Decision Model of Double Channel Recycling Closed Loop Supply Chain Considering Service Level

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Abstract: With the development of economy and the iteration and upgrading of science and technology, the upgrading rate of electronic products has been gradually accelerated. Improving the recycling volume of waste electronic products and forming a standardized recycling system are the key issues facing the current recycling link. Under this background, based on Stackelberg game model, the author establishes a closed loop supply chain model of dual channel recycling of waste electronic products, and takes profit maximization as the decision objective to conduct a numerical analysis. The paper proves that under certain conditions, consumers' online channel preference will promote the profits and recycling capacity of the supply chain system, and improve the service level of recycling participants, which has a positive effect on the system profits.

1 INTRODUCTION

With the gradual improvement of the upgrading rate of electronic products, the recycling of waste electronic products has attracted more attention. Electronic product recycling can effectively reduce environmental pollution and production costs. At present, domestic and foreign scholars mainly consider pricing decisions and contract coordination under such influencing factors as consumer behavior, demand, channel dominance, and fairness concerns. There is less research on service level decisions. At the same time, there is also insufficient research on reverse supply chains where different entities provide different types of recovery services. Therefore, this paper mainly constructs a dual channel recycling model of waste electronic products considering service level, analyzes the game relationship between different players in the supply chain, and judges the impact of service level on decision-making.

2 PROBLEM DESCRIPTION AND MODEL ASSUMPTION

2.1 Problem Description

The main body of this paper is a dual channel recycling closed-loop supply chain, which includes two links: forward logistics and reverse logistics. In the positive process, manufacturers wholesale their goods to retailers at wholesale prices, and retailers sell their products to consumers at retail prices. In the process of reverse logistics, third-party recyclers and Internet recycling platforms respectively recycle waste electronic products from consumers at different offline and online recycling prices, and manufacturers recycle them from both at recycling transfer prices. The closed-loop supply chain structure of dual channel recycling is shown in Figure 1.

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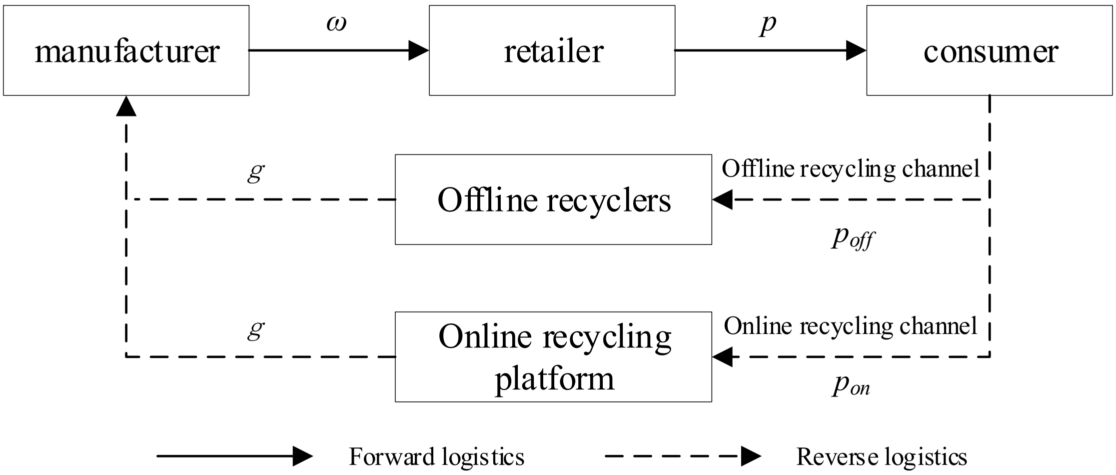


Figure 1. Double channel recycling closed-loop supply chain

In the supply chain system, the manufacturer and retailer, offline recycler and online recycling platform are Stackelberg game relations, the manufacturer is the leader of the game, and the other three are followers. The decision-making process of the system is as follows:

(1) the manufacturer determines the wholesale price ω and recycling price g .

(2) Retailers set the selling price p based on ω, offline recyclers and online recycling platforms set the offline recycling price p_{off} and online recycling price p_{on} based on p and g respectively.

2.2 Model Assumption

In order to accurately describe the operation mode of the supply chain system model, this paper proposes the following assumptions:

(1) The decision-making objective of each subject is to maximize economic benefits, without considering the influence of irrational factors.

(2) In the game relationship, the decision is made under the condition of complete information, the manufacturer gives priority to the decision, then others follow.

(3) The quality of remanufactured products is the same as that of new products, the sales price of both is the same, and the consumer acceptance is the same. The production cost of remanufactured products is c_r, and the production cost of new products is c_n, $\Delta = c_n - c_r > 0$. (Giri, 2017)

(4) The damage degree of WEEE is consistent, and the recovery conversion rate is 100%, that is, Δ remains unchanged. (Wu, 2019)

(5) Because the service level of traditional offline recycling channels is very low, this paper does not consider the service level of this channel, but only considers the service level of online recycling channels.

(6) Discuss a single cycle decision-making model, assuming that the products of the previous cycle can be recycled in the current research cycle.

(7) The recycling function of waste products is assumed to be a linear function of online recycling price, offline recycling price and service level. A large number of literatures have used this function (Wu, 2019; Wu, 2012; Huang, 2012). Manufacturers and Internet recycling platforms need to pay corresponding service costs to provide recycling services. This paper assumes that the service cost is positively correlated with the square of the service level. (Wang, 2017; Guo, 2019)

3 MODEL BUILDING

3.1 Parameter Definition

Two dual-channel supply chain inventory models are constructed based on the multi-agent method. The parameters and relevant symbols of the model are shown in Table 1.

Table 1: Symbols and parameter definitions.

Symbols	Definition	Symbols	Definition
ω	Manufacturer wholesale price	p	Retailer selling price
c_n	Unit new product manufacturing cost	c_r	Unit recovered manufacturing cost
γ	Price elasticity of product demand	q	Market demand in sales. Maximum demand is Q
q_t	Recycling volume of offline recycling channels	q_e	Recycling volume of online recycling channels
θ	Consumer channel preference	β	Recovery elastic coefficient of competitive channel recycling price
α	Recovery elastic coefficient of operation channel recycling price	p_e	Unit recycling price of online recycling platform
p_t	Unit recycling price of offline recyclers	g	Unit recycling price of manufacturer
s_1	Convenience service level of online recycling platform	s_2	Safety service level of manufacturer
c_{s1}	Convenience service cost of online recycling platform	c_{s2}	Safety service cost of manufacturer
μ_1	Service cost coefficient of online recycling platform	μ_2	Service cost coefficient of manufacturer
a	Market recycling volume	i	Recovery elastic coefficient of operation channel recycling volume
j	Recovery elastic coefficient of competitive channel recycling volume	Π_m	Profit of manufacturer
Π_e	Profit of onling recycling platform	Π_t	Profit of offline recyclers
Π_r	Profit of retailer	Π	Profit of Supply chain system

The model construction takes into account the system differences between the provision of recycling services and the provision of recycling services. A superscript S indicates that the provision of recycling services is a parameter and variable of the system.

3.2 Model Construction

A dynamic game model is built for the situation that manufacturers provide security services and online recycling platforms provide convenience services, in order to explore the impact of the existence of recycling services and the improvement of service levels on supply chain system decisions and profits. The following quantity relations exist in the model:

$$\begin{aligned}\Pi_m^S &= (\omega - c_n)q + \Delta(q_t + q_e) - g(q_t + q_e) - c_{s2} \\ &= (\omega - c_n)(Q - \gamma p) + (\Delta - g)[a + p_t + p_e + (i_1 - j_1)s_1 + (i_2 - j_2)s_2] - \mu_2 s_2^2\end{aligned} \quad (1)$$

$$\Pi_e^S = (g - p_e)q_e - c_{s1} = (g - p_e)(\theta a + 2p_e - p_t + i_1 s_1 + i_2 s_2) - \mu_1 s_1^{\,2} \quad (2)$$

$$\Pi_t^S = (g - p_t)q_t = (g - p_t)\left[(1-\theta)a + 2p_t - p_e - j_1 s_1 - j_2 s_2\right] \quad (3)$$

$$\Pi_r^S = (p - \omega)q = (p - \omega)(Q - \gamma p) \quad (4)$$

Under the condition of complete information, manufacturers can estimate the impact of their own decisions on the decisions of other followers, and make optimal decisions based on understanding the follower's decision response function. Therefore, reverse induction can be used to solve the model, that is, the optimal profit decision of retailers, offline recyclers and online recycling platforms can be solved first, and then the manufacturer make a decision.

Retailers need to make decisions on price p, and take the partial derivative of Π_r^S to p. It can be seen that there is p to maximize Π_r^S.

$$p = \frac{Q + \gamma\omega}{2\gamma} \quad (5)$$

Offline recyclers need to make decisions on price p_t, and take the partial derivative of Π_t^S to p_t. It can be seen that there is p_t to maximize Π_t^S.

$$p_t = \frac{1}{4}\left(-a + 2g + a\theta + p_e + j_1 s_1 + j_2 s_2\right) \quad (6)$$

Online recovery needs to make decisions on p_e and s_1, and take partial derivative of Π_e^S to p_e and s_1 respectively. Through the judgment of Hessianmatrix of p_e and s_1, it can be seen that there are p_e and s_1 to maximize Π_e^S.

$$p_e = \frac{1}{4}\left(2g - a\theta + p_t - i_1 s_1 - i_2 s_2\right) \quad (7)$$

$$s_1 = \frac{i_1(g - p_e)}{2\mu_1} \tag{8}$$

Solve by simultaneous formula (5)~(8) and substitute the result into formula (1).

$$\Pi_m^S = \frac{\begin{array}{c} 10\mu_1\left[4D(a+2g) - 3Q\omega + 3\gamma\omega^2 + 3Ec_n + 4D(i_2 - j_2)s_2 + 6s_2^2\mu_2\right] \\ +4i_1^2\left[s_2(Dj_2 - 2s_2\mu_2) - D(a+g-a\theta) + \omega E - Ec_n\right] \\ +i_1 j_1\left[Ec_n + 2s_2(s_2\mu_2 - 2Di_2) - 4D(g+a\theta) - Q\omega + \gamma\omega^2\right] \end{array}}{8i_1^2 - 2i_1 j_1 - 60\mu_1} \tag{9}$$

$$A = 4i_1^2 - i_1 j_1 - 30\mu_1 \tag{10}$$

$$B = a + 3a\theta + (4i_2 - j_2)s_2 \tag{11}$$

$$C = 4a - 10g - 3a\theta + (i_2 - 4j_2)s_2 \tag{12}$$

$$D = g - \Delta \tag{13}$$

$$E = Q - \gamma\omega \tag{14}$$

After knowing the above information, the manufacturer could make a decision on g , ω and s_2 . Through the judgment of Hessianmatrix of g , ω and s_2 , it can be seen that there are g , ω and s_2 to maximize Π_m^S .

$$\omega^{S*} = \frac{Q + \gamma c_n}{2\gamma} \tag{15}$$

$$s_2{}^{s*} = \frac{\left(10K\mu_1 - Ji_1^2 - Li_1 j_1\right)F}{-G} \tag{16}$$

$$g^{S*} = \frac{\Delta F^2 - A\mu_2\left[(\Delta + aH)i_1^2 + (\Delta - a\theta)i_1 j_1 + 10(a - 2\Delta)\mu_1\right]}{G} \tag{17}$$

$$F = i_1^2 j_2 - i_1 i_2 j_1 + 10(i_2 - j_2)\mu_1 \tag{18}$$

$$G = F^2 - 2A[i_1(i_1 + j_1) - 20\mu_1]\mu_2 \tag{19}$$

$$K = a + 2\Delta \tag{20}$$

$$L = \Delta + a\theta \tag{21}$$

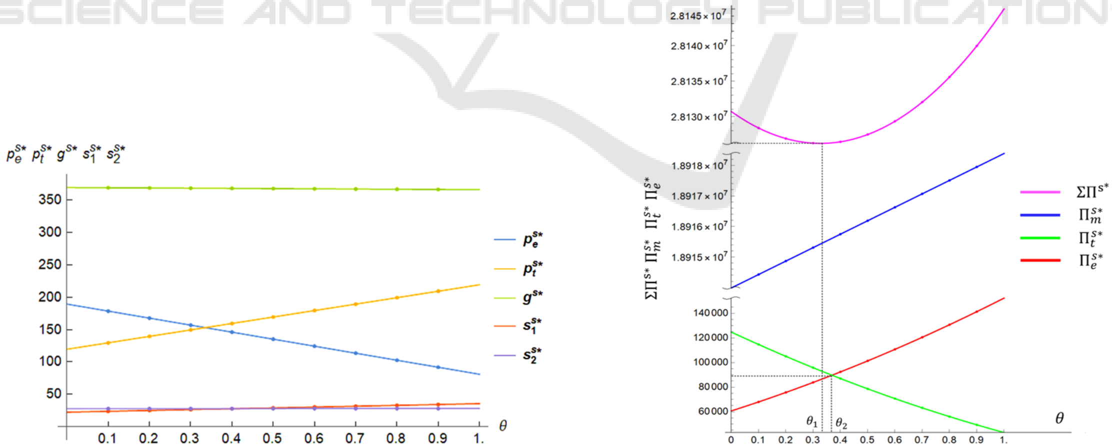
4 EXAMPLE ANALYSIS

4.1 Parameter Setting

n this paper, Mathematica software is used for simulation analysis. Because some data related to the interests of enterprises are difficult to obtain, this study chooses to design parameters based on existing literature. Set the parameters as follows: $Q = 20000$, $\gamma = 2$, $c_n = 1500$, $c_r = 500$, $a = 500$, $\alpha = 2$, $\beta = 1$, $i_1 = i_2 = 2$, $j_1 = j_2 = 1$.

4.2 Influence of Consumer Channel Preference on Decision-Making

This section assumes that the service cost coefficient $\mu_1 = \mu_2 = 8$, the remaining parameters remain unchanged, and the consumer channel preference is gradually increased from 0 to 1 in steps of 0.1. The model results are shown in Figure 2.



(a) Decision variable curve (b) Profit curve

Figure 2: System simulation results on θ .

As consumers prefer online channels, online recycling platforms can continuously reduce recycling prices, while offline recyclers need to increase recycling prices to strengthen competitiveness, and manufacturers can slowly reduce recycling prices. Online recycling platforms and manufacturers should improve their service levels and retain more consumers. In addition, with the increase of x, the profits of offline recyclers continue to decrease, while the profits of manufacturers and online recycling platforms increase, and the total profits of the system show a trend of first decreasing and then increasing. This shows that there are difficulties in the initial development of online recycling platform construction, and there are negative benefits for the system as a whole. However, with the increase of platform customer groups, the system benefits will gradually increase.

4.3 Influence of Service Cost Coefficient on Decision-Making

In this section, it is assumed that consumer channel preference remains unchanged, $\theta = 0.4$, other parameters remain unchanged, μ_1 and μ_2 change from 10 to 3, and the step size is -1. The model results are shown in Figure 3.

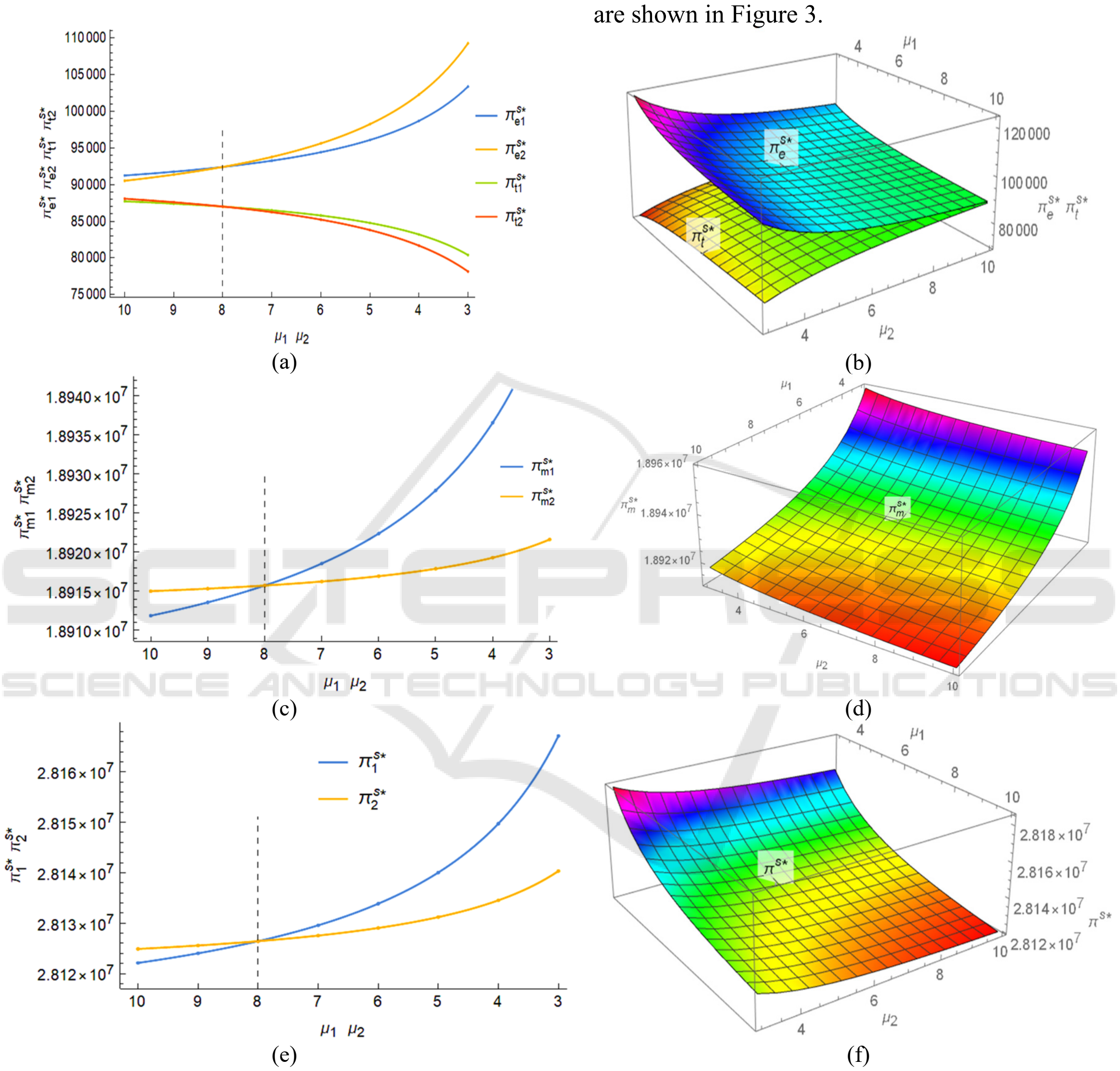


Figure 3: System simulation results on μ_1 and μ_2.

μ_2 has a particularly significant impact on the profits of online recycling platforms and offline service providers. Optimizing μ_2 will improve the profits of online recycling platforms, but reduce the profits of offline service providers. The impact of optimizing μ_1 on both is the same as optimizing μ_2, but the impact is smaller than μ_2. The influence of optimizing μ_1 on the profit of manufacturer and supply chain system is significantly higher than that of optimizing μ_2. To sum up, optimizing the convenience service cost coefficient is more beneficial to the improvement of the supply chain profit, and the profit loss of the offline recyclers is also the smallest in this state. Based on this, when pursuing the profit stability of each entity and maximizing the system profit, priority can be given to optimizing the convenience service level.

5 CONCLUSION

This paper establishes a closed-loop supply chain game model consisting of manufacturers, retailers, third-party recyclers and Internet recycling platform, and considers the impact of service level on the decision-making of supply chain participants. Through the analysis of an example, it is verified that the improvement of consumers' online recycling channel preference has a more positive role in promoting the pricing and profits of online recycling platforms, but has a more negative role in weakening offline recyclers. At the same time, it can also promote manufacturers and online recycling platforms to improve service levels, which has a positive impact on the supply chain system. The service cost also plays a positive role in the system benefits, but in the pursuit of environmental protection effects, priority can be given to optimizing the security service level, while in the pursuit of profit maximization, priority can be given to optimizing the convenience service level.

This paper also has limitations. It believes that the service level of online recycling services has become worse, and its influencing factors have not been taken into account in the model. However, with the renewal of policies such as dual carbon, the service mode of offline service providers will also change, and the service level will be improved. Relevant factors can be considered in future research.

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