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Research on Pricing Strategy of Closed-Loop Supply Chain Considering Consumer Expectation

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Abstract

When consumers participate in recycling, they value the used products to form an expected price, and then they compare it with the actual recycling price to determine whether to recycle or not. A game model of different recovery modes is constructed, analyzes the impact of consumer expectation sensitivity coefficient on recycling price and quantity, and analyzes the impact of the elasticity coefficient of the recycling price on the decision variables. The results show that: recyclers adjust the recycling price close to consumer expectation, and recycling price and quantity vary inversely with the consumer expectation sensitivity coefficient. In addition, we find consumers benefit from purchases and returns in centralized decision-making, while retailer recycling is more effective for enterprises.

Keywords

Closed-loop Supply Chain; Consumer Expectation; Recycling Channels; Pricing Decisions.

1. Introduction

With the development of technology, the product life cycle begins to shorten, resulting in a serious loss of used products and a waste of social resources. And recycling and remanufacturing can reduce the use of energy and the consumption of fresh raw materials, which is very helpful to the environment. So it has got the attention of the country, government, and enterprises. Consumers are the main body involved in the recycling process of used products, they decide whether to participate in recycling by comparing the expected price in their mind with the actual recycling price. This affects recycling price, quantity and enterprise profit. Therefore, the impact of consumer expectation on enterprise decision-making becomes more important.

At present, the related research of closed-loop supply chain has been widely concerned by scholars at home and abroad. Research on pricing and the selection of recycling channels in closed-loop supply chain, Savaskan et al. studied the manufacturer-led selection and pricing of three single recycling models and found that retailer recycling is the best recycling mode [1]. Giri et al. considered cross-channel influences and constructed a closed-loop supply chain model consisting of a single manufacturer, a single retailer, and a single third party, and explored the effects of key parameters on the profits of channel members under different circumstances. They found that it performed the best when it was led by retailers and the worst when it was led by third parties[2]. Gu Qiaolun et al. comparatively analyzed the efficiency of three different pricing strategies[3]. Liu Yongqing et al. studied the issue of consumer preferences for recycling channels and explored the impact of consumer recycling behavior on the recycling decision of recyclers and disposers. The results showed that the recycling price of the online recycling channel was higher than the traditional recycling channel[4]. Guo Sandang et al. studied the optimal pricing problem of different recycling channels under two types of subsidies: remanufacturing subsidies and recycling subsidies[5]. The above literature studies the pricing decision of closed-loop supply chain under different recycling channel models but ignores the impact of consumer expectation on closed-loop supply chain.

In addition, in terms of consumer expectation, Zhang Yaming et al. applied game theory to explore the impact of developers' and consumers' psychological expectation on house prices. He pointed out that consumers' psychological expectation determined their purchasing behavior, which in turn determined the basic trend of house price[6]. According to the characteristics of consumers' and online recyclers' valuation of used products. Xu Liming et al.studied the pricing decision of "Internet+Recycling" under the short-sighted and far-sighted behaviors of consumers. The results showed that online recycling could obtain higher profits when the recycling price and the estimated recycling price level satisfied certain conditions, and online recycling channels could increase the quantity of used products[7]. Gu Qiaolun et al. pointed out that consumers will consider the price of new products, trade-in price, and subsidies as the reference effect to consider whether they satisfied their expectation and then chose the recycling method[8]. Li Wenlong et al. studied the impact of the consumer sensitivity coefficient on the recycling quantity and the optimal profit of supply chain members under different recycling modes[9]. Besides, Hu et al.pointed out that in the reverse supply chain, consumers would not sell their used products until an appropriate price, which achieves their willingness[10]. At the same time, consumers will make reasonable decisions between direct and indirect recycling channels[11]. Therefore, it is important to consider the behavior of consumers in the recycling process.

Therefore, this paper studies the impact of consumer expectation on closed-loop supply chain operations. And constructs a closed-loop supply chain system consisting of one manufacturer and one retailer, and analyzes the impact of consumer expectation on recycling price and quantity, as well as analyses the impact of the elasticity coefficient of recycling price on decision-making behavior of closed-loop supply chain members.

2. Model Construction

This paper constructs a closed-loop supply chain consisting of one manufacturer and one retailer. The manufacturer sells products through traditional retail channels, and the manufacturer acts as a Stackelberg leader. This paper mainly considers two recycling modes: manufacturer recycling (model M) and retailer recycling (model R). The manufacturer wholesales products to the retailer at the wholesale price w, and the retailer sells them to the consumer at the price p . The model is shown in Figure 1:

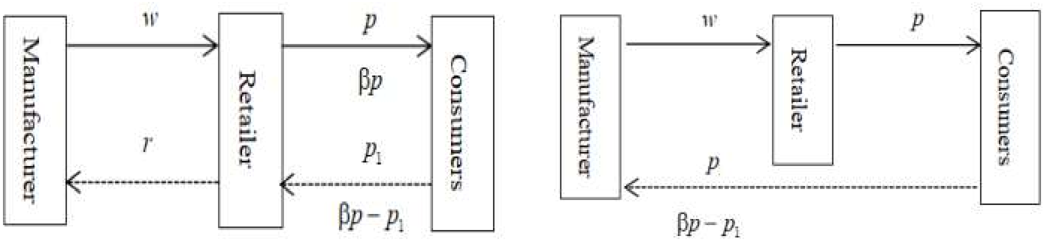

Figure 1. Model structure

2.1 Model Assumptions

For the convenience of research, this paper makes the following assumptions:

Assumption 1: c_m and c_r represent the unit cost and unit remanufacturing cost of used product of the manufacturer, and $c_r < c_m$. $\Delta = c_m - c_r$ is the cost savings per unit of remanufactured product. In addition, there is no difference between the new products and remanufactured products.

Assumption 2: The recycling price of used products not only affects the recycling quantity, but also affects the market demand for new products, and a higher recycling price can increase the demand for new products[12]. Therefore, the market demand is affected by the selling and recycling price. Then the market demand function is: $D=a-bp+kp_1$, where $a,b>0$, a is the base market demand, b is the sensitivity of consumers to the selling price, k is the elasticity coefficient of demand to the recycling price, where $k>0$.

Assumption 3: Consumer willingness to recycle is influenced by consumer expectation and actual recycling price. According to literature [12], we assume that consumer expectation is based on the selling price of the new products being purchased at that time, and is reflected in recycling quantity, as: $R=\phi-h(\beta p-p_1)$, ϕ represents a base return quantity, h is a positive parameter, βp is an expected price for used products, β is the price sensitivity coefficient of consumer expectation, where $0\le\beta<1$. Therefore, when the consumer expectation is higher than the actual recycling price, the recycling quantity will decrease; Otherwise, the recycling quantity will increase.

Assumption 4: It is assumed that all used products are used for remanufacturing, the information is symmetric, and members are risk-neutral.

In this paper, we use π_j^i to denote profit function for supply chain members j in model i, $i\in\{C,M,R\}$ represent a centralized decision, manufacturer recycling model, and retailer recycling model; $j\in\{m,r\}$ represent manufacturer and retailer.

3. Model Solution

3.1 Centralized Decision (Model C)

The centralized decision model describes the manufacturer and the retailer as a complete decision maker, viewing them as a central decision maker who decides the selling price and recycling price of the products. In this case, the decision model is as follows:

$$\pi^C=\pi_m^C+\pi_r^C=(p-c_m)D+(\Delta-p_1)R \tag{1}$$

According to equation (1), the total profit of the system π^C to find the first and second order derivatives with respect to p^C and p_1^C, the Hessian matrix π^C is $H(p^C,p_1^C)=\begin{bmatrix}-2b & k+\beta h\\ k+\beta h & -2h\end{bmatrix}$, where $\frac{\partial^2\pi^C}{\partial(p^C)^2}=-2b<0$, $\left|H(p^C,p_1^C)\right|=4bh-(k+\beta h)^2>0$, i.e. $b>\frac{(k+\beta h)^2}{4h}$, π^C is a strictly concave in p^C and p_1^C. By solving the first-order conditions $\frac{\partial\pi^C}{\partial p^C}=0$ and $\frac{\partial\pi^C}{\partial p_1^C}=0$ can get the best selling price p^{C*} and recycling price p_1^{C*}. The optimal decision for model C can be obtained by using inverse solution:

$$p^{C*}=\frac{\Delta\beta h^2+c_mk^2+(c_mk+\phi)\beta h+(\phi-\Delta h)k-2(a+c_mb)h}{k^2+\beta^2h^2+2bh(k-2)} \tag{2}$$

$$p_1^{C*}=\frac{\Delta\beta^2h^2+(\Delta k-a-bc_m)\beta h+(c_mb-a)k+2b(\phi-\Delta h)}{k^2+\beta^2h^2+2bh(k-2)} \tag{3}$$

Bringing in equations (2) and (3) can obtain the optimal demand, quantity of used products and total profit:

$$D^{C*}=\frac{((2bc_m-a-\Delta k)k-(\Delta k+a)\beta h)\beta h+(k+\beta h)\Delta hb+b\phi(\beta h-k)+2(a-bc_m)h}{4bh-k^2-\beta h(\beta h-2k)} \tag{4}$$

$$R^{C*}=\frac{(\beta hc_m-\phi)k^2+((\beta^2h-b)c_mh+(a-2\Delta\beta h+\beta\phi)h)k+\beta b(2\phi+2\Delta h-c_m\beta h)}{4bh-k^2-\beta h(\beta h-2k)} \tag{5}$$

$$\pi^{C*}=\frac{-\Delta\phi k^2+\Delta\beta h(c_mk+c_m\beta h-\Delta h-\phi)k+(a-bc_m)k((\beta c_m+\Delta)h-\phi)+C}{4bh-k^2-\beta h(\beta h-2k)} \tag{6}$$

where $C=(a-bc_m)^2h+(\Delta^2h^2+(2\Delta h+b)\phi)b-(a+bc_m)(\Delta\beta h^2+\phi\beta h)$.

3.2 Manufacturer Recycling Model (Model M)

In model M, the manufacturer wholesales new products, recycles and remanufactures used products. The retailer is responsible for selling new products. The profit functions of the retailer and the manufacturer are as follows:

$$\pi_m{}^M=(w-c_m)D+(\Delta-p_1)R \tag{7}$$

$$\pi_r{}^M=(p-w)D \tag{8}$$

The manufacturer acts as a Stackelberg leader, the manufacturer decides the wholesale price w^M and the recycling price p_1^M to maximize π_m^M, and then the retailer decides the selling price p^M to maximize π_r^M. By solving equations (7) and (8), the optimal decision under model M is:

$$w^{M*}=\frac{-(bc_m+\Delta\beta h)k^2+((2b+\beta^2h)\Delta h-(a+3bc_m)\beta h-2b\phi)k+2(2(c_mb+a)h-M_1}{8b^2h-bk^2-6bk\beta h-b\beta^2h^2} \tag{9}$$

$$p^{M*}=\frac{-(c_mb+2\Delta\beta h)k^2-((2a+bc_m)k+\Delta bh+b\phi)\beta h+3(\Delta h-\phi)bk+2(3a+c_mb)hb}{8b^2h-bk^2-6bk\beta h-b\beta^2h^2} \tag{10}$$

$$p_1^{M*}=\frac{((bc_m-a)+3\Delta\beta h)k+(\Delta\beta h-(3a+bc_m))\beta h+4b(\phi-\Delta h)}{k^2+6k\beta h+\beta^2h^2-8\beta h} \tag{11}$$

Bringing in equations (10) and (11) can obtain the optimal demand and quantity of used products:

$$D^{M*}=\frac{\beta h(b\phi-\Delta k^2+\Delta bh+(2c_mb-a)k)-\beta^2h^2(\Delta k+a)+b(k(\Delta h-\phi)+2h(a-bc_m))}{8bh-k^2-6k\beta h-\beta^2h^2} \tag{12}$$

$$R^{M*}=\frac{(\beta h(2\Delta k+2a+bc_m)+(c_m k-6\Delta h-3b\phi)b)\beta hk-b\phi k^2+((a-bc_m)k-M_2}{8b^2h-bk^2-6bk\beta h-b\beta^2h^2} \tag{13}$$

where $M_1=(\Delta h+\phi)\beta h)b+a\beta^2h^2, M_2=(3a+bc_m)\beta h+4b(h\Delta+\phi))bh$.

The optimal profit $\pi_m{}^{M*}$, $\pi_r{}^{M*}$ can be obtained by bringing in equations (9), (10) and (11).

3.3 Retailer Recycling Model (Model R)

In model R, the manufacturer wholesales new products and remanufactures used products, and the retailer is responsible for selling new products and recycling used products. The profit functions of the retailer and the manufacturer are as follows:

$$\pi_m{}^R=(w-c_m)D+(\Delta-r)R \tag{14}$$

$$\pi_r{}^R=(p-w)D+(r-p_1)R \tag{15}$$

The manufacturer decides the wholesale price w^R to maximize π_m^R, and the retailer decides the selling price p^R and the recycling price $p_1{}^R$ to maximize π_r^R. By solving equations (14) and (15), the optimal decision under model R is:

$$w^{R*}=\frac{(\Delta-2r)(\beta hk(k+\beta h)+bh(k-\beta h))-k\beta h(a+2bc_m)-b\phi k+R_1}{4h(b^2-b\beta h)} \tag{16}$$

$$p^{R*}=\frac{(\Delta-2r)R_2+((a+2bc_m)\beta h+b\phi)\beta k^3+R_3k^2+((\beta a+(3\Delta-2r)b)k\beta^2h^3+R_4}{4b\beta h(k^3+2\beta hk^2+\beta^2h^2k-(6k-1)bh)+4(bh^2-hk^2)b^2} \tag{17}$$

$$p_1^{R*}=\frac{((\Delta-2r)(\beta k+b)h+R_5)k^2+((\Delta+2r)\beta^3h^3+R_6)k-((\Delta+2r)\beta^2b+a\beta^3)h^3+R_7}{4\beta h(k^3+2\beta hk^2+\beta^2h^2k-(6k-1)bh)+4(bh^2-hk^2)b} \tag{18}$$

Bringing in equations (17) and (18) can obtain the optimal demand and quantity of used products:

$$D^{R*}=\frac{R_8+((\Delta b+(2bc_m-a)\beta)h-\phi b)k+(\beta b\Delta-a\beta^2)h^2+(2a-2bc_m+\beta\phi)bh}{-2(k^2+2\beta hk+\beta^2h^2-4bh)} \tag{19}$$

$$R^{R*}=\frac{(\Delta-2r)R_9+(3b\phi-(a+2bc_m)\beta h)k^2+(R_{10}+2(bc_m-a+2\beta\phi)bh)k+R_{11}}{4(bk^2+2b\beta hk+b\beta^2h^2-4b^2h)} \tag{20}$$

The optimal profit $\pi_m{}^{R*}$, $\pi_r{}^{R*}$ can be obtained by bringing in equations (16), (17) and (18).

Where:

$R_1=(2a+2bc_m+\beta\phi)bh-a\beta^2h^2$, $R_2=bhk^3-(\beta h(\beta h+2k)+k^2)\beta hk^2$;

$R_3=(4\beta b(\Delta-3r)+2\beta^2(a+bc_m))h^2+2(2\beta\phi-bc_m-a)bh$;

$R_4=(2b(4r-\Delta)+3\beta(\beta\phi-4a-2bc_m))kbh^2-6b^2h\phi-2b\beta(\Delta b+\beta a)h^3+2(6a-2bc_m-\beta\phi)b^2h$;

$R_5=\beta h(4r\beta h+2bc_m-3a)$, $R_6=2(2\beta a+6br+\beta bc_m)\beta h^2+2(a-bc_m+3\beta\phi)bh$;

$R_7=((2bc_m+\beta\phi+6a)\beta b+8rb^2)h^2-8b^2h\phi$, $R_8=-\beta h\Delta k(k+\beta h)$;

$R_9=\beta h(k^3+2\beta hk^2+\beta^2h^2k)-bh(1+\beta^2h^2)$;

$R_{10}=2(b(6r-\Delta)-(a+bc_m)\beta)\beta h^2$, $R_{11}=(\beta b(2bc_m+\beta\phi+6a)-8rb^2)h^2-8b^2h\phi-a\beta^3h^3$;

In addition, to ensure that the recycling quantity in the market is less than the market demand, i.e. $R\le D$, can obtain the maximum value ϕ for each model. This condition should be taken into account in the subsequent numerical simulation.

Due to the complexity of the equilibrium solution, the effect of key parameters on each decision variable is analyzed through numerical simulation.

4. Numerical Examples

This part analyzes the above models through specific numerical values. To analyze the impacts of consumer expectation sensitivity coefficient β on recycling price and quantity, and the impacts of elasticity coefficient of recycling price k on the price and profit. The values of relevant parameters are set as Table 1.

Table 1. Setting for parameters

Parameters	Values	Parameters	Values
a	250	ϕ	100
c_m	40	b	2
c_r	8	r	30
h	1.8		

We set the consumer expectation sensitivity coefficient $\beta=0.5$. When the elasticity coefficient of recycling price $k\in[0,1.5]$, Figure 2(a) and 2(b) show the impact of k on the recycling price; Figure 2(c) shows the impact on the price; Figure 2(d) shows the impact on the demand; Figure 3(e) and 3(f) show the impact on profit.

Meanwhile, We set the elasticity coefficient of recycling price $k=1.9$. When the consumer expectation sensitivity coefficient $\beta\in[0,0.8]$, Figure 3(g) shows the impact of β on recycling price and Figure 3(h) shows the impact on recycling quantity.

From Figure 2(a) to 2(d) and Figure 3(e), 3(f), the recycling price, price, demand, retailer's and total profit increase as the elasticity coefficient of recycling price increases, This suggests that the higher elasticity coefficient of recycling price is, the higher demand for new products. At the same time, manufacturers and retailers will raise their selling price to gain greater profit. Total profit increases as the positive effect of the increase in selling price and demand outweigh the negative effect of the increase in recycling price.

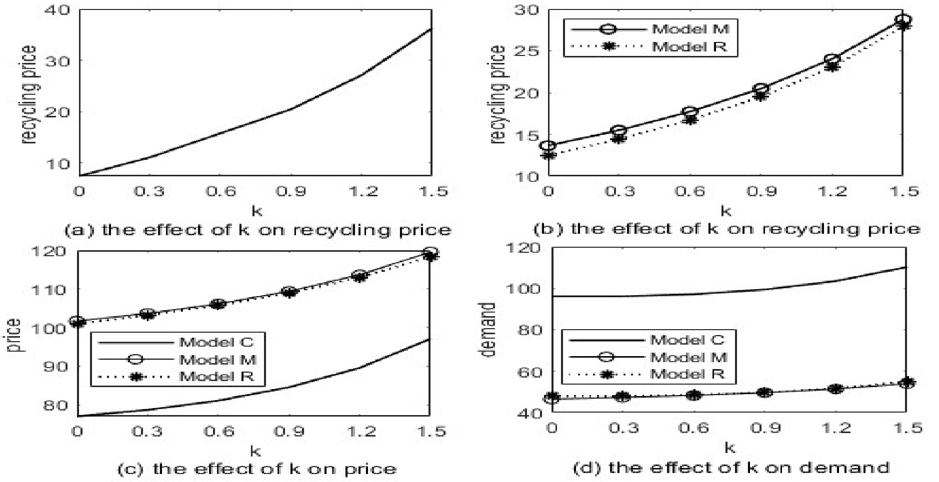

Figure 2. The effects of k on recycling price, price and demand for each model

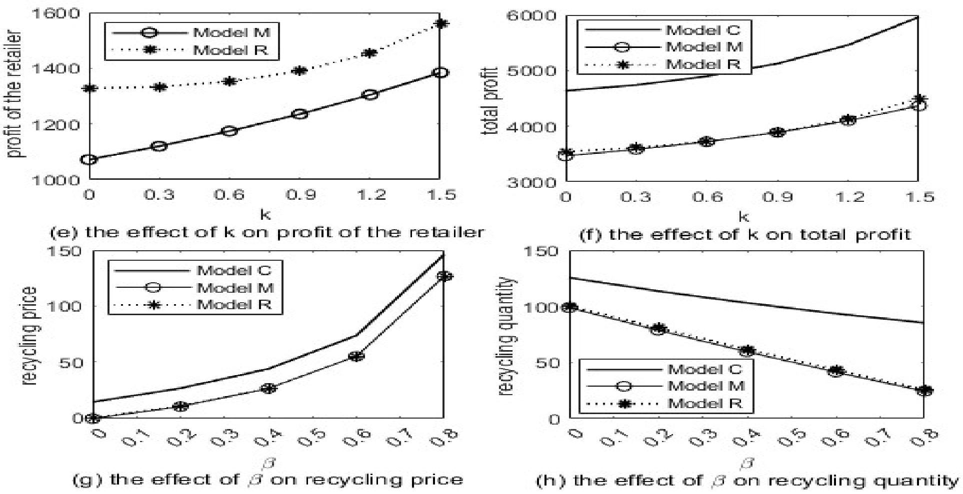

Figure 3. The effects of k on profit and β on recycling price and quantity for each model

According to Figure 3(g) and 3(h), when consumer expectation sensitivity coefficient increases, the recycling price of used products will increase, but the recycling quantity will decrease. This suggests that with the higher consumer expectation of recycling price, the recyclers will raise the recycling price close to the consumer expectation to ensure recycling quantity. However, when consumer expectation becomes higher, the recyclers can not satisfy consumer expectation by raising recycling price, so recycling quantity will decrease. Therefore, the recyclers should take appropriate measures to reduce consumer expectation, which will generate more profits for enterprises.

In addition, Figure 2 and Figure 3 indicates that the recycling price and total profit are greater in centralized decision than in decentralized decision, and the selling price is lower. In Models M and Models R, Model R has a lower selling price than Model M, and higher demand and profit than Model M. This shows that customers benefit from purchases and returns in centralized decisions. At the same time, the retailer recycling model is the best for enterprises.

5. Conclusion

This paper constructs a closed-loop supply chain consisting of one manufacturer and one retailer, and analyzes the impacts of consumer expectation on the recycling price and quantity, and analyzes the impact of the elasticity coefficient of recycling price on the decision variables. The main conclusions are as follows: (1) When consumer expectation sensitivity coefficient increases, the recyclers increase

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the recycling price close to consumer expectation, but the recycling quantity decrease; (2) The higher elasticity coefficient of recycling price is, the more profit can be obtained by supply chain members; (3) In the centralized model, customers benefit from both purchases and returns. At the same time, it is the best for enterprises to choose the retailer recycling model that is close to the consumer market.

Through the analyses, the following important managerial insights are offered: Firstly, the recyclers should take relevant measures to reduce the sensitivity of consumer expectation to increase recycling quantity and obtain more profit; Secondly, enterprises should set different recycling price based on the sales price of different products, which can promote the demand for products and increase the enterprises' profits; And finally, the enterprises should choose the retailers for recycling.

This paper only considers the model of one product, one manufacturer and one retailer. In reality, the complexity of the environment will inevitably lead to competition between products and enterprises. The next step can be extended to the model of multiple products, multiple manufacturers and multiple retailers. At the same time, this study does not consider advertising, service efforts, etc. During the actual sales process, the sellers will take relevant measures to expand demand.

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