Research on Pricing Decisions in Closed-Loop Supply Chains under O2O Recycling Model

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Abstract: With the development of the O2O business model, the O2O recycling model has also begun to rise. Under the O2O recycling model, consumers can use the money obtained from recycling waste for purchasing new or remanufactured products. Compared to the traditional channel recycling model, the O2O recycling model achieves the integration of online and offline resources, and the recycling price is unified. The article, based on the characteristics of waste product recycling under the O2O model, establishes an O2O recycling model pricing decision model for closed-loop supply chains to seek the optimal pricing strategy to promote the healthy development of remanufacturing closed-loop supply chains under the O2O recycling model, thereby obtaining the market conditions and development space for the implementation of the O2O recycling model.

Keywords: Dual-Channel; Pricing Decision; Closed-Loop Supply Chain; Remanufactured Products; O2O Recycling Model

1. Introduction

With the development of the Internet, the O2O business model has been widely applied in various industries, including the recycling and utilization of renewable resources. Under the O2O recycling model, the recycling and utilization industry of renewable resources can better utilize the Internet platform to improve the efficiency and convenience of resource recycling. These platforms provide consumers with more convenient channels for recycling renewable resources. Through the online platform, consumers can easily find the nearest recycling point or schedule door-to-door recycling services. At the same time, these platforms also provide recyclers with a broader market and more efficient operation methods. Through data analysis and online promotion, etc., the efficiency of recycling business has been improved and the coverage of recycling has been increased. One of the biggest characteristics of the O2O recycling model is that it is a dual-channel recycling model for both online and offline, but different from the traditional dual-channel recycling model, the online and offline recycling rates levels are kept consistent under the O2O recycling model, and the online and offline channels work together to complete the recycling work.

At present, many enterprises are shifting from dual-channel recycling models to O2O recycling models, and many emerging enterprises also choose the O2O recycling model when entering the recycling field. There are many O2O platforms dedicated to waste recycling in the market. Recycling Treasure is a leading O2O waste recycling platform in China. Users can schedule waste and recyclable items for recycling through mobile applications. Recycling Treasure will send professional recycling personnel to collect and pay the corresponding recycling fees. This model not only facilitates users but also improves the efficiency of waste recycling. ReCollect is an O2O waste recycling platform located in Singapore. They provide an online platform where users can schedule waste recycling services. The platform also provides waste recycling knowledge and guidance to help users better understand the importance of waste recycling and encourage them to participate in environmental protection actions. These platforms all demonstrate the advantages of the O2O recycling model, which is to conveniently connect users and recyclers, enhance waste recycling efficiency, and foster environmental awareness. It is evident that the O2O recycling model has its unique advantages in the current recycling market and is attracting enterprises to choose this model.

In summary, the O2O recycling model has been widely applied in many countries and regions and is a trend when choosing market recycling models. However, the O2O recycling model also faces some challenges in its current development, such as high logistics costs, difficulties in evaluating the quality and value of recycled products, and insufficient user participation. Among them, the pricing issues in the O2O recycling market are particularly important. In practice, product pricing in the remanufacturing closed-loop supply chain has always been a matter of concern. The current O2O recycling market pricing is chaotic, impacting the original recycling pricing. How to price online and offline to better promote the development of the O2O recycling industry. Based on this issue, this article will focus on analyzing the pricing decision characteristics of the O2O recycling model to provide a theoretical basis for better O2O recycling model closed-loop supply chain pricing.

2. Literature Review

2.1 Research Status of Dual-Channel Supply Chain Recycling Pricing

Di Wu et al. [1] (2019) studied the profit sharing and fairness concerns of recycling centers and third-party recyclers in the supply chain system under the background of developing offline and online recycling channels for recycling centers with dual channels. Jian Wang et al. [2] (2019) considered three modes of recycling old products in the reverse supply chain: through manufacturers, through retailers, or through the joint recycling mode of manufacturers and retailers. Yanhong Yuan et al. [3] (2019) used optimization analysis and game theory to analyze the necessary conditions for manufacturers, retailers, and third-party online recyclers to coordinate interests under equilibrium conditions. Domestically, You Jun et al. [4] (2018) established a recycling pricing model based on the dual-channel recycling third-order supply chain, studying the impact of subsidies to different supply chain objects on channel pricing. Jun Yang et al. [5] (2020) proposed a waste product recycling model and used game theory to study the model, thereby analyzing the impact of buyer preferences on recycling channels. Chen Zhu et al. [6] (2021) studied the optimal decision impact of two different channel structures on the dual-channel closed-loop supply chain.

2.2 Research Status of O2O Model

Yong Long et al. [7] (2017) studied the optimal pricing strategy for tour operators and online travel agencies to cooperate in achieving the O2O model through online sales and offline services. Domestically, Yao Yuan [8] (2018) established different types of game models for suppliers and O2O e-commerce platforms under different distribution models. Zhao Mei [9] (2018) took O2O e-commerce platforms as an example, for the situation where merchants sell goods on O2O e-commerce platforms, based on the uncertainty of whether consumers can satisfy their requirements for the goods, and established game models for two sales methods: agency and wholesale, studying the optimal product price and logistics service level selection. Yi Wen Tao et al. [10] (2023) took the O2O model as the background, with online direct sales and online agency sales as the research objects, established an optimization model for pricing and delivery time in the O2O model sales network, and optimized the design to study the optimal decisions of each channel.

2.3 Literature Review

This study targets the closed-loop supply chain where online and offline sales coexist. Based on a wide range of existing literature, it is found that the highly relevant model to this pattern is the dual-channel closed-loop supply chain, which has been studied by many scholars. These studies have effectively addressed the pricing decision issues in dual-channel closed-loop supply chains. The corresponding model for this type of supply chain is the O2O closed-loop supply chain, which is a novel business model based on the Internet. Since its emergence, it has been highly concerned and studied by domestic and foreign scholars, but there is not much research on recycling. The difference between the O2O recycling model and other recycling models is that consumers use the money recycled to buy new products or remanufactured products again. Therefore, this paper applies the O2O model to the reverse recycling channel, analyzes the characteristics of the O2O recycling model, and to some extent, expands the research scope of reverse recycling and O2O models.

3. O2O Recycling Model Description and Assumptions

3.1 O2O Recycling Model Description

The O2O recycling model uses two different channels for waste recycling, including online and offline channels. In the online channel recycling, users can submit recycling requests through applications or websites. In the offline channel recycling, users can directly go to specific physical stores or service points and hand over waste or old goods to staff for recycling. As shown in Figure 1, the O2O recycling model has two channels for recycling, among which the manufacturing enterprise occupies a dominant position in the O2O recycling model, and the manufacturing enterprise can collect waste products from consumers through online recycling, and can also collect waste products through retailers offline. Retail enterprises can also recycle waste products from consumers offline on their own. The flowchart of the O2O recycling model is as follows:

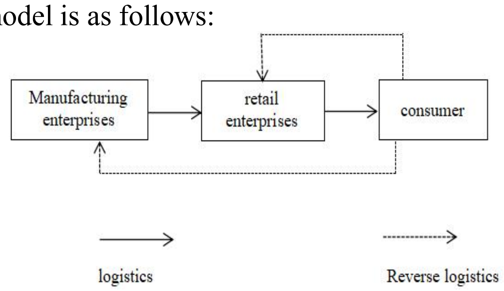

Figure 1. O2O Model Waste Product Recycling Pricing Model

3.2 Model Assumptions

In the O2O recovery model established in this paper, manufacturers occupy a dominant position, and the retailer determines the sales price of remanufactured products based on the manufacturer's pricing, in a subordinate position. Based on the problems studied in the article, the following assumptions are made:

(1) Offline recycling is carried out in proportion, and the corresponding online recycling proportion is offline recycling with a recycling cost of, and the online and offline recycling prices are the same, represented by. Among them.

(2) Part of the money consumers get from selling waste products will be used to buy remanufactured products, which is called the demand function's sensitive coefficient, represented by the character. Among them.

(3) The demand for remanufactured products by consumers is represented by the function.

(4) While consumers consume, they also provide discarded goods to retailers or manufacturing enterprises; the proceeds from selling discarded goods will encourage consumers to buy these remanufactured products.

(5) In the O2O model, the online and offline recycling prices are the same, but the online and offline recycling costs are different. Among them, the offline recycling cost is higher than the online recycling cost, so we can assume that the online recycling cost is zero.

(6) Due to the market not being completely closed, information can be shared instantly among all members in the supply chain, and there is no information lag. In the supply chain, information is symmetric.

(7) Each cycle is similar, so this paper only discusses the range of one cycle.

4. O2O Model Waste Product Recycling Pricing Model

From the above model description and assumptions, the demand function for remanufactured products, the manufacturer's economic benefit function, and the retailer's economic benefit function are as follows:

$$q = 1 - p + \delta P_c \quad (1)$$

$$\pi_m = w(1 - p + \delta P_c) - P_c(1 - \alpha - p + \delta P_c) \quad (2)$$

$$\pi_d = (p - w)(1 - p + \delta P_c) - (P_c + C_1\alpha)(\alpha - p + \delta P_c) \quad (3)$$

Taking the first derivative of (2) with respect to p:

$$\partial \pi_d / \partial p = 1 - 2p + \delta P_c + w + P_c + C_1\alpha \quad (4)$$

Order $\partial \pi_d / \partial p = 0$,get the selling price of the retailer:

$$P = \frac{1 + C_1\alpha + \delta P_c + w + P_c}{2} \quad (5)$$

Substitute the retailer's selling price function for the manufacturer's economic return function, i.e., the function of (5) for the function of (2), and find the primary differentiation with respect to w:

$$\partial \pi_m / \partial w = \frac{1 - C_1\alpha + \delta P_c - 2w}{2} \quad (6)$$

Also, find the primary differential with respect to P_c:

$$\partial \pi_m / \partial P_c = \frac{(C_1+2)\alpha + (w-2P_c)\delta + 2P_c - 1}{2} \quad (7)$$

Combine (6) and (7) to get the optimal wholesale price and recycling price:

$$w^* = \frac{2-\delta+\delta C_1\alpha - 2C_1\alpha - 2\delta\alpha}{\delta^2 - 4\delta + 4} \quad (8)$$

$$P_c^* = \frac{2-\delta+\delta C_1\alpha - 2C_1\alpha - 4\alpha}{\delta^2 - 4\delta + 4} \quad (9)$$

Substitute (8) and (9) into (5) to get the optimal batch sales price:

$$p^* = \frac{4-2\delta+\delta^2 C_1\alpha - 2\delta C_1\alpha - 3\delta\alpha - 2\alpha}{\delta^2 - 4\delta + 4} \quad (10)$$

In summary, substitute the obtained optimal recycling price, optimal wholesale price, and optimal sales price into the manufacturer's economic benefit function, that is, substitute (8), (9), and (10) into (2), to get the manufacturer's economic benefit:

$$\pi_m = \frac{((\delta C_1 - 2C_1 - 2)\alpha - \delta + 2)\alpha}{(\delta-2)^2} \quad (11)$$

Then, substitute the obtained optimal recycling price, optimal wholesale price, and optimal sales price into the retailer's economic benefit function, that is, substitute (8), (9), and (10) into (2), to get the retailer's economic benefit:

$$\pi_d = \frac{(-C_1\delta^2 + 3\delta C_1 - 2C_1 + 5)\alpha^2 + (C_1\delta^2 + (-3C_1+1)\delta + 2C_1 - 6)\alpha - \delta + 2}{(\delta-2)^2} \quad (12)$$

Finally, add (11) and (12) to get the overall supply chain profit:

$$\pi^* = \frac{(-C_1\delta^2 + 4\delta C_1 - 4C_1 + 3)\alpha^2 + (C_1\delta^2 - 3\delta C_1 + 2C_1 - 4)\alpha - \delta + 2}{(\delta-2)^2} \quad (13)$$

Conclusion 1 The market condition for the O2O recycling model is that the C_1 value range of is $(0, \frac{\delta^2 - 3\delta + 2 + \delta\alpha + 2\alpha}{\alpha(\delta^2 - 3\delta + 2)})$, and the α value range of is $(0, \frac{\delta^2 - 3\delta + 2}{\delta^2 C_1 - 3\delta C_1 - \delta - 2 + 2C_1})$.

Proof: The value range of C_1 and α can be obtained through known conditions $0 < P_c < 1, 0 < w < p < 1, 0 < p - w < 1$.

Conclusion 1 indicates that the O2O recycling model has certain market conditions, and the O2O recycling pricing model can only be established within this condition range. Under the O2O recycling model, the offline recycling cost and offline recycling ratio must be controlled within a certain value range; otherwise, excessive offline recycling costs will make retailers unwilling to recycle waste products offline, thus making the O2O recycling model unable to operate normally. Therefore, wholesalers and retailers need to set reasonable offline recycling costs and offline and online channel recycling ratios to ensure that the O2O recycling model can operate normally.

Conclusion 2 The retailer's sales price is positively correlated with the unit recycling price P_c.

Proof: From the above calculation, the sales price is obtained $p = \frac{1 + C_1\alpha + \delta P_c + w + P_c}{2}$ and, this formula shows that the sales price P_c increases with the increase of the unit recycling price.

Conclusion 2 suggests that as the recycling price per unit of waste products rises, the retailer's selling price will also increase. This is because due to the increase in the unit recycling price of waste products, the income consumers get from selling waste products will increase, so consumers have more money to buy remanufactured products. The increase in consumers' purchasing power allows retailers to raise the sales price of remanufactured products based on the increase in the payment ability of buyers in the market. In addition, the increase in the unit recycling price of waste products means that retailers need to pay higher production costs, and to increase profits, retailers will also raise the sales price of remanufactured products. It can be concluded that the sales price and the unit recycling price are positively correlated.

Conclusion 3 The manufacturer's wholesale price tends to increase as the unit recycling price goes up.

Proof: Let the function of (6) $\partial \pi_m / \partial w = \frac{1 - C_1\alpha + \delta P_c - 2w}{2}$ equal 0, and obtain $w = \frac{1 + \delta P_c - C_1\alpha}{2}$. From this formula, it is known that the wholesale price w increases with the increase of the unit recycling price P_c.

Conclusion 3 indicates that when the unit recycling price increases, the manufacturer's wholesale price will also increase. Similarly to Conclusion 2, the increase in the unit recycling price means that consumers have more income to buy remanufactured products, so manufacturers can raise the wholesale price. In addition, the increase in the unit recycling price means that manufacturers, considering profit, will raise the wholesale price. Although raising the wholesale and sales prices can increase the profits of manufacturers and retailers, when the sales price is too high, consumers may no longer buy the remanufactured product, so manufacturers and retailers need to set a reasonable unit recycling price, not too high or too low, otherwise, it will affect the sales of remanufactured products and their profits.

Conclusion 4 When $\frac{\alpha C_1 + \mathrm{w}\delta + 2\alpha - 1}{2(\delta - 1)} < \mathrm{P}_c < 1$, the manufacturer's economic benefits are positively correlated with the unit recycling price. When $0 < \mathrm{P}_c < \frac{\alpha C_1 + \mathrm{w}\delta + 2\alpha - 1}{2(\delta - 1)}$, the manufacturer's economic benefits are negatively correlated with the unit recycling price.

Proof: By calculating the known conditions $0 < \alpha < \frac{1}{C_1 + 2}, 0 < w < -\frac{\alpha C_1 + 2\alpha - 1}{\delta}$, it can be obtained that when $\frac{\alpha C_1 + \mathrm{w}\delta + 2\alpha - 1}{2(\delta - 1)} < \mathrm{P}_c < 1$, $\partial \pi_m / \partial \mathrm{P}_c = \frac{(C_1 + 2)\alpha + (w - 2\mathrm{P}_c)\delta + 2\mathrm{P}_c - 1}{2}$ is greater than zero, and when $0 < \mathrm{P}_c < \frac{\alpha C_1 + \mathrm{w}\delta + 2\alpha - 1}{2(\delta - 1)}$, $\partial \pi_m / \partial \mathrm{P}_c = \frac{(C_1 + 2)\alpha + (w - 2\mathrm{P}_c)\delta + 2\mathrm{P}_c - 1}{2}$ is less than zero.

Conclusion 4 indicates that in the O2O recycling pricing model, when the unit recycling price is $(0, \frac{\alpha C_1 + \mathrm{w}\delta + 2\alpha - 1}{2(\delta - 1)})$, the increase in the unit recycling price will increase the manufacturer's recycling cost, thus reducing the manufacturer's economic benefits. When the unit recycling price is $(\frac{\alpha C_1 + \mathrm{w}\delta + 2\alpha - 1}{2(\delta - 1)}, 1)$, the manufacturer's economic benefits are positively affected by the unit recycling price. It is easy to know from Conclusion 3 that when the unit recycling price increases, the wholesale price will increase. Therefore, manufacturers can obtain more income by selling recycled products, thus increasing profits. And the increase in the unit recycling price means that manufacturers will incur higher costs when recycling waste products. According to the calculation results, the increased cost is lower than the obtained income, so when the unit recycling price increases within the range $(\frac{\alpha C_1 + \mathrm{w}\delta + 2\alpha - 1}{2(\delta - 1)}, 1)$, the manufacturer's profits will still increase.

Conclusion 5 When $\frac{\delta C_1\alpha - 2C_1\alpha - \delta + 8\alpha - 6}{\delta^2 - 4\delta + 4} < \mathrm{P}_c < 1$, the retailer's economic benefits are positively correlated with the unit recycling price. When $0 < \mathrm{P}_c < \frac{\alpha C_1 + \mathrm{w}\delta + 2\alpha - 1}{2(\delta - 1)}$, the retailer's economic benefits are negatively correlated with the unit recycling price.

Proof: Substitute $w = \frac{1 + \delta \mathrm{P}_c - C_1\alpha}{2}$ into $\mathrm{p} = \frac{1 + C_1\alpha + \delta P_c + w + P_c}{2}$ to obtain $\mathrm{P} = \frac{C_1\alpha + 3\delta P_c + 2P_c + 3}{4}$, and then substitute p, w into the retailer's economic benefit function and take the first derivative to obtain $\partial \pi_{\mathrm{d}} / \partial \mathrm{P}_{\mathrm{c}} = \frac{\mathrm{P}_{\mathrm{c}}\delta^2 + (-\mathrm{C}_1\alpha - 4\mathrm{P}_{\mathrm{c}} + 1)\delta + (-8 + 2\mathrm{C}_1)\alpha + 4\mathrm{P}_{\mathrm{c}} + 6}{8}$. By calculation $\frac{6 + \delta}{\delta C_1 - 2C_1 + 8} < \alpha < 1$, it is obtained that when $\frac{\delta C_1\alpha - 2C_1\alpha - \delta + 8\alpha - 6}{\delta^2 - 4\delta + 4} < \mathrm{P}_c < 1$, the first derivative of the retailer's economic benefit function is greater than zero. When $0 < \mathrm{P}_c < \frac{\delta C_1\alpha - 2C_1\alpha - \delta + 8\alpha - 6}{\delta^2 - 4\delta + 4}$, the first derivative is less than zero.

Conclusion 5 indicates that when the unit recycling price is $(0, \frac{\delta C_1\alpha - 2C_1\alpha - \delta + 8\alpha - 6}{\delta^2 - 4\delta + 4})$, the increase in the unit recycling price will increase the retailer's recycling cost, thus reducing the retailer's economic benefits. When the unit recycling price is $(\frac{\delta C_1\alpha - 2C_1\alpha - \delta + 8\alpha - 6}{\delta^2 - 4\delta + 4}, 1)$, the increase in the unit recycling price will increase the retailer's economic benefits. Similarly to Conclusion 4, when the unit recycling price increases, the retailer's sales price will also increase, meaning that the retailer gets more sales income, so the retailer's profits will increase. However, when the sales price is too high, consumers may no longer buy the remanufactured product, so in the O2O recycling pricing model, manufacturers and retailers need to set a reasonable unit recycling price to achieve the optimal profit for themselves and ensure the normal operation of the O2O recycling model.

Conclusion 6 The retailer's selling price is directly proportional to the sensitivity coefficient of the demand function.

Proof: It can be known from the sales price function $\mathrm{p}=\dfrac{1+C_1\alpha+\delta P_c+w+P_c}{2}$ that the sales price p increases with the increase of the sensitive coefficient of the demand function.

Conclusion 6 suggests that the demand function's sensitivity coefficient positively influences the retailer's sales price. The sensitive coefficient of the demand function refers to the proportion of the income consumers get from selling waste products that is used to buy the company's remanufactured products again. If this coefficient is higher, it means that consumers are willing to spend more money to buy the company's remanufactured products, so retailers, in order to maximize their own benefits, will set a higher sales price. The increase in the money consumers spend on remanufactured product purchases will lead to an increase in the retailer's sales price. It can be concluded that the retailer's sales price is positively correlated with the sensitive coefficient of the demand function.

Conclusion 7 The manufacturer's wholesale price is positively correlated with the sensitive coefficient of the demand function.

Proof: Let the function of (6) $\partial\pi_m/\partial w=\dfrac{1-C_1\alpha+\delta \mathrm{P}_c-2w}{2}$ equal 0, and obtain $w=\dfrac{1+\delta\mathrm{P}_c-C_1\alpha}{2}$. From this formula, it is known that the wholesale price increases with the increase of the sensitive coefficient of the demand function.

Conclusion 7 indicates that as the sensitive coefficient of the demand function increases, the manufacturer's wholesale price will also increase. Similarly to Conclusion 6, when the sensitive coefficient of the demand function increases, it indicates that consumers are willing to spend more money to buy remanufactured products. Manufacturers, considering profit, will raise the wholesale price. It can be seen that the sensitive coefficient of the demand function has a positive correlation with the manufacturer's wholesale price and the retailer's sales price. Therefore, studying and predicting the sensitive coefficient of consumers' demand functions is of reference significance for manufacturers and retailers to set their wholesale prices and sales prices respectively. The sensitive coefficient of the demand function is a coefficient worth paying attention to in the process of recycling pricing research, and it has an impact on the entire pricing process.

Conclusion 8 When $0<\delta<\dfrac{2(C_1\alpha+2\alpha-1)}{C_1\alpha-1}$, the manufacturer's economic benefits are positively correlated with the sensitive coefficient of the demand function. When $\dfrac{2(C_1\alpha+2\alpha-1)}{C_1\alpha-1}<\delta<1$, the manufacturer's economic benefits are negatively correlated with the sensitive coefficient of the demand function.

Proof: The manufacturer's economic benefit function is $\pi_m=\dfrac{((\delta C_1-2C_1-2)\alpha-\delta+2)\alpha}{(\delta-2)^2}$ known, and the first derivative with respect to is taken to obtain $\partial\pi_m/\partial\delta=-\dfrac{((\delta C_1-2C_1-4)\alpha-\delta+2)\alpha}{(\delta-2)^3}$. By calculation $0<\alpha<\dfrac{1}{C_1+2}$, it is obtained that when $0<\delta<\dfrac{2(C_1\alpha+2\alpha-1)}{C_1\alpha-1}$, $\partial\pi_m/\partial\delta=-\dfrac{((\delta C_1-2C_1-4)\alpha-\delta+2)\alpha}{(\delta-2)^3}$ is greater than zero, and when $\dfrac{2(C_1\alpha+2\alpha-1)}{C_1\alpha-1}<\delta<1$, $\partial\pi_m/\partial\delta=-\dfrac{((\delta C_1-2C_1-4)\alpha-\delta+2)\alpha}{(\delta-2)^3}$ is less than zero.

Conclusion 8 indicates that when the sensitive coefficient of the demand function is $(0,\frac{2(C_1\alpha+2\alpha-1)}{C_1\alpha-1})$, the increase in the sensitive coefficient of the demand function will increase the manufacturer's profits. This is because the increase in this coefficient means that consumers spend more money on buying remanufactured products, thus increasing the manufacturer's income and profits. When the sensitive coefficient of the demand function is $(0,\frac{2(C_1\alpha+2\alpha-1)}{C_1\alpha-1})$, the increase in the sensitive coefficient of the demand function will reduce the manufacturer's economic benefits. Because when the wholesale price and sales price keep increasing due to the increase in the demand function, the excessively high sales price will make consumers no longer buy the remanufactured product, leading to a decrease in profits. Therefore, although the increase in the sensitive coefficient of the demand function within $(0,\frac{2(C_1\alpha+2\alpha-1)}{C_1\alpha-1})$ can increase the wholesale price and profits, under the condition that the O2O recycling model pricing model is established, when exceeds the critical value, the increase in the sensitive coefficient of the demand function will cause the manufacturer's economic benefits to decrease. Therefore, in the O2O recycling model, the sensitive coefficient of the demand function should be within a reasonable range, otherwise, the pricing model will not be established.

Conclusion 9 When $0<\delta<\frac{2(C_1\alpha^2-C_1\alpha+5\alpha^2-5\alpha+1)}{C_1\alpha^2-C_1\alpha-\alpha+1}$, the retailer's economic benefits are positively correlated with the sensitive coefficient of the demand function. When $\frac{2(C_1\alpha^2-C_1\alpha+5\alpha^2-5\alpha+1)}{C_1\alpha^2-C_1\alpha-\alpha+1}<\delta<1$, the retailer's economic benefits are negatively correlated with the sensitive coefficient of the demand function.

Proof: The retailer's economic benefit function takes the first derivative to obtain $\partial\pi_m/\partial\delta=\frac{((\delta C_1-2C_1-10)\alpha^2+((-C_1-1)\delta+2C_1+10)\alpha+\delta-2}{(\delta-2)^3}$, and by calculation $0<C_1<\frac{-5\alpha^2+5\alpha-1}{\alpha(\alpha-1)}$, it is obtained that when $0<\delta<\frac{2(C_1\alpha^2-C_1\alpha+5\alpha^2-5\alpha+1)}{C_1\alpha^2-C_1\alpha-\alpha+1}$, the first derivative of the retailer's economic benefit function is greater than zero. When $\frac{2(C_1\alpha^2-C_1\alpha+5\alpha^2-5\alpha+1)}{C_1\alpha^2-C_1\alpha-\alpha+1}<\delta<1$, the first derivative is less than zero.

Conclusion 9 indicates that when the sensitive coefficient of the demand function does not exceed the value $\frac{2(C_1\alpha^2-C_1\alpha+5\alpha^2-5\alpha+1)}{C_1\alpha^2-C_1\alpha-\alpha+1}$, it has a positive impact on the retailer's economic benefits, and when it exceeds this value, it will have a negative impact. Similarly to Conclusion 8, the increase within $(0,\frac{2(C_1\alpha^2-C_1\alpha+5\alpha^2-5\alpha+1)}{C_1\alpha^2-C_1\alpha-\alpha+1})$, due to the increase in the money spent on buying remanufactured products, leads to an increase in the retailer's profits. As the sales price keeps increasing, the excessively high sales price will make consumers no longer buy the remanufactured product, leading to a decrease in the retailer's profits. It can be seen that the sensitive coefficient of the demand function is a parameter that needs to be observed, and it has an important impact on the entire O2O model pricing. Retailers should predict the consumer purchase willingness in the market to better set prices and maximize their own profits.

Conclusion 10 The unit recycling price is negatively correlated with the sensitive coefficient of the demand function.

Proof: Take the first derivative of the optimal recycling price function with respect to $P_c^*=\frac{2-\delta+\delta C_1\alpha-2C_1\alpha-4\alpha}{\delta^2-4\delta+4}$ to obtain $\partial P_c/\partial\delta=\frac{(-\delta C_1+2C_1+8)\alpha+\delta-2}{(\delta-2)^3}$ is less than zero, the unit recycling price decreases as the sensitive coefficient of the demand function increases.

Conclusion 10 indicates that the higher the sensitive coefficient of the demand function, the higher the purchase volume of remanufactured products, and the recycling scale will also increase. Under the influence of economies of scale, the unit recycling price of a single product will correspondingly decrease.

Therefore, it can be concluded that the unit recycling price is negatively correlated with the sensitive coefficient of the demand function.

Conclusion 11 The retailer's selling price increases with the offline recycling ratio, while the manufacturer's wholesale price decreases with it.

Proof: It can be known from the sales price function $\mathrm{p}=\frac{1+C_1\alpha+\delta P_c+w+P_c}{2}$ that the sales price p increases with the increase of the offline recycling ratio. It can be known from the wholesale price function $w=\frac{1+\delta \mathrm{P}_c-C_1\alpha}{2}$ that the wholesale price decreases with the increase of the offline recycling ratio.

Conclusion 11 indicates that as the offline recycling ratio increases, the retailer's sales price will increase. This is because the offline recycling price is equal to the online recycling price, and the offline recycling has an additional recycling cost, so the total cost of offline recycling is higher. If the proportion of offline recycling increases, then the total cost of recycling waste products for retailers will increase, and retailers will correspondingly increase the sales price to improve profits. It can be seen that the offline recycling ratio has a positive impact on the retailer's sales price. On the contrary, the offline recycling ratio has a negative impact on the manufacturer's wholesale price.

Conclusion 12 When $0<\alpha<\frac{\delta-2}{2(\delta C_1-2C_1-2)}$, the manufacturer's economic benefits are positively correlated with the offline recycling ratio.

When $\frac{\delta-2}{2(\delta C_1-2C_1-2)}<\alpha<\frac{\delta^2-3\delta+2}{\delta^2C_1-3\delta C_1-\delta-2+C_1}$, the manufacturer's economic benefits are negatively correlated with the offline recycling ratio.

Proof: The manufacturer's economic benefit function is $\pi_m=\frac{((\delta C_1-2C_1-2)\alpha-\delta+2)\alpha}{(\delta-2)^2}$, and the first derivative is taken to obtain $\partial\pi_m/\partial\alpha=\frac{(2\delta C_1-4C_1-4)\alpha-\delta+2}{(\delta-2)^2}$. Let it be greater than zero, combined with the value range of various parameters when the O2O pricing model is established, the value range is $(0, \frac{\delta-2}{2(\delta C_1-2C_1-2)})$. Let it be less than zero, and the value range is $(\frac{\delta-2}{2(\delta C_1-2C_1-2)}, \frac{\delta^2-3\delta+2}{\delta^2C_1-3\delta C_1-\delta-2+C_1})$.

Conclusion 12 indicates that when the offline recycling ratio increases, it will have a positive impact on the manufacturer's economic profits, and when the offline recycling ratio exceeds the value $\frac{\delta-2}{2(\delta C_1-2C_1-2)}$, it will have a negative impact. This is because online recycling is less than offline recycling by an offline recycling cost, and when online recycling reaches a certain scale, its total recycling cost will be less than offline recycling. Therefore, it is necessary to reasonably allocate the proportion of online and offline recycling to maximize the profits of manufacturers and retailers, and to give full play to the advantages of the O2O recycling model, and to maximize the overall recycling profit by making full use of the combination of online and offline recycling.

Conclusion 13 The unit recycling price is negatively correlated with the offline recycling ratio.

Proof: It can be known from the optimal recycling price function $\mathrm{P}_c^*=\frac{2-\delta+\delta C_1\alpha-2C_1\alpha-4\alpha}{\delta^2-4\delta+4}$ that the unit recycling price decreases as the offline recycling ratio increases.

Conclusion 13 indicates that when the offline recycling ratio increases, the unit recycling price of manufacturers and retailers will decrease. This is because offline recycling has an additional recycling cost compared to online recycling, and an increase in the offline recycling ratio will increase the total cost of recycling waste products. At this time, retailers will reduce the unit recycling price to ensure their own profits. It can be seen that the unit recycling price will decrease as the offline recycling ratio increases.

Conclusion 14 The retailer's selling price is directly proportional to the offline recycling cost, while the manufacturer's wholesale price is inversely proportional to it.

Proof: It can be known from the sales price function $p=\frac{1+C_1\alpha+\delta P_c+w+P_c}{2}$ that the sales price p increases with the increase of the offline recycling cost. It can be known from the wholesale price function $w=\frac{1+\delta P_c-C_1\alpha}{2}$ that the wholesale price decreases with the increase of the offline recycling cost.

Conclusion 14 indicates that an increase in offline recycling costs will lead to an increase in the retailer's sales price p. In the case of increased recycling costs, retailers will pay more for recycling, and to improve profits, retailers will correspondingly increase the sales price. Since online recycling does not require recycling costs, the total cost of manufacturers' recycling will not increase with the increase of offline recycling costs, and manufacturers may reduce their wholesale prices to obtain more online recycling opportunities, so the wholesale price will decrease instead. In summary, in order to achieve higher economic benefits for retailers and the overall closed-loop supply chain, it is necessary to control the offline recycling costs as much as possible.

Conclusion 15 The manufacturer's profit is negatively correlated with the offline recycling cost.

Proof: From the manufacturer's profit function $\pi_m=\frac{((\delta C_1-2C_1-2)\alpha-\delta+2)\alpha}{(\delta-2)^2}$, it can be obtained that the manufacturer's profit decreases as the offline recycling cost increases.

Conclusion 15 indicates that if the offline recycling cost increases, the retailer's recycling cost will increase, and the budget retailers use to buy remanufactured products from manufacturers will decrease, which will reduce the manufacturer's wholesale price, and thus the manufacturer's profit will decrease. In addition, from the above conclusions, it is known that the manufacturer's wholesale price will decrease as the offline recycling cost increases. Since the wholesale price has decreased, the manufacturer's economic benefits will also decrease, which also explains the reason why the manufacturer's economic benefits are negatively correlated with the offline recycling cost.

Conclusion 16 The retailer's profit is negatively correlated with the offline recycling cost.

Proof: Take the first derivative of the retailer's economic benefit function with respect to to obtain $\partial\pi_d/\partial C_1=-\frac{\alpha(\delta-1)(\alpha-1)}{\delta-2}$ less than zero, it is known that when the offline recycling cost increases, the retailer's economic benefits will decrease.

Conclusion 16 indicates that in the O2O recycling model, when the offline recycling cost increases, the retailer's profit will decrease. An increase in offline recycling costs means that retailers have to pay more for recycling, so the retailer's expenditure increases, and thus the profit decreases. Therefore, retailers, for their own profit consideration, should try to reduce the offline recycling cost and not allow the offline recycling cost to be too high, resulting in too low retailer profits and no motivation to recycle waste products.

Conclusion 17 The unit recycling price is negatively correlated with the offline recycling cost.

Proof: From the optimal recycling price function $P_c^*=\frac{2-\delta+\delta C_1\alpha-2C_1\alpha-4\alpha}{\delta^2-4\delta+4}$, it can be known that the unit recycling price decreases as the offline recycling cost increases.

Conclusion 17 indicates that as the offline recycling cost increases, the unit recycling price will decrease. This is because when the offline recycling cost is too high, retailers will pay more for recycling, and to reduce the total recycling cost, retailers will correspondingly reduce the expenditure on the unit recycling price, so the unit recycling price will decrease.

5. Conclusion

This paper studies the pricing decisions in the closed-loop supply chain under the O2O recycling model and obtains the market conditions for the implementation of the O2O recycling model, that is, the offline recycling ratio and offline recycling cost must be controlled within a certain value range. In addition, the relationships between relevant parameters and the pricing and profits of manufacturers and retailers are derived, including the impact of unit recycling price, demand function sensitive coefficient, offline recycling ratio, and offline recycling cost on the pricing and profits of manufacturers and retailers under the O2O recycling model. From the above conclusions of this paper, in order to make the O2O recycling work normally, it is necessary to set reasonable ratios and prices, coordinate the profits of operators, and thus achieve the benign development of the recycling industry under the O2O recycling model.

There are also shortcomings in this study. In previous studies, most scholars have assumed that remanufactured goods and new items are homogeneous and priced the same. Therefore, this study also assumes that reconditioned products and new products are homogeneous and priced the same. However, in reality, consumers have different psychological expected pricing for these two types of products. Therefore, subsequent studies can focus on the differential pricing issues of reprocessed products and new products.

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