

## TO BE RAISED UP OR KICKED OUT? INSIGHTS FOR THE RECYCLER IN CLOSED-LOOP SUPPLY CHAIN WITH THE REGULATION OF GOVERNMENT

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**Abstract.** In order to improve the recovery rate of waste products and maximize the social welfare, this paper investigates the problem of government setting a recovery rate threshold for the recycler in the closed-loop supply chain (CLSC) with the information asymmetry. By establishing the government incentive regulation model, the government can disclose the true recovery cost of the recycler and guide the recycler to make a reasonable effort. In this study, our model obtains the best recovery rate threshold for the recycler from the perspective of maximizing social welfare. Then, we conduct some sensitivity analyses and explore the impacts of related factors on the strategies-making of government and supply chain players. The results of the study indicates that the recovery rate threshold set not only depends on the operation efficiency of the recycler, it also affected by the consumers behavior and the production efficiency of manufacturer. The government should not pursue a high recovery rate blindly, more attention should be paid to control the cost of effort made by the recycler. With the increasing of the negative utility for the recycler to make effort, the government will improve the recovery threshold, otherwise, the threshold will decrease. The results facilitate scientific incentive mechanism development, and provide a reference for promoting CLSC operations.

Received September 25, 2020. Accepted April 20, 2021.

### 1. INTRODUCTION

In the 21st century, a large amount of waste electronic equipment have attracted people's attention. On the one hand, the waste products pollute the environment, on the other hand, it causes a waste of resources, thus the recycling and remanufacturing of waste electronic equipment are the primary solution to deal with electronic waste pollution [8, 9, 12]. In terms of developing the waste recycling activities, Xerox set up a resource recycling plant in 2006, and the recycling rate of recycled products reached 99.99% by 2017. Furthermore, take Mercedes Benz as an example, its real remanufactured parts program can save 13 500 tons of raw materials and 54 000 megawatt hours of energy per year. However, due to the constraints of the technical, cost and capital, there are few enterprises implement the CLSC management spontaneously at present. In order to encourage the more enterprises to participate in the recycling of waste products activities actively and realize the sustainable development of human society and improve the social welfare, the countries around the world have issued the related laws and regulations with the nature of rewards and punishments to require the enterprises to recycle and remanufacture waste products [14, 17, 26, 41]. For example, in 2005, the European Union promulgated

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*Keywords.* Government regulation, closed-loop supply chain, threshold, information asymmetry, incentive regulation model.

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and implemented the “Waste Electronic and Electrical Products Disposal Ordinance” (WEEE), which clearly stipulated that the producers and distributors of electronic products have the obligation to recycle and reuse the waste electronic products. Since 2009, China has successively issued a series of incentive mechanisms and management systems with the “Regulations on the Recycling and Treatment of Waste Electrical and Electronic Products” as the core. At this time, under the pressure of the national laws and regulations on the environmental protection, and if the enterp rises handle the recycling and remanufacturing process properly, it can not only reduce the cost, but also obtain a better corporate reputation. Therefore, the enterprises will pay more and more attention to the recycling and remanufacturing activities of waste products [1,18], which can also promote the social welfare level effectively.

Based on the importance of recycling and remanufacturing of waste products, many scholars have put forward different opinions on the research of CLSC. The early studies involved multiple fields, which include the supply chain design, the CLSC decisions-making under the information symmetry/asymmetry, and the CLSC management with the government intervention. Here we only focus on the research which is highly related to this paper. There are three reasons why the enterprises choose to develop the recycling remanufacturing activities, one of the reasons is that the generation of waste electronic products will pollute and destroy the ecological environment after a simple landfill and incineration, and then affect the human health and social sustainable development. However, the development of remanufacturing activities can effectively solve the problems of idle resources and environmental pollution. The other is the development of remanufacturing activities can not only reduce costs and increase profits for the enterprises, but also obtain a better corporate reputation and improve the social responsibility. In addition, from the perspective of the whole society, the remanufacturing activities can improve the overall social welfare level. See [3, 6, 7, 11, 22, 25, 28, 33] for examples. At the beginning, Moorthy [23] studied the impacts of cost and price competition on the product decisions according to established a two-level game model, in which each company first decides the attributes of the products, and then posts the price. This is one of the earliest studies considering the product design. Then, due to the environmental issues and seek for more cost savings, Guide and Wassenhove [15] developed a framework to analyze the profitability of reuse activities. Xiong *et al.* [36] investigated the CLSC decisions-making with the dealers engage in remanufacturing activities. By establishing a two-level game model, they obtained the optimal price strategies of the manufacturer and dealer. Then, Biswas *et al.* [5] studied how to choose a contract to solve the coordination problem of the supply chain by analyzing whether the market information is shared or not. When the market information is not shared, Wu *et al.* [35] solved the buyback contract problem by designing variable parameters, and realized the perfect coordination of the CLSC with the information asymmetry. Finally, Wang *et al.* [29] constructed the incentive model of CLSC under the principal-agent framework to analyze the problem of how the remanufacturer designs incentive model to guide the recycler to make an optimal effort under the condition of dual information asymmetry. The above studies without considered the decision-making goal and modeled as a game player of the government. In our research, we investigate the effects of the government interventions on the management of CLSC, the intervention measures could include the financial incentive and the compulsory measures. However, no matter what kind of intervention measures, it will have a impacts on the optimal strategies of CLSC players. In this study, the financial policy can be defined as an incentive means to the recycler, while the threshold set by the government can be defined as a compulsory means, that is also to say that under the condition of the government aiming to maximize the social welfare, in order to improve the efficiency of market resource allocation, when the recovery rate of recyclers does not reach this standard, they will be dropped out the market. Therefore, the threshold set by the government can directly improve the recovery rate of waste products in the market, which will have a greater impact on the decisions-making of the CLSC players.

Under the pressure of environmental protection, the governments attach great importance to the recovery of waste products. However, due to the high recovery cost, the enterprises have not enough initiative to improve the recovery rate. At this time, the government participates in the recycling activities in various ways [10, 19, 20, 24, 27, 31] building the principal-agent theory to study the CLSC model with the information

asymmetry and the government's reward mechanism. By applying the information screen contract, they can obtain the real information of the manufacturer's effort level. Zhang and Jing [37] used the government incentive regulation model to solve the problem of pricing mechanism in the transmission and the distribution markets. Li *et al.* [21] examined the impact of the government policies on CLSC decisions. They found that the government's reward and punishment policies play an active role in improving the production process and recovery level of the manufacturer. Then, Zhang *et al.* [40] investigated how the government develops an incentive measure to promote the power plant to reduce the carbon emissions effectively by establishing the government incentive regulation model. Wu *et al.* [34] proposed a low-carbon incentive model for online shopping supply chain based on the online stores and their suppliers. Combined with the government's low-carbon incentive, the incentive model of total cost and carbon emission cost of supply chain collaborative operation is established by using the expression of supply chain cost. Finally, Atasu *et al.* [2] considered the dual effects of economy and environment, and established a game model among the government, the manufacturer and the consumers. Different from most of the studies above, our paper considers the scenario of dual market information asymmetry, which will make the study more in line with the real life.

The above studies on CLSC decision-making mainly focus on the condition that the market information is shared. Wu *et al.* [35] and Biswas *et al.* [5] considered the impacts of market information asymmetry on the supply chain operation, and solved the problem of market information asymmetric. However, the above references mainly studied the "single" information asymmetry, and only the problem of moral hazard or the adverse selection is existed in the research. Wang *et al.* [29] applied the incentive theory to study how the manufacturer designs an incentive mechanism to guide the recycler to improve the recovery effort under the dual- information asymmetry, but the research did not consider the impact of government intervention on the decision-making of the supply chain. Now, most of the scholars focus on the studying of government's financial incentive for the enterprises or the government formulating the unified emission standards with the financial policy to reduce carbon emissions under symmetrical information, however, few scholars investigate the issue of government regulation under dual -information asymmetry. In our research, from the perspective of maximizing social welfare, we introduce the government's financial incentive and compulsory intervention to the CLSC. Due to the stakeholders have the motivation to hide some information to maximize their own profits, such as the information of cost and effort, thus we introduce the problem of dual-information asymmetry and study how the government develops an reasonable mechanism to reveal the true information and promote the CLSC players to improve the recovery efficiency effectively. The government aims to improve the level of social welfare, while the CLSC players aim to maximize their own benefits.

Based on the previous research, this paper applies the incentive theory, we consider a CLSC composed of the manufacturer, the recycler and the consumers under government incentive regulation, and study the problem of how the government develops a recovery rate threshold for the recycler in the waste products market with dual information asymmetry. The recovery rate and effort are the private information of the recycler while the government cannot observed, and the government will design an incentive mechanism to the recycler, which will disclose the true recovery cost information of the recycler and guide the recycler to make an optimal recovery effort to improve the recovery efficiency. Under the government's regulation goal of maximizing social welfare, we obtain the optimal recovery rate threshold set by the government when the recycler entering the market, and discuss what factors mainly affect the threshold implementing. According to the analysis of the threshold, this paper provides the basis for the government to formulate a reasonable incentive mechanism for the enterprises under the dual information asymmetry.

The paper is structured as follows. Section 1 summarizes the relevant literature and positions this work. In Sections 2 and 3, the assumptions, notations, models, and the solutions procedures are described. Section 4 presents a numerical example and the parametric analysis for better understanding. Section 5 outlines the conclusions and the future research suggestions.

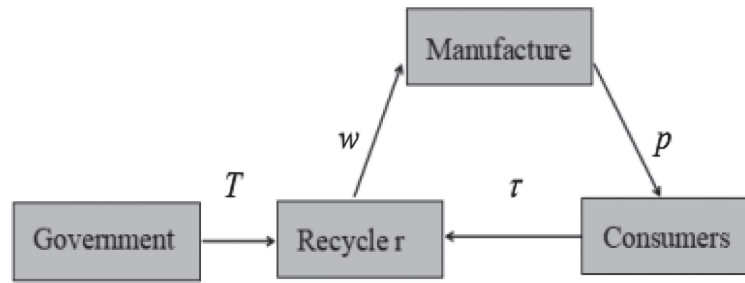


FIGURE 1. The structure of the closed-loop supply chain.

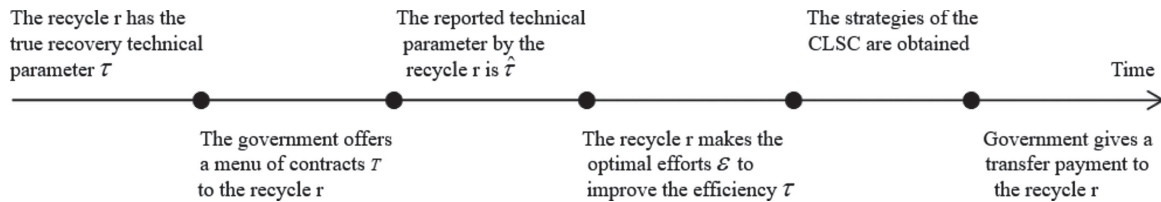


FIGURE 2. Game sequence.

## 2. MODELS

Here, we establish the related models about the process of recovery rate, effort, pricing and transfer payment decisions considering the government implements the incentive regulation mechanism to the CLSC players.

### 2.1. Problem description

This research considers a CLSC composed of the manufacturer, the recycler and the consumers, the structure of the CLSC is shown in Figure 1. In this CLSC system, the recycler is responsible for recycling the waste products in the market, and the unit cost of recovery is  $c$ . The manufacturer buys back the recycled materials from the recycler at the price of  $w$  and remanufacturing it, the unit cost of the new products produced with the recycled materials is  $c_r$  and with new materials is  $c_n$ . When the new products enter the market, the manufacturer sells it to the consumers at the price of  $p$ . In the CLSC with the manufacturer as the leader, the government regulates the whole supply chain system, which the government as the leader and the players of the CLSC as the followers, and the government implements incentive regulation to the recycler. When the government cannot obtain the real recovery rate of the recycler, the government will design an incentive mechanism to make the recycler reports the true information. In addition, the government will offer a menu of contracts to the recycler, the recycler chooses a contract and makes a corresponding recovery effort, which can promote the recycler to improve the recovery efficiency effectively. More importantly, according to establishing the incentive model, this research calculates the standard value of the recovery rate set by the government. Therefore, under the condition of the government takes the maximization of social welfare as the regulation goal, how to design a reasonable threshold of recovery rate with dual-information asymmetry and what factors would affect the make of the threshold by the government are the key issues to be discussed in this paper. The game sequence as shown in Figure 2.

Furthermore, the symbols used in the government incentive regulation model are shown as follows (Tab. 1): Then, we make the following assumptions:

**Assumption 2.1.** This research consider the moral hazard and adverse selection. According to the studies of [37, 40], we assume the recovery rate of the recycler is the private information, which the government cannot

TABLE 1. The related symbols and descriptions.

| Exogenous variables                      |   |
|--|---|
| $C_n$                                    | Unit cost of new products produced by the manufacturer with new materials                       |
| $C_r$                                    | Unit cost of remanufactured products produced by the manufacturer with recycled waste materials |
| $C$                                      | The unit cost of recovery for the recycler  |
| $b$                                      | Difficulty coefficient of recycling waste products for the recycler                             |
| $m$                                      | The expected profit of the manufacture  |
| $I$                                      | The recovery rate with effort (monitored by the government)                                     |
| $\lambda$                                | Environmental risk avoidance coefficient of the government                                      |
| $a$                                      | Basic capacity of the market  |
| $\xi$                                    | Price demand elasticity of the products   |
| $\alpha$                                 | The fixed cost input coefficient of the government  |
| $\varphi(\varepsilon)$                   | The cost for the recycler to make effort  |
| $\pi_r$                                  | Profit of the recycler  |
| $\pi_m$                                  | Profit of the manufacture   |
| $\tau$                                   | The original waste products recovery rate of the recycler( real recovery rate)                  |
| $D$                                      | The demand of products in the market  |
| SW                                       | The social welfare  |
| Controlled variables by the CLSC players |   |
| $p$                                      | Sales price of the products set by the manufacture  |
| $w$                                      | The waste products recovery price of the manufacturer from the recycler                         |
| $\varepsilon$                            | The effort made by the recycler   |
| $\hat{\tau}$                             | The reported recovery rate by the recycler  |
| Controlled variable for the government   |   |
| $T$                                      | The transfer payment  |

be observed and it can be improved by the effort such as updating the recycling equipment and increasing the investments in R&D of recycling technology, and the effort cost is  $\varphi(\varepsilon)$ . Therefore, the recovery rate of the recycler with effort is shown as:

$$I = \tau + \varepsilon$$

where  $\tau \in (\underline{\tau}, \bar{\tau})$ , the higher of the higher of the recovery efficiency. The probability density and probability distribution functions are  $f(\tau)$  and  $F(\tau)$  respectively when  $\tau \in (\underline{\tau}, \bar{\tau})$ , and it satisfies  $f(\tau) > 0$ . The monotone hazard rate  $d(F(\tau)/f(\tau))/d\tau \geq 0$ . For most distribution, such it meets the condition of  $\varepsilon$  is the moral hazard coefficient and related to the recovery rate, which is also to say that  $\varepsilon = \varepsilon(\tau)$ . In addition, the effort cost is an increasing function on the effort made by the recycler, thus when the effort  $\varepsilon > 0$ , the  $\phi' > 0$  and the increasing speed  $\phi'' > 0$ ,  $\phi''' \geq 0$ . It also satisfies  $\phi(0) = 0$ , and when the effort  $\varepsilon \rightarrow 1 - \tau$ , the effort cost  $\phi(\varepsilon) = +\infty$ .

**Assumption 2.2.** For the manufacturer, the costs of new products produced with new materials and recycled materials are  $C_n$  and  $C_r$  respectively, and  $C_n > C_r$  [21], which shows that the development of remanufacturing activities by the manufacturer is profitable.

**Assumption 2.3.** Similar to the studies of [30, 32],  $I$  is related to the investment cost of recovery. Assuming that the investment cost of recovery  $\Pi = bI^2$ ,  $b$  is the difficulty coefficient of recycling. The investment cost of recovery is a convex function on the recovery rate, which shows that the investment cost of recovery increases sharply with the increase of the recovery rate. Therefore, it is uneconomical for the recycler to pursue a high recovery rate excessively.

**Assumption 2.4.** The quality of the new products produced with new materials and recycled materials is identical and all the remanufactured products can be sold to the consumers [4, 40].

**Assumption 2.5.** *This study assumes that the sales price and the recovery price of the manufacture meet the condition of  $p = w + m$ ,  $m$  is the expected profit of the manufacture.*

**Assumption 2.6.** *According to the study of [13], we assume that the social welfare function of the government mainly includes the items of “(PS), consumer surplus (CS), environmental benefits by recycling the waste products (EB) and the (EI) measures”. A PS is the additional profit brought by the difference between the minimum supply price of production factors and products and the current market price. A CS is the difference between the highest price of the consumers are willing to pay for the products in the market with the actual market price. The is the total environmental benefit generated by the recycling activities. The is defined as the budget surplus after the government takes financial incentives measures. Thus similar to the research of [13, 16], we assume that  $CS = D^2/2$ ,  $PS = \pi_r + \pi_m$ ,  $EB = ID$ ,  $EI = (1 + \alpha)T$ .  $\alpha$  is the fixed cost input coefficient of the government with implements the incentive regulation. Therefore,  $SW = CS + PS + \lambda EB + EI$ .  $\lambda$  is the environmental risk avoidance coefficient of the government.*

According to the analysis in Section 1, we apply the incentive theory to establish the government incentive regulation model. In addition, on the basis of game theory, we develop a Stackelberg game model among the government and supply chain players. Therefore, in this research, we study the incentive regulation of government to CLSC players under dual information asymmetry. Firstly, the establishment of the related models can effectively solve the problem of information asymmetry. Secondly, the models can provide a scientific basis for the government to implement the incentive mechanism for the enterprises, and guide the supply chain players to make the optimal pricing, effort and recovery rate decisions.

The process of modeling and equilibrium solutions is as follows.

Firstly, in order to solve the problem of information asymmetry of the recycler, the government designs an incentive mechanism to reveal the true recovery rate and recovery effort level of the recycler under the goal of maximizing social welfare. After obtaining the true recovery rate and effort of the recycler, the government gives the recycler a transfer payment and guides the recycler to make the best effort. Next, from the perspective of maximizing their own profit, the recycler and the manufacturer make the optimal decisions. At this time, there is a three-level Stackelberg game between the government, the manufacturer and the recycler. In this game, the supply chain players can make the optimal price strategies.

## 2.2. The government incentive regulation model and the Stackel-berg game model

### The government incentive regulation model

#### The profit of the recycler

The recycler sells the recycled waste products to the manufacturer at the price of, and the government gives the recycler a transfer payment of In order to improve the recovery efficiency, the recycler makes an effort and suffers certain costs. Therefore, the profit function of the recycler is shown as follows:

$$\begin{aligned} \pi_r(\tau) &= I(\tau)D(w(\tau) - c) - bI(\tau)^2 - \phi(\varepsilon) + T(\tau) \\ &= I(\tau)(a - \xi p(\tau))(w(\tau) - c) - bI(\tau)^2 - \phi(\varepsilon) + T(\tau) \end{aligned} \tag{2.1}$$

where  $a - \xi p$  is the demand of the new products, is the price demand elasticity of the new products.

The profit of the manufacture.

The manufacturer applies new materials and recycled materials for remanufacturing, and sells the new products to consumers at the price of  $p$ . Thus the profit function of the manufacture is shown as follows:

$$\pi m(\tau) = (a - \xi p(\tau))(p(\tau) - cn + I(\tau)cn - I(\tau)cr - I(\tau)w(\tau)). \tag{2.2}$$

The target of government.

The goal of government incentive regulation is to maximize the social welfare. At this time, the social welfare function mainly includes producer surplus, consumer surplus, the total environmental benefits generated by

recycling the waste products and the budget surplus of the government. Therefore, the total social welfare from different recyclers with different recovery rates is shown as follows:

$$SW = \int_{\underline{\tau}}^{\bar{\tau}} (CS + PS + \lambda EB + EI)dF(\tau). \quad (2.3)$$

The incentive constraints to the recycler.

The government signs a contract with the recycler based on the reported recovery rate  $\hat{\tau}$  by the recycler and gives the recycler a transfer payment according to the contract chosen by the recycler, which may not reveal the real recovery rate information. Therefore, the profit function of the recycler is composed of the true recovery rate and the reported recovery rate  $\hat{\tau}$ , and is shown as follows:

$$\pi_r(\tau, \hat{\tau}) = I(\hat{\tau})a - \xi p(\hat{\tau})(w(\hat{\tau}) - c) - bI(\hat{\tau})^2 - \phi(I(\hat{\tau}) - \tau) + T(\hat{\tau}). \quad (2.4)$$

Therefore, when each  $\tau_1, \tau_2 \in [\underline{\tau}, \bar{\tau}]$ , we can obtain the incentive constraints of the government are:

$$\begin{aligned} I(\tau_1)(a - \xi p(\tau_1))(w(\tau_1) - c) - bI(\tau_1)^2 - \phi(I(\tau_1) - \tau_1) + T(\tau_1) &\geq \\ I(\tau_2)(a - \xi p(\tau_2))(w(\tau_2) - c) - bI(\tau_2)^2 - \phi(I(\tau_2) - \tau_1) + T(\tau_2) &\end{aligned} \quad (2.5)$$

$$\begin{aligned} I(\tau_2)(a - \xi p(\tau_2))(w(\tau_2) - c) - bI(\tau_2)^2 - \phi(I(\tau_2) - \tau_2) + T(\tau_2) &\geq \\ I(\tau_1)(a - \xi p(\tau_1))(w(\tau_1) - c) - bI(\tau_1)^2 - \phi(I(\tau_1) - \tau_2) + T(\tau_1). &\end{aligned} \quad (2.6)$$

The participant constraint to the recycler.

In order to encourage the recycler to carry out the recycling activities normally and participate in this regulation actively, the government should make the profit of the recycler no less than it is absent. Thus we have:

$$\pi_r(\tau, \hat{\tau}) \geq 0. \quad (2.7)$$

To sum up the analysis, the problem can be described as follows:

$$SW = \max_{T(\cdot)} \int_{\underline{\tau}}^{\bar{\tau}} (CS + PS + \lambda EB + EI)dF(\tau) \quad \text{s.t. (5), (6), (7)}. \quad (2.8)$$

Combining the equations (2.5) and (2.6), we can obtain the equation (2.9):

$$\int_{\tau_1}^{\tau_2} \int_{I(\tau_1)}^{I(\tau_2)} \phi''(x - y) dx dy \geq 0. \quad (2.9)$$

Due to  $\phi''(\cdot) \geq 0$ , therefore, according to the equation (2.9), we can conclude that  $I^\bullet(\tau)$  is an increasing function on  $\tau$  and  $I(\tau) \geq 0$ , or it is equivalent to the equation (2.10):

$$\varepsilon'(\tau) \geq -1. \quad (2.10)$$

The recycler with low recovery rate may falsely report the information of recovery rate in order to obtain more profit, therefore, by applying the envelope theorem in the equation (2.4), we can get:

$$\pi_r'(\tau) = \phi'(I(\tau) - \tau) \geq 0. \quad (2.11)$$

In addition, when the recycler gets more profit, the government payment would increase accordingly. In order to save the cost, the government will order  $\pi_r(\underline{\tau}) = 0$ , and we can get the  $\pi_r(\tau)$  from the equation (2.11):

$$\pi_r(\tau) = \int_{\underline{\tau}}^{\tau} \phi'(\varepsilon(\tilde{\tau})) d\tilde{\tau}. \quad (2.12)$$

**Proposition 2.7.** *When the recovery rate of waste products is high, the profit surplus of the recycler is shown as equation (2.12), which we call it the information rent.*

Proposition 2.7 shows that under the government regulation, the profit of the recycler is related to the effort. In real life, when the government encourages the recycler to make an effort to improve the recovery rate, it will generate certain cost, which lead to the investment increasing. Therefore, it is reasonable for the recycler to keep the profit surplus.

**Corollary 2.8.** *Equation (2.11) shows that the redundant profit changes with the recovery rate in the same direction. That is also to say that the higher of the recovery rate, the more profit of the recycler obtains. Obviously, the government incentive regulation can promote the recycler to improve the recovery rate for more redundant profit.*

Thus the total information rent of the recycler with different recovery rate  $\tau$  is shown as follows:

$$\begin{aligned} \int_{\underline{\tau}}^{\bar{\tau}} \pi_r(\tau) dF(\tau) &= \int_{\underline{\tau}}^{\bar{\tau}} \int_{\underline{\tau}}^{\tau} \varphi'(\varepsilon(\tilde{\tau})) dF(\tau) \\ &= \int_{\underline{\tau}}^{\bar{\tau}} \frac{1-F(\tau)}{f(\tau)} \varphi'(\varepsilon(\tau)) dF(\tau). \end{aligned} \quad (2.13)$$

By substituting the equations (2.2), (2.4), and (2.13) into the equation (2.8), we can get the government's problem which can be rewritten as follows:

$$\begin{aligned} \text{SW} &= \max_{T(\cdot)} \int_{\underline{\tau}}^{\bar{\tau}} \left\{ \frac{D^2(\tau)}{2} + \lambda I(\tau) D(\tau) + \frac{D(\tau)(a - D(\tau) - \xi c_n + I(\tau)\xi c_n - I(\tau)\xi c_r - I(\tau)\xi w(\tau))}{\xi} \right. \\ &\quad \left. - (1 + \alpha)(\phi(\varepsilon(\tau)) + bI^2(\tau) - I(\tau)D(\tau)(w(\tau) - c) - \alpha \frac{1-F(\tau)}{f(\tau)} \phi'(\varepsilon(\tau))) \right\} dF(\tau) \\ &\text{s.t.} \quad (10). \end{aligned} \quad (2.14)$$

The Stackel-berg game model.

In a market dominated by the manufacturer under the government incentive regulation, the relationship among the government, the manufacturer and the recycler can be constructed as a three stage Stackelberg game model. In the first stage, the government takes the maximization of social welfare as the regulation goal, by giving a transfer payment to the recycler, and implementing the incentive constraints to expose the true recovery rate information of the recycler and encourage the recycler to make an optimal effort. In the second stage, the manufacturer makes the sales price of the product to the consumers. In the third stage, based on the strategies in the previous stages, the recycler sets a reasonable recovery price to the manufacture. The backward induction is applied to solve this problem.

In the third stage, the recycler determines the optimal recovery price. When the report recovery rate by the recycler is  $\hat{\tau}$ , the profit function of the recovery is shown as follows:

$$\pi_r(\hat{\tau}) = I(\hat{\tau})(a - \xi w(\hat{\tau}) - \xi m)(w(\hat{\tau}) - c) - \Pi - \phi(\varepsilon(\hat{\tau})) + T(\hat{\tau}). \quad (2.15)$$

For  $\pi_r(\hat{\tau})$  in equation (2.15), due to  $\partial \pi_r^2(\hat{\tau})/w^2(\hat{\tau}) = -2\xi 0$ , therefore, the recovery price  $w(\hat{\tau})$ . is a concave function on  $\pi_r(\hat{\tau})$  and there is an optimal solution for  $w(\hat{\tau})$ .

The first derivative of is obtained and made it to be zero, the optimal recovery price with the reported recovery rate  $\hat{\tau}$  is calculated and shown as follows:

$$w = \frac{(c - m)\xi + a}{2\xi}. \quad (2.16)$$



In the second stage, the manufacturer determining the optimal sells price with the reported recovery rate  $\hat{\tau}$  by the recycler.

Due to  $p = w + m$ , therefore, the optimal sales price is obtained as follows:

$$p = \frac{(c + m)\xi + a}{2\xi} \tag{2.17}$$

and the value of  $m$  is a constant.

In the first stage, the government gives a transfer payment to the recycler for promoting the recovery rate and guiding the recycler to make an reasonable effort. In order to obtain the optimal allocation of the social resources, the government provides a contract equal to the total expected cost of the recycler, so as to fully absorb the expected rent.

According to the assumptions, we can know that  $\varphi'''(\varepsilon) = 0$ . Then, ignoring the constraint of equation (2.10) temporary and calculating the first derivative of  $\varepsilon(\tau)$  from the equation (2.14), we can get:

$$\varphi'(\varepsilon(\tau)) = \frac{D(c_n - c_r - w + \lambda)}{1 + \alpha} - 2bI(\tau) + Dw - Dc - \frac{\alpha}{1 + \alpha} \frac{1 - F(\tau)}{f(\tau)} \varphi''(\varepsilon(\tau)). \tag{2.18}$$

**Proposition 2.9.** *The optimal effort level to the recycler with the government incentive regulation is decided by equation (2.18). Equation (2.18) describes a one-to-one correspondence between the recovery rate and the effort The recycler with different recovery rates will select different effort.*

**Corollary 2.10.** *The optimal effort level made by the recycler has the same trend with the waste product recovery rate.*

we can get the first derivative of from equation (2.18) is as follows:

$$\dot{\varepsilon}(\tau) = \frac{-2b - (\alpha/1 + \alpha)d/d\tau(1 - F(\tau)/f(\tau))\varphi''(\varepsilon(\tau))}{\varphi''(\varepsilon(\tau)) + 2b}. \tag{2.19}$$

From equation (2.19), it is obvious that  $\dot{\varepsilon}'(\tau) \geq -1$ , which meets the constraint of equation (2.10).

Consequently, we can get the optimal effort  $\varepsilon^*(\tau)$  made by the recycler from equation (2.19). Therefore, the waste product recovery rate of the recycler is also obtained:

$$I^*(\tau) = \tau + \varepsilon^*(\tau) \tag{2.20}$$

According to the equations (2.16) and (2.17), we can obtain the optimal profit of the manufacture is:

$$\pi_m^*(\tau) = \frac{(a - c\xi - m\xi)(c\xi + m\xi + a - 2\xi c_n + 2\xi c_n I^*(\tau) - 2\xi c_r I^*(\tau) - aI(\tau) - \xi c I^*(\tau) + \xi m I^*(\tau))}{4\xi}. \tag{2.21}$$

**Proposition 2.11.** *The profit of the manufacturer improves with the increase of the recycler’s recovery rate.*

From equation (2.21) we can see that  $\pi_m^*(\tau)/\partial I^*(\tau) = (a - c\xi - m\xi)(2\xi c_n - 2\xi c_r - a - \xi c + \xi m)/4\xi > 0$ . Due to the profit of remanufacturing by the manufacturer is profitable, and according to the limit conditions of the decision function is positive,thus the above conclusion is approved. It shows that the profit function of the manufacture appears the increasing trend with the recovery rate improves. The larger of the recovery rate, the higher of the profit.  $\tau$  represents the recovery technology type, which reflects the level of the recycler’s operation management. The smaller of  $\tau$ , the lower level of the recycler’s operation management. Therefore, the higher of the recovery rate can not only bring more profit to the recycler, but improve the manufacturer’s profit, both of the game players achieve a win-win situation.

The optimal profit of recycler  $\pi_r^*(\tau)$  and the transfer payment by the government  $T^*\tau$  are as follows:

$$\pi_r^*(\tau) = \int_{\underline{\tau}}^{\tau} \varphi'(\varepsilon^*(\tilde{\tau}))d\tilde{\tau} \tag{2.22}$$

$$T^*(\tau) = \pi_r^*(\tau) - DI^*(\tau)(w - c) + bI^*(\tau)^2 + \varphi(\varepsilon^*(\tau)). \tag{2.23}$$

**Proposition 2.12.** *In order to monitor the waste product recovery rate with the effort  $I^*(\tau)$  by the recycler, the government can obtain the original recovery rate information of the recycler from  $I^*(\tau) = \tau + \varepsilon^*(\tau)$ , where the results of  $\varepsilon^*(\tau)$  is given in equation (2.18).*

**Proposition 2.13.** *The profit of the recycler is related to the effort level and with the improvement of the recycling technology level  $\tau$ , the profit also increases.*

From the equations (2.10) and (2.22), we can know that the recycler could increase the recycling effort to get more profit. However, a high effort level is always accompanied with a high investment, at this time, the government regulates the recycler to guide them to make an optimal decision, which can improve the level of recovery technology and achieve the maximum profits for the recycler.

**Proposition 2.14.** *Under the government regulation to maximize the social welfare, there is an optimal level of the transfer payment implemented by the government to the recycler:*

$$T^*(\tau) = \pi_r^*(\tau) - DI^*(\tau)(w - c) + bI^*(\tau)^2 + \varphi(\varepsilon^*(\tau)). \tag{2.24}$$

From the conclusion we can know that under the government regulation, when the government observes the recovery rate of the recycler with the effort, there is a best point in transferring payment lines to the recycler. From  $\partial SW^*(\tau)/\partial T^*(\tau) = -(1 + \delta) < 0$ , it can be seen that the social welfare is a concave function with the transfer payment. When the transfer payment of the government is lower than the optimal level, the social welfare increases with the improve of incentive intensity, however, when the transfer payment is higher than the optimal level, the social welfare decreases with the improve of incentive intensity.

**Proposition 2.15.** *With the improvement of the market capacity, the intensity of government incentive decreases.*

From equation (2.24), we know that  $\partial T^*(\beta)/\partial \alpha = (I^*(\tau)(a\xi + a - c\xi - m\xi - c\xi^2 - m\xi^2))/(-2) < 0$ . It shows that the larger of the market capacity, the lower of the incentive intensity. Therefore, when the government implements the inventive mechanism, they should consider the market capacity of the product to formulate the a reasonable transfer payment rather than adopting the “one size fits all” approach for all interest players.

**Proposition 2.16.** *With the improvement of the recycler’s effort investment, the intensity of government incentive increases.*

From equation (2.4), we know that  $\partial T^*(\tau)/\partial \varphi(\varepsilon^*(\tau)) = \varphi'(\varepsilon^*(\tau)) > 0$ . The recycler improves the effort to improve the level of recycling technology. At this time, they more need the support from government to alleviate the investment pressure. Thus with the increase of incentive intensity, the recycler can be motivated to innovate the recycling technology effectively.

**Proposition 2.17.** *Asymmetric information reduces the intensity of incentive measure (less effort).*

The government incentive mechanism is conducive to promoting the recycler to increase effort to improve the level of recovery rate. However, when both sides of the game players are in information asymmetry, it makes the government more difficult to control the recycler’s recycling activities, therefore, it cannot improve the social welfare and promote the recycler to make the optimal effort effectively.

It is noted  $I^*(\tau)$  that can be replaced by its inverse function  $\tau = \tau^*(I)$ . Thus, the optimal transfer payment by the government can be expressed as:

$$T^*(I) = \int_{\underline{\tau}}^{\tau} \varphi'(\varepsilon^*(\tilde{\tau}(I)))d\tilde{\tau} - D(\tau(I) + \varepsilon^*(\tau(I)))(w - c) + b(\tau(I) + \varepsilon^*(\tau(I)))^2 + \varphi(\varepsilon^*(\tau(I))). \tag{2.25}$$

In summary, this study builds an incentive regulation mechanism that suitable for the government to supervise the CLSC players to improve the recovery rate of waste products. With the incentive regulation mechanism,

we can know that the government can obtain the original waste recovery rate of the recycler by monitoring the recovery rate with effort. The design of the mechanism can guide the recycler to make a reasonable effort, and the government will give the recycler a transfer payment for the effort correspondingly. According to the game model, the manufacturer and the retailer can make their own optimal sales strategies. In a word, by developing the above models, the government can achieve the purpose of disclosing the private information of the recycler and improve the level of social welfare, the CLSC players will also maximize their own profits.

### 3. THE RECOVERY RATE THRESHOLD SET BY THE GOVERNMENT FOR THE RECYCLER

Based on the models in Section 2, this section studies the problem of government closes down the inefficient recycling enterprises. In order to maximize the social welfare, the government sets a market recovery rate threshold for the recycler. When the recovery rate of the recycler reaches the standard, the government will allow them to operate normally.

Assuming that there are many similar recyclers responsible for recycling waste products in the market. Taking the maximization of social welfare as this research goal, we now consider the possibility that the recycling activities of the recycler would not be achieved for all types. Assuming  $\tau^*$  is the “critical” production type, the recycler with the type of  $\tau$  produced in  $[\tau^*, \bar{\tau}]$  and not produced in  $[\underline{\tau}, \tau^*]$ .  $U(\tau, \tau^*)$  is the profit of the recycler with the type of  $\tau$  and when the critical type of production is  $\tau^*$ .

Therefore, from the government social welfare function in equation (2.8) and based on the optimal strategies of the CLSC players in Section 2, due to the recycler can produce in  $[\tau^*, \bar{\tau}]$ , thus we can obtain the function of the social welfare is shown as follows:

$$\begin{aligned}
 SW = \int_{\tau^*}^{\bar{\tau}} & ((-\alpha)\pi_r(\tau, \tau^*) + D^2/2 + I^*(\tau)\lambda D + D(a - D - \xi c_n + \xi I^*(\tau)c_n - \xi I^*(\tau)c_r - \xi I^*(\tau)w)/\xi \\
 & - (1 + \alpha)(\varphi(\varepsilon^*(\tau)) + bI^*(\tau)^2 - I^*(\tau)D(w - c)) dF(\tau).
 \end{aligned} \tag{3.1}$$

The equation (2.11) means that for all  $\tau \geq \tau^*$ ,

$$\pi_r(\tau, \tau^*) = \int_{\tau^*}^{\tau} \varphi'(\varepsilon^*(\tilde{\tau}))d\tilde{\tau}. \tag{3.2}$$

Therefore, under the condition of maximizing the social welfare as the government incentive regulation goal, we substitute the equation (3.2) into the equation (3.1) and formulate the derivative of  $\tau^*$  on the expected social welfare, if we take the interior point( $\tau_1 < \tau^*$ ) to solve it, we obtain that:

$$\tau^* = \frac{A\xi f(\tau^*) + [\xi^2 A^2 f(\tau^*)^2 + 4b\xi f(\tau^*)(1 + \alpha)B]^{1/2}}{2b(1 + \alpha)} - \varepsilon^*(\tau^*) \tag{3.3}$$

which  $A = \frac{1}{4\xi}[4\xi c_n - 4\xi c_r - 8a\xi - 8c\xi^2 + 9m\xi^2 + 2a\lambda\xi - 2c\lambda\xi^2 - 2m\lambda\xi^2 + a^2 + c^2\xi^2 - 2am\xi + a\alpha^2 + c^2\xi^2\alpha + 2cm\xi^2 - 2ac\xi - 2ama\xi + \alpha m^2\xi^2 - 2aca\xi + 2cm\alpha\xi^2]$ ; and  $B = \frac{1}{4}[a^2\xi f(\tau^*) + c^2\xi^3 f(\tau^*) + m^2\xi^3 f(\tau^*) - 2ac\xi^2 f(\tau^*) - 2am\xi^2 f(\tau^*) + 2cm\xi^3 f(\tau^*) + a^2 f(\tau^*)c^2\xi^2 f(\tau^*) - m^2\xi^2 f(\tau^*) - 2cm\xi^2 f(\tau^*) - ac_n\xi f(\tau^*) + cc_n\xi^2 f(\tau^*) + c_n m\xi^2 f(\tau^*) - 4\varphi(\varepsilon^*(\tau^*))\xi f(\tau^*) - 4\alpha\varphi(\varepsilon^*(\tau^*))\xi f(\tau^*) - 4\alpha\varphi(\varepsilon^*(\tau^*))\xi + 4\alpha\varphi(\varepsilon^*(\tau^*))\xi F(\tau^*)]$ .

**Proposition 3.1.** Equation (3.3) is the recovery threshold set by the government for the recycler. Only when the minimum recovery rate standard is satisfied, the recycler is permitted to operate normally.

**Proposition 3.2.** For the recycler, if the difficulty coefficient of recycling is low, the recovery threshold set by the government will rise.

From  $\frac{\partial \tau^*}{\partial b} = -\frac{A\xi f(\tau^*)}{2b^2(1+\alpha)} - \left[ \frac{4(1+\alpha)(\xi^2 f(\tau^*)^2 A^2 + \xi f(\tau^*)b(1+\alpha)B)}{8b^2(1+\alpha)^2(\xi^2 f(\tau^*)^2 A^2 + \xi f(\tau^*)4b(1+\alpha)B)^{1/2}} \right] < 0$ , we can see that when the

recovery difficulty coefficient is high, the government will reduce the minimum recovery rate standard. However, when the recovery technology of the recycler is high and the difficulty coefficient is low, the government would raise the threshold value of the recovery rate, on the one hand to improve the recovery amount and promote environmental protection, on the other hand to maximize the social welfare.

**Proposition 3.3.** *When  $F(\tau^*) > 1$ , with the increasing of the negative utility for the recycler to make effort, the government would improve recovery threshold. Otherwise, the recovery threshold would decrease.*

From  $\frac{\partial \tau^*}{\partial \varphi(\varepsilon^*(\tau^*))} = \frac{b\xi^2 f(\tau^*)\alpha(1+\alpha)\varphi''(\varepsilon^*(\tau^*))(F(\tau^*) - 1)}{2b\xi(1+\alpha)f(\tau^*)(\xi^2 f(\tau^*)^2 A^2 + \xi f(\tau^*)4b(1+\alpha)B)^{1/2}}$ , it obvious that when the recovery

efficiency of the recycler is high, with the improvement of the negative utility brought by the effort, the threshold of the government recovery rate is also increased. However, when the recovery efficiency of the recycler is low, with the increase of the negative utility of the effort, the government reduces the threshold of the recovery rate. Therefore, the government should not blindly pursue a high recovery rate, they should pay more attention to control the cost of improving recovery rate and guiding the recycler to invest rationally.

**Proposition 3.4.** *The larger of the distribution function  $F(\tau^*)$ , the higher of recovery threshold.*

Due to  $\frac{\partial \tau^*}{\partial F(\tau^*)} = \frac{\alpha f(\tau^*)\xi^2 \varphi(\varepsilon^*(\tau^*))}{(\xi^2 f(\tau^*)^2 A^2 + \xi f(\tau^*)4b(1+\alpha)B)^{1/2}} > 0$ , thus we know that when the recycler has a high

recovery technical parameter, the government would raise the recovery level in the whole society under the goal of maximizing social welfare, which greatly promote the recovery effort of the recycler, and fully realize the reuse of waste product, and achieve environmental protection finally.

In CLSC system, the supply chain players interact with each other, the operation management level of the manufacturer not only affects its own profit, but affects the profit of the recycler.

**Proposition 3.5.** *With the manufacturing cost of the manufacture  $C_r$  decreases, the recovery threshold by the government  $\tau^*$  increases.*

From we can draw that the manufacturer's production efficiency also affect the government's decisions on the recycler. With the increase of manufacturer's remanufacturing cost, the government sets a lower recovery threshold to reduce the pressure of remanufacturing investment. At this time, it is easier for the recycler to enter the market for recycling activities.

From  $\frac{\partial \tau^*}{\partial c_r} = \frac{1}{2b(1+\alpha)} \left[ -f(\tau^*)\xi - \frac{2A\xi^2 f(\tau^*)^2}{2(\xi^2 f(\tau^*)^2 A^2 + \xi f(\tau^*)4b(1+\alpha)B)^{1/2}} \right] < 0$ . The above analysis, we can conclude that in addition to the recycler's own factors, the management level of the manufacturer could also have an impact on the decision-making made by the government to close down inefficient recovery activities. Therefore, in the CLSC system, in order to achieve win-win result, all players should strengthen the cooperation to improve the recovery rate of the CLSC.

## 4. EXAMPLE ANALYSIS

### 4.1. Numerical example analysis

In this section, we provide a numerical example to explain and verify the above theoretical results. Due to it is difficult to obtain the real industry data, thus we apply the data set included in previous studies [37, 39, 40]. Where the relevant parameters of a home appliance product are shown in Table 2. In addition, the data settings conform to the assumptions of the model and follow the reasonable relationship between the parameters (*e.g.*). In this paper, the negative utility for the recycler to make effort. The recovery rate of the recycler is uniformly

TABLE 2. Values of relevant parameters of CLSC.

| Parameters | $\tau$  | $b$ | $\lambda$ | $\xi$ | $C$ | $C_r$ | $C_n$ | $a$ | $m$ | $\alpha$ | $\sigma$ |
|------------|---------|-----|-----------|-------|-----|-------|-------|-----|-----|----------|----------|
| Values     | [0.0.6] | 320 | 0.3       | 0.2   | 10  | 30    | 90    | 250 | 150 | 0.2      | $10^5$   |

TABLE 3. Variable equilibrium values.

|                 | $\tau$                                  | $I$                                |
|-----------------|---|------------------------------------|
| $\tau$          | $\tau$                                  | $0.9563I - 0.01313$                |
| $\varepsilon^*$ | $0.0137 + 0.0457\tau$                   | $0.0437I + 0.0131$                 |
| $I^*$           | $0.0137 + 1.0457\tau$                   | $I$                                |
| $T^*$           | $-1031.49 + 6249.15\tau + 640.29\tau^2$ | $6.3405 - 72340.151I + 403.048I^2$ |

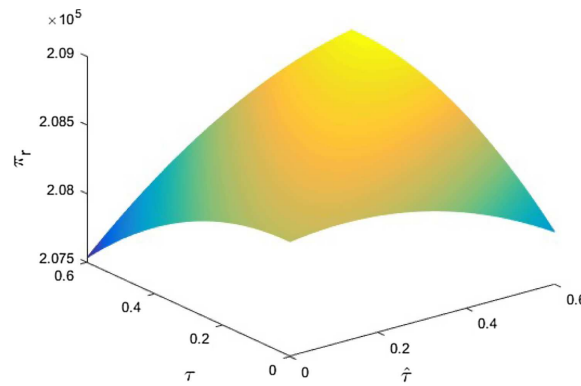


FIGURE 3.  $\tau$  and  $\hat{\tau}$  on the recycler’s redundant profit  $\pi_r$ .

distributed on the cumulative distribution function and the density function. The government could regulate the recycler based on or for the data set given above, the optimal equilibrium strategy values of CLSC players and government are obtained as shown in Table 3.

According to the optimal equilibrium strategies of CLSC players and government that calculated in the Sections 2 and 3, we provide some related parameter values in this section which are shown in Table 2. Next, we substitute the parameter values in Table 2 into the equilibrium decisions obtained in the Sections 2 and 3, and the corresponding numerical simulation results are shown in Table 3. The setting of this part can provide a more intuitively relationship between the equilibrium strategies and coefficients of  $\tau$  and  $I$ , and can also verify the propositions and conclusions in the Sections 2 and 3. In addition, the data provided in Table 2 can lay an data foundation for the important parameters sensitivity analysis in the next section. In summary, the significance of this part is to verify the effectiveness of the model and algorithm by the analysis of an example.

### 4.2. Basic variable sensitivity analysis

To investigate the changes in parameters of the models, we conducted sensitivity analysis on the coefficients  $\tau, \hat{\tau}, \lambda$  and  $\alpha$  which could provide more methods and suggestions for the government and CLSC players.

The impact of changes in the coefficients  $\tau$  and  $\hat{\tau}$  on the recycler’s redundant profit  $\pi_r$  is shown in Figure 3. The impact of changes in the coefficient  $\tau$  on the recovery rate of the recycler regulated by the government the

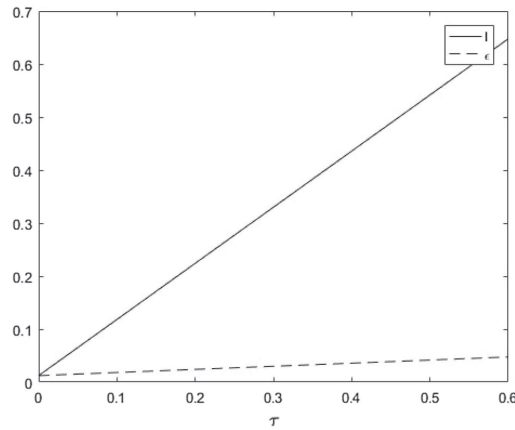


FIGURE 4. The effect of  $\tau$  on  $I$  and  $\varepsilon$ .

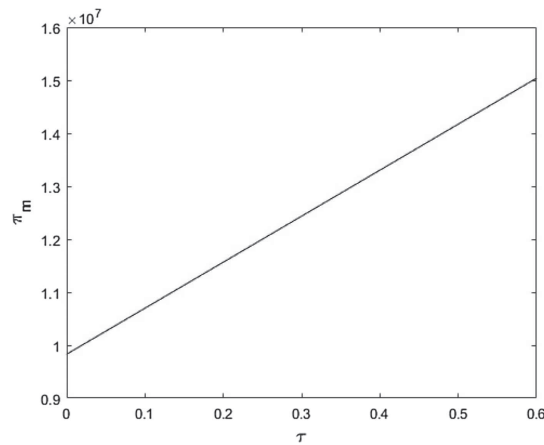


FIGURE 5. The effect of  $\tau$  on the profit of the manufacture  $\pi_m$ .

effort made by the recycler to change the recovery efficiency with the government regulation and the profit of the manufacture  $\pi_m$  are shown in Figures 4 and 5. From Figures 3 to 5, we can conclude:

- (1) Under the incentive regulation, government makes the lowest recovery efficiency recycler's rent is 0, namely  $\pi_r(\underline{\tau}) = 0$ . Figure 3 describes the redundant profit of the recycler. From the figure, we can see that as the recovery rate of  $\tau$  recycler increases, the redundant profit  $\pi_r$  also increases. In addition, it can be seen that when the recovery rate reported by the recycler  $\hat{\tau}$  is the same as the true recovery rate  $\tau$ , the redundant profit reaches the maximum in this case. Therefore, the recycler would tell the true recycling rate information and the government gives them an optimal transfer payment under the incentive regulation.
- (2) According to Figure 4, as the original recovery rate  $\tau$  increases, the effort degree  $\varepsilon$  and recovery efficiency of the recycler with effort also increase. It shows that with the government incentive regulation, the recycler could improve the recovery rate according to increasing the effort.
- (3) Figure 5 indicates that the profit of the manufacture  $\pi_m$  is also affected by the real recovery rate of the recycler  $\tau$ . The profit of the manufacture increase while the original recovery rate improving. Therefore, we can know that the recycler improves the recovery technology level could also increase the profit of the

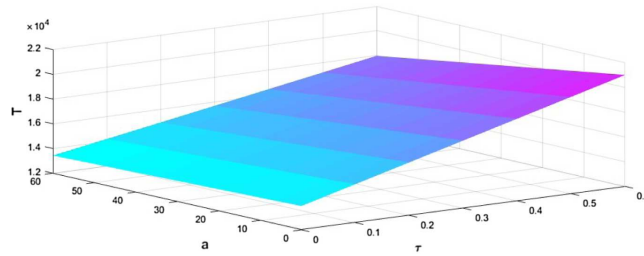


FIGURE 6. The simultaneous effect of  $a, \tau$  on the transfer payment  $T$ .

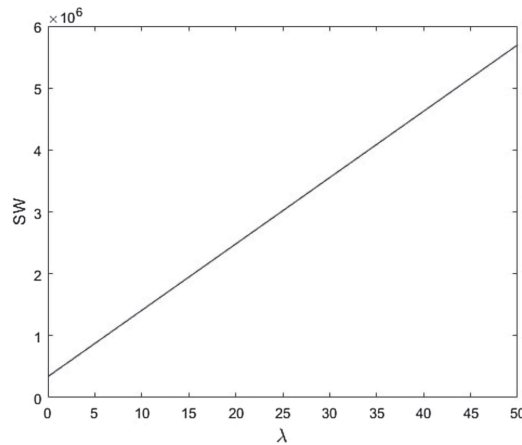


FIGURE 7. The effect of  $\lambda$  on the social welfare  $SW$ .

manufacture and bring more economic benefit for CLSC system, both sides of the game could achieve a win-win situation.

The impacts of the simultaneous change in the coefficients,  $\tau$  on the government’s transfer payment  $T$  are shown in Figure 6. As we know, the government plays an important role in environmental protection and the government’s concern for the environment affects the level of environmental benefits brought by the enterprise production. Therefore, Figure 7 describes the changes in the government environmental risk avoidance coefficient  $\lambda$  on the social welfare  $SW$ . From Figures 6 and 7, we can conclude:

- (4) In Figure 6, the simultaneous effect of  $\tau, a$  on the transfer payment  $T$  are described. We can see that with the increase of market capacity  $a$ . The government reduces incentive intensity  $T$ . The government formulates different incentive intensity according to different market capacity. When the market capacity increases, the product demand improves. At this time, under the pressure of market competition, each players in the CLSC strives to promote the operation and management level to maximize their own profit. In this case, the government does not need to strengthen the incentive intensity, thus the subsidy is reduced. In addition, from Figure 6, we can see that when the original recovery rate of recyclers is low, the government would impose financial punishment on them to promote them to improve the recovery efficiency. However, when the original recovery rate is raised, the government reduces the tax intensity. Correspondingly, when the original recovery rate is large enough, to reduce the investment pressure of the recycler, the government implements financial subsidy to promote the recovery technology level.
- (5) In Figure 7, it obvious that the government’s concern for the environment changes in the same direction as the social welfare. It shows that the government plays an important role in leading CLSC players to recycle

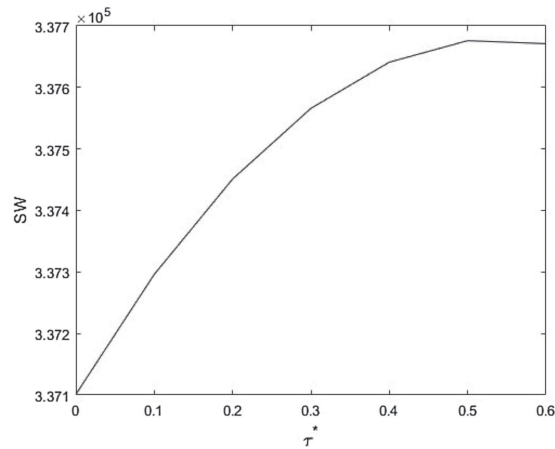


FIGURE 8. The effect of  $\tau^*$  on the social welfare SW.

and remanufacture to relieve environmental pressure. With the government pays more attention to the environment, it will strengthen the monitoring of CLSC players and urge them to have the high recovery and remanufacturing technical parameters. Therefore, under the background of serious social environmental pollution, it is urgent for the government to participate in recycling and remanufacturing activities, guiding the recycling and remanufacturing activities of enterprises reasonably, and maximizing the social welfare. In summary: the values of variables can be changed by changing the value of the coefficient. Government tends to pay more attention to the environment and operation and production of CSSC to achieve the social welfare maximize. Under conditions where the recycler reports the true recovery rate to the government under the incentive regulation, the profit would achieve optimal.

### 4.3. The influence of basic variables on the recovery threshold by the government

This part analyzes the factors that influence the close of inefficient recycling enterprises by the government. Figure 8 shows the effect of  $\tau$  on the social welfare, and from the figure, we can obtain that when  $\tau$  closes to the value of 0.5, which  $\tau^* = 0.5$ . The social welfare achieves optimal. In addition, the factors of the recycler, manufacturer and basic market capacity also affect the recovery threshold set by the government, thus the impacts of the change in the basic capacity of the market on the the recovery threshold  $\tau^*$  is shown in Figures 9 and 10 describes the impact of the unit cost of new products produced by the manufacturer with new materials  $C_n$  on the recovery threshold  $\tau^*$ . Figure 11 shows the changes in the unit cost of recycling for the recycler  $c$  on the the recovery threshold  $\tau^*$ . Finally, Figure 12 describes the impact of price demand elasticity of consumers  $\xi$  on the the recovery threshold  $\tau^*$ . From Figures 9 to 12, we can conclude:

- (6) With the market share of products increases, the recovery threshold by the government also improves, which more intuitive described in Figure 9. As the basic capacity of market products increases and the demand for products expands, the CLSC system needs to strengthen the production efficiency to meet the market demand. At this time, the proportion of in the market also increases, thus it is urgent for the recycler to engage in the recycling activities. Correspondingly, the government would also raise the recycling threshold to promote the reuse rate.
- (7) From Figure 10, we can see that the higher of the remanufacturing cost for the manufacture, the more motivated of the government to improve the recovery threshold, which shows that when the manufacturing cost of new materials is high, the government increases the remanufacturing rate of to promote energy



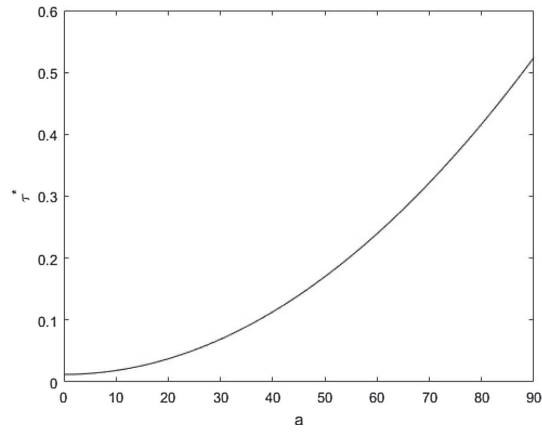


FIGURE 9. The effect of  $a$  on the recovery rate threshold  $\tau^*$ .

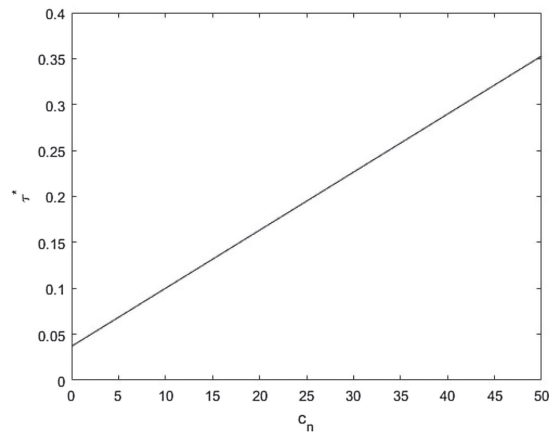


FIGURE 10. The effect of  $C_n$  on the recovery rate threshold  $\tau^*$ .

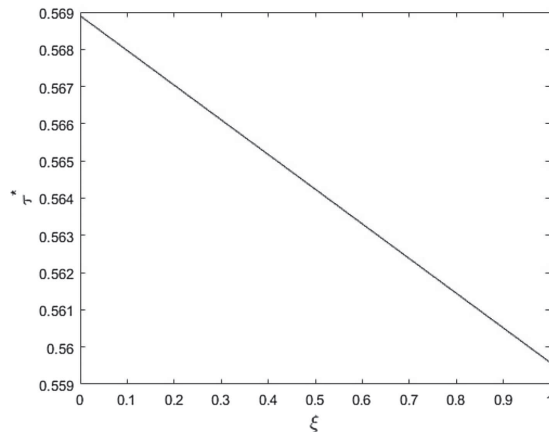


FIGURE 11. The effect of  $\xi$  on the recovery rate threshold  $\tau^*$ .

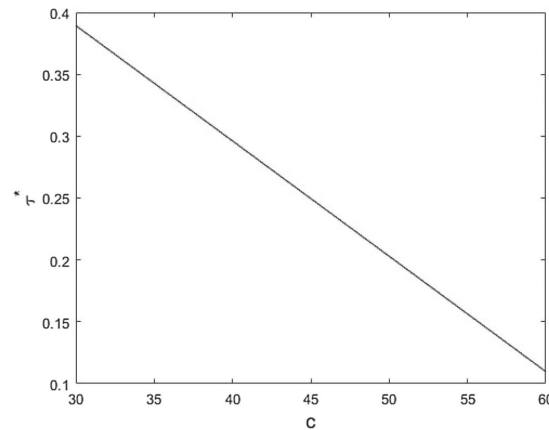


FIGURE 12. The effect of  $C$  on the recovery threshold  $\tau^*$ .

conservation and environmental protection and improve the cost saving of the manufacturer according to increasing the threshold of recovery rate.

- (8) From Figure 11, we can draw that when the recycler's recovery cost is small enough, the government would improve the recovery threshold for the recycler. Therefore, for the recycler, if they want to get more profit in multiple ways and survive in the compete market, it is very necessary to improve the management and operation level and increase the technological innovation of recycling to promote the technical parameter.
- (9) Figure 12 shows that with the lower price elasticity of consumer demand, the recovery threshold more higher. Under the government regulation to maximize the social welfare, the CLSC's players should pay a attention to improving the product quality, increasing the publicity, enhancing the brand recognition, and striving to innovate to reduce the product substitutability in the market, thus to reduce the price elasticity of consumer demand and realize the stable operation of the enterprise.

## 5. CONCLUSIONS

Under the government incentive regulation, the manufacturer as the leader in the CLSC and the recycler carries out the recycling activities, this paper studies the government incentive mechanism and the CLSC decisions under the condition of dual information asymmetric in moral hazard and adverse selection. We obtain the threshold of recovery rate set by the government for recycler and investigates the problem of what factors mainly affect the threshold setting. According to the numerical simulation and parameter sensitivity analysis, the reliability of the incentive model are studied.

According to the above analysis, we make the following conclusions. (1) The government could effectively solve the impact of asymmetric information on CLSC management by establishing the relevant incentive mechanisms. (2) When the recycler reports the true recovery rate to the government, the profit would be maximized. (3) To maximize the social welfare, there is an optimal transfer payment for the government, when it lower than the optimal level, with the incentive intensity increases, the social welfare also increases. However, when it is higher than the optimal level, the social welfare decreases with the increase of incentive intensity. (4) The recovery efficiency of the recycler not only affects their own profit, but affects the profit of the manufacturer. Thus to achieve a win-win situation, the recycler and manufacturer should improve the recovery level from the overall situation. (5) The government could regulate the recycler in different ways, such as the regulation based on and the regulation based on (6) As the recycler makes efforts to improve the level of recycling, the government increases the incentive intensity. However, with the increase of investment cost, which to some extent reduces the motivation of the recycler in terms of investment. Therefore, the government cannot blindly require the

recycler to improve the recovery rate and strengthen the regulation, it should pay more attention to control the investment cost. (7) With the increase of market capacity, the incentive intensity would increase. (8) In addition to the management factors of the recycler, the government's close of low recovery efficiency enterprises is also affected by many other factors, such as the basic capacity of the product market, the elasticity of consumer price demand and the manufacturer's production technology level.

Therefore, in a win-win society, we call on the manufacturer and recycler to focus on the overall situation, thus to maximize the total profits of the CLSC and achieve win-win social environmental and economic benefits of the enterprises. At the same time, the government should also play its role of intervention, strengthen the guidance and regulate the market to guarantee it stable operation.

To facilitate the research, this paper assumes that the situation is a CLSC system composed of a single manufacturer and a single recycler, and does not consider the quality difference of the new products and remanufactured products, while the actual situation is more complex and diverse. Possible extensions of this research are the following: The different pricing strategies of the products and a CLSC system composed of multiple manufacturers and recyclers are our future research directions. In addition, the consideration of consumers can also be an important research direction.

*Acknowledgements.* This study was funded by the National Social Science Fund of China (Grant No. 17BGL252).

*Data availability.* All the data in this manuscript are from the references, and all the data are available.

*The conflict of interest statement.* I declare that I do not have any conflict of interest in the process of submission and have been approved by the author for publication.

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