and model D optimal selling price

In order to compare the relationship between the optimal selling price and the rebate between the two models, we will enter a deeper analysis and compare the relationship between the same rebate and the price under the difference rebate. According to the conditions and assumptions set in this article, the value analysis of Proposition 11 is carried out.

Table 1 Comparative analysis of the best selling price under different rebate situations

Model type	Best selling price	The rebate given to consumers by the enterprise under the same rebate s_a					
		0. 05	0. 1	0. 15	0. 2	0. 25	0. 3
Same rebate	p_n^S	0. 6375	0. 7	0. 7625	0. 825	0. 8875	0. 95
Same rebate	p_r^S	0. 2125	0. 275	0. 3375	0. 4	0. 4625	0. 525
Trade-old-for-new rebate	s_t	0. 03	0. 08	0. 13	0. 18	0. 23	0. 28
Trade-old-for-rerebate	s_r	0. 06	0. 12	0. 17	0. 22	0. 27	0. 3
Difference rebate	p_n^D	0. 6463	0. 72	0. 7825	0. 845	0. 9075	0. 9475

Difference rebate	p_r^D	0. 2588	0. 36	0. 5913	0. 5225	0. 6038	0. 3638

Table 2 can verify the conclusion of Proposition 11 through data simulation. When the rebate setting of differentiated rebate meets certain conditions, the selling price of new products and remanufactured products of model D will be lower than model S . At this time, setting differential rebate is beneficial to closed-loop supply the healthy development of the chain and the reduction of prices have increased consumer demand and increased sales, which is conducive to the development of the market. The promotion of re-products is conducive to the recovery and reuse of waste products, and the environmental benefits are improved, which is in line with the trend of social development. Therefore, when an enterprise implements a product promotion strategy, it should set up differentiated rebates within certain conditions, while obtaining economic and environmental benefits.

5. CONCLUSION

This article is based on the background of the government's subsidy policy for remanufacturers under the "old-for-replacement" policy, and by analyzing how to set the rebate given by the enterprise to consumers when the company conducts both "old-for-new" and "old-for-replacement", the same rebate is established The S model and the D model of differential rebate, by comparing the pricing and profit of the two models, draw the following conclusions:

When the rebate is controlled at a certain threshold, it can increase the profit of the closed-loop supply chain. The higher the better, the existence of the rebate represents the increase in the business cost of the enterprise. For the company's own interests and survival considerations, the rebate should be set Within the scope of business management.

Compared with the same rebate model, the differential rebate model is more conducive to remanufacturing. Through comparative analysis, under the differentiated rebate, the demand for participating in exchange for old is higher than the demand for participating in exchange for new, which is more conducive to the marketing of re-products.

The profits of manufacturers and retailers in the closed-loop supply chain have increased with the increase in government subsidies for manufacturers to participate in remanufacturing. Therefore, the government should provide greater support when companies bear the pressure of paying rebates and encourage more in the market. A wider range of enterprises participate in remanufacturing, which has increased the recognition of re-products in the society, and social demand is increasing, so that waste products can be recycled and reused, resource reuse and environmental protection can be achieved.

This article also has issues that can be further explored: in reality, the competition of products on the market does not stop there, and there are many refurbished products on the market that will compete with remanufactured products. Therefore, the model of the supply chain in the following research may be more complicated.

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