WEEE-CLSC Pricing Strategy Study Based on the Government Regulation

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***Abstract*— This paper establishes a WEEE-CLSC pricing model considering the influences of government regulations, obtaining the optimal operating strategy and profit for the member enterprises based on game analysis method, as well as the consumer surplus and social welfare. The result shows that, the higher of the WEEE treatment fund of the government imposing on the manufacturers, the wholesale price, direct selling price and distribution price are higher; the higher of the WEEE treatment subsidies of the government granting on the manufacturers, the recycling price and amount of WEEE of the member enterprises are higher; the higher of the consumer's environment awareness ,as well as the more sensitive to the WEEE recycling price, are more helpful for the enterprises to improve the WEEE recovery, while increasing the revenue of the CLSC parties.**

Keywords -WEEE; Closed-loop Supply Chain; Government Regulation

1. INTRODUCTION

The recovery and processing of the waste electrical and electronic equipment (WEEE) has become a hot spot of the word's attention, many countries and regions have study and formulated related laws and regulations to explore the WEEE recycling system and management mechanism positively. Currently there are some scholars to conduct research on the issues of WEEE recycling. For example, Savaskan[1] studied the optimal reverse logistics structure of recycling waste products from the consumer, which showed that the recycling subject is more closer to the consumers, the recovery efficiency is higher. Based on the above study, Savaskan[2] further studied the decision-making problems of CLSC recycling channels with one manufacturer and two competing retailers. In view of the producers pay case under the system of extender producer responsibility (EPR), considering the game between the government, the production enterprises and consumers, Atasu[3] analyzed the environmental and economic impacts of recycling laws and regulations, the results showed that it was unreasonable to set the rate of recovery and reutilization according to the different weight of WEEE, while it should consider the environmental impact of different types of WEEE. Webster [4] established a two-stage model, analyzing the competition strategy of the manufacturers and remanufacturers under the case of manufacturers' recycling and commissioned recycling, and the influence of recycling laws. Hammond [5] built a two layer electric and electronic products CLSC network equilibrium model formed by the manufacture and consumer market, and analyzed the influence of the minimum ratio of recovery and reutilization ruled by WEEE directive. Georgiadis [6]used the system dynamics method to analyze the influence of the factors, such as environmental legislation and green image, on the environmental and economic sustainability of the electric and electronic products CLSC, which pointed out that it should be forced to perform the indices such as the recovery and reutilization rate specified by the WEEE directive.

The above literature rarely considered the hybrid recycling channels and hybrid sale channels at the same time, also did not consider the effect of government regulation policy. In view of this, this article cosiders the hybrid recycling channels constituted by three recycling channels, namely recycled by the third-paty recyling enterpries, vendors and manufactures, as well as the hybrid sale channels componeted by distributors' distribution and manufactures' direct selling, and establiesed a WEEE-CLSC decision-making model under the government regulation, analyzes the optimal strategy of the member enterprises.

2. MODEL DESCRIPTION

Figure 1 is a electric and electronic products CLSC composed by manufacturers, sellers, summers and the third party recycling enterprise, including the hybrid recycling channels (constituted with the third party recyling enterprises, sellers and manufacturers), and the hybrid sales channels (formed by distribution of distributors and direct selling of manufaucturers). The solid line shows the forward logistics, while the dashed line of reverse logistics. The third party recyling enterprises are only responsible for recyling WEEE; the sellers are responsible for the sales of the new electric and electronic equipment and recyling WEEE; the manufactures produce and sell the new electric and electronic products, as well as recyle and remanurecture WEEE. In addition, the government regulates the WEEE recyling through collecting WEEE processing funds from the manufactures and giving WEEE subsidies. The hypothesis of the model is as following:

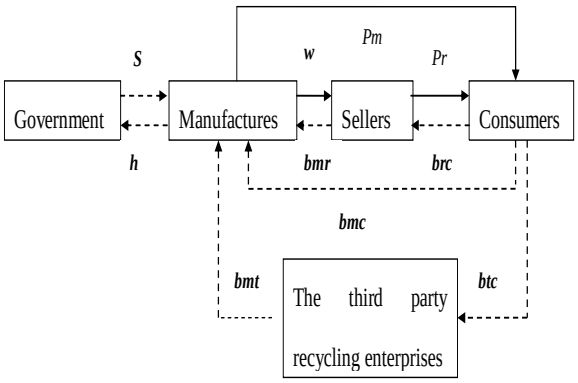

Figure.1 WEEE－CLSC

(1)The manufactures first produce new products with WEEE recycling components remanufactured, when there is lack of demand, the new raw material again is used to produce. There is no difference on quality of the electric and electronic products produced in the two ways, as well as the same price. But the unit cost of the products produced with the raw material is c_m, while the unit cost of old parts remanufacturing is c_h, and $c_m - c_r - c_h > 0$

(2) There are two selling channels of distribution of distributors and direct selling of manufactures. The manufactures' wholesale price is p_r and p_m for the direct selling price, the distribution price of vendors is p_r, and $p_m \le p_r$ electric and electronic products. The introduction of direct channel will not expand the total capacity of the market, that is the sale of the distribution channel is $D_r = r_0 - r_1 p_r - r_2 \left(p_r - p_m \right)$, while the sale of the direct selling channel is $D_m = r_2 \left(p_r - p_m \right)$, and r_0、r_1、r_2 are constants all greater than 0, r_0 is the market capacity, r_1 is the sensitive coefficient of consumers on the distribution price, and r_2 is the sensitive coefficient of consumers on the gap of distribution price and direct selling price.

(3) There are three ways of recycling channels for WEEE, they are the third party enterprises' recycling, vendors' recycling and manufactures' recycling, and the WEEE recycled by the third party and the vendors are all handled by the manufacturers. The unit price of WEEE recycling paid to the consumers of the third party enterprises is b_{tc}, as well as b_{rc} for sellers paid to consumers, and b_{mt}、b_{mr}、b_{mc} respectively for the manufactures paid to the third party, sellers and consumers, according to the recycling situation of recycling convenience, there should be $b_{tc} < b_{rc} < b_{mc}$. The amount of WEEE recycled by the third party is $G\left(b_{tc}\right) = c + db_{tc}$, as well as $G\left(b_{rc}\right) = d\left(b_{rc} - b_{tc}\right)$ for the distributors and $G\left(b_{mc}\right) = d\left(b_{mc} - b_{rc}\right)$ for the manufactures, among which c and d are both constants greater than 0, and c is the amount of the consumers' willing to deliver the WEEE, while d is the sensitive coefficient of WEEE recycling price for consumers.

(4) The government imposes WEEE processing funds h for each electric and electronic product from the manufactures, and gives them subsidy S for processing unit WEEE.

(5) The environment cost of the consumption of each electric and electronic product is C, while the environment benefit for recycling each WEEE is V

Considering the hybrid selling channels and recycled CLSC under the government regulation, the interaction between the government, manufactures, sellers and the third party can build a three stages game model, of which the decision-making sequence is as follows: the first stage is for the formulation of environmental policy, in which the goal of the government is the maximization of social welfare, to decide the processing funds h and the processing subsidy s; the second stage provides policy instrument for the manufactures according to the government regulation, with the goal of the maximization of their own profit, to decide the wholesale w and direct price p_m of the electric and electronic products, and the WEEE recycling price b_{mt}, b_{mt} and b_{mc} respectively paid to the third party enterprises, the retailers and the consumers; the third stage is that under the price of w、p_m and b_{mr} given by the manufactures, with the goal of the maximization of their own profit, the sellers decide the distribution price p_r of the electric and electricity products and the WEEE recycling price b_{rc} paid to the consumers, while according to the recycling price b_{mt} determined by the manufactures, the third party decide the WEEE recycling price b_{tc} paid to the consumers to make their biggest gains.

At this time, the goals and decisions of the third party recycling companies, distributors, manufactures and the government can be respectively described as:

$$\max_{b_{tc}} \pi_t = \left(b_{mt} - b_{tc}\right) G\left(b_{tc}\right) \tag{1}$$

$$\max_{b_{rc}, p_r} \pi_r = \left(b_{mr} - b_{rc}\right) G\left(b_{rc}\right) + D_r \left(p_r - w\right) \tag{2}$$

$$\max_{b_{mt},b_{mr},b_{mc},w,p_m} \pi_m = -b_{mt}G(b_{tc}) - b_{mr}G(b_{rc})$$
$$-b_{mc}G(b_{mc}) + D_r(w - c_m - h) + D_m(p_m - c_m - h)$$
$$+\left(G(b_{tc}) + G(b_{rc}) + G(b_{mc})\right)(s + c_m - c_r - c_h) \tag{3}$$

$$\max_{s,h} \pi = \pi_t + \pi_r + \pi_m + \pi_c + h(D_r + D_m)$$
$$-s\left(G(b_{tc}) + G(b_{rc}) + G(b_{mc})\right) - C(D_r + D_m)$$
$$+V\left(G(b_{tc}) + G(b_{rc}) + G(b_{mc})\right)$$
$$= -b_{tc}G(b_{tc}) - b_{rc}G(b_{rc}) - b_{mc}G(b_{mc}) +$$
$$\left(G(b_{tc}) + G(b_{rc}) + G(b_{mc})\right)(c_m - c_r - c_h + V) +$$
$$D_r\left(\frac{1}{2}p_r - c_m - C + \frac{r_0}{2r_1}\right) +$$
$$D_m\left(\frac{1}{2}p_r + \frac{1}{2}p_m - c_m - C\right) + cb_{mc} + \frac{1}{2}db_{mc}^2 \tag{4}$$

In addition, the consumer surplus exists in the forward supply chain and the reverse supply chain, that is：

$$\pi_c = \frac{D_r}{2}\left(\frac{r_0}{r_1} - p_r\right) + \frac{D_m^2}{2r_2} + cb_{mc} + \frac{1}{2}db_{mc}^2 \tag{5}$$

3.THE MODELING AND SOLUTION

A.the third party recycling enterprises

The third party recycling enterprises are only responsible for the recycling of WEEE from the consumers, then sell them to the manufactures, so the goal of the third party is the maximization of their own profit, deciding the WEEE recycling price b_{tc} paid to the consumers, if $\frac{\partial \pi_t}{\partial b_{tc}} = 0$, then

$$b_{tc} = \frac{db_{mt} - c}{2d} \tag{6}$$

B. The sellers

On one hand, the sellers is responsible for the sale of the new electric and electronic products, on the other hand, they recycle WEEE from the consumers, so with the goal of the maximization of their own profit, the sellers decide the new electric and electronic products' distribution price p_r and WEEE recycling price b_{rc}, making $\frac{\partial \pi_r}{\partial b_{rc}} = 0$、$\frac{\partial \pi_r}{\partial p_r} = 0$, getting

$$b_{rc} = \frac{b_{tc} + b_{mr}}{2} \tag{7}$$

$$p_r = \frac{r_0 + r_2 p_m}{2(r_1 + r_2)} + \frac{w}{2} \tag{8}$$

C. the manufactures

On one hand, the manufactures recycle WEEE from the third party recycling enterprises, distributors and consumers to remanufacture, on the other hand, they sell the new electric and electronic products through the direct sales channels, so with the maximization of their own profit as the goal, the manufactures decide the wholesale price w of the new electric and electronic products giving to the retailers, the direct selling price p_m through the direct sale channel, and the WEEE recycling price b_{mt}、b_{mr} and b_{mc} respectively for the third party, distributors and consumers. Formula (6) - (8) into equation (3) to get:

$$\pi_m = -b_{mt}\frac{c + db_{mt}}{2} - b_{mr}\frac{c + 2db_{mr} - db_{mt}}{4}$$
$$-b_{mc}\frac{c + 4db_{mc} - 2db_{mr} - db_{mt}}{4}$$
$$+(c + db_{mc})(s + c_m - c_r - c_h)$$
$$+\frac{1}{2}\left[r_0 + r_2 p_m - (r_1 + r_2)w\right](w - c_m - h)$$
$$+r_2\left[\frac{r_0 - (2r_1 + r_2)p_m}{2(r_1 + r_2)} + \frac{w}{2}\right](p_m - c_m - h) \tag{9}$$

Making $\frac{\partial \pi_m}{\partial b_{mt}} = 0$、$\frac{\partial \pi_m}{\partial b_{mr}} = 0$、$\frac{\partial \pi_m}{\partial b_{mc}} = 0$、$\frac{\partial \pi_m}{\partial w} = 0$、$\frac{\partial \pi_m}{\partial p_m} = 0$, the simultaneous solution is:

$$b_{mt} = \frac{1}{4}(s + c_m - c_r - c_h) - \frac{3c}{4d} \tag{10}$$

$$b_{mr} = \frac{3}{8}(s + c_m - c_r - c_h) - \frac{5c}{8d} \tag{11}$$

$$b_{mc} = \frac{5}{8}(s + c_m - c_r - c_h) - \frac{3c}{8d} \tag{12}$$

$$p_m = w = \frac{c_m + h}{2} + \frac{r_0}{2r_1} \tag{13}$$

Formula (10)-(13) to substitute back into (6)-(8)，to obtain:

$$b_{tc} = \frac{1}{8}(s + c_m - c_r - c_h) - \frac{7c}{8d} \tag{14}$$

$$b_{rc} = \frac{1}{4}(s + c_m - c_r - c_h) - \frac{3c}{4d} \tag{15}$$

$$p_r = \frac{r_1(r_1 + 2r_2)(c_m + h) + 3r_0 r_1 + 2r_0 r_2}{4r_1(r_1 + r_2)} \tag{16}$$

D. the government

On one hand, the government offer the subsidies to the manufactures who handle WEEE to improve their enthusiasm; on the other hand, they collect WEEE processing funds from the manufactures who produce the new electric and electronic products, so the government put the social welfare maximization as the goal, to decide the processing subsidy S for the unit of WEEE and the

professing funds h for the production of unit of the new electric and electronic products.

Formula (10)-(16) into equation (4), that is

$$\pi=-\frac{11d}{128}\left(s+c_m-c_r-c_h\right)^2+\frac{29c}{64}\left(s+c_m-c_r-c_h\right)$$
$$+\frac{5}{8}\left[d\left(s+c_m-c_r-c_h\right)+c\right]\left(c_m-c_r-c_h+V\right)$$
$$+\frac{5c^2}{128}+\left[\frac{\left(r_1^2+6r_1r_2+6r_2^2\right)\left(c_m+h\right)}{8\left(r_1+r_2\right)^2}\right.$$
$$\left.-\frac{\left(r_1+2r_2\right)\left(c_m+C\right)}{r_1+r_2}+\frac{r_0\left(7r_1^2+18r_1r_2+10r_2^2\right)}{8r_1\left(r_1+r_2\right)^2}\right]*$$
$$\frac{r_0-r_1\left(c_m+h\right)}{4} \tag{17}$$

Making $\frac{\partial\pi}{\partial s}=0$ 、 $\frac{\partial\pi}{\partial h}=0$, then

$$s=\frac{29}{11}\left(c_m-c_r-c_h\right)+\frac{29c}{11d}+\frac{40V}{11} \tag{18}$$

$$h=\frac{4\left(r_1+r_2\right)\left(r_1+2r_2\right)\left(c_m+C\right)}{r_1^2+6r_1r_2+6r_2^2}-$$
$$\frac{r_0\left(3r_1^2+6r_1r_2+2r_2^2\right)}{r_1\left(r_1^2+6r_1r_2+6r_2^2\right)}-c_m \tag{19}$$

Formula (18)、(19) back into(10)-(16)，then the final decision of the third party recycling enterprises is:

$$b_{tc}=\frac{5}{11}\left(c_m-c_r-c_h+V\right)-\frac{6c}{11d} \tag{20}$$

The final decision of the retailers:

$$b_{rc}=\frac{10}{11}\left(c_m-c_r-c_h+V\right)-\frac{c}{11d} \tag{21}$$

$$p_r=\frac{\left(r_1+2r_2\right)^2\left(c_m+C\right)}{r_1^2+6r_1r_2+6r_2^2}+\frac{2r_0r_2\left(r_1+r_2\right)}{r_1\left(r_1^2+6r_1r_2+6r_2^2\right)} \tag{22}$$

The final decision of the manufactures is:

$$b_{mt}=\frac{10}{11}\left(c_m-c_r-c_h+V\right)-\frac{c}{11d} \tag{23}$$

$$b_{mr}=\frac{15}{11}\left(c_m-c_r-c_h+V\right)+\frac{4c}{11d} \tag{24}$$

$$b_{mc}=\frac{25}{11}\left(c_m-c_r-c_h+V\right)+\frac{14c}{11d} \tag{25}$$

$$p_m=w=\frac{2\left(r_1+r_2\right)\left(r_1+2r_2\right)\left(c_m+C\right)}{r_1^2+6r_1r_2+6r_2^2}$$
$$+\frac{r_0\left(-r_1^2+2r_2^2\right)}{r_1\left(r_1^2+6r_1r_2+6r_2^2\right)} \tag{26}$$

E. the earnings of the relevant parties

Formula the decisions of the CLSC member enterprises back into (1)-(5), the final profits, social welfare and consumer surplus of the member enterprises is respectively:

$$\pi_t=d\left[\frac{5}{11}\left(c_m-c_r-c_h+V\right)+\frac{5c}{11d}\right]^2 \tag{27}$$

$$\pi_r=d\left[\frac{5}{11}\left(c_m-c_r-c_h+V\right)+\frac{5c}{11d}\right]^2+$$
$$\left(r_1+r_2\right)\left[\frac{r_1\left(r_1+2r_2\right)}{r_1^2+6r_1r_2+6r_2^2}\left(\frac{r_0}{r_1}-c_m-C\right)\right]^2 \tag{28}$$

$$\pi_m=20d\left[\frac{5}{11}\left(c_m-c_r-c_h+V\right)+\frac{5c}{11d}\right]^2+$$
$$2r_1\left(r_1^2+3r_1r_2+2r_2^2\right)\left[\frac{r_1+2r_2}{r_1^2+6r_1r_2+6r_2^2}\left(\frac{r_0}{r_1}-c_m-C\right)\right]^2 \tag{29}$$

$$\pi=\frac{25d}{22}\left(c_m-c_r-c_h+V\right)^2+\frac{25c}{11}\left(c_m-c_r-c_h+V\right)$$
$$+\frac{7c^2}{11d}+\frac{1}{2}r_1\left(r_1+2r_2\right)\left(r_1^3+8r_1^2r_2+18r_1r_2^2+12r_2^3\right)*$$
$$\left[\frac{1}{r_1^2+6r_1r_2+6r_2^2}\left(\frac{r_0}{r_1}-c_m-C\right)\right]^2 \tag{30}$$

$$\pi_c=\frac{625d}{242}\left(c_m-c_r-c_h+V\right)^2+\frac{625c}{121}\left(c_m-c_r-c_h+V\right)+$$
$$\frac{254c^2}{121d}+\frac{1}{2}r_1\left(r_1^2+4r_1r_2+2r_2^2\right)*$$
$$\left[\frac{\left(r_1+2r_2\right)}{r_1^2+6r_1r_2+6r_2^2}\left(\frac{r_0}{r_1}-c_m-C\right)\right]^2 \tag{31}$$

4.MODEL ANALYSIS

According to the above analysis:

Conclusion 1：$\frac{\partial G\left(b_{tc}\right)}{\partial s}>0$ 、 $\frac{\partial G\left(b_{rc}\right)}{\partial s}>0$ 、 $\frac{\partial G\left(b_{mc}\right)}{\partial s}>0$, $\frac{\partial\pi_r}{\partial s}>0$ 、 $\frac{\partial\pi_m}{\partial s}>0$ 、 $\frac{\partial\pi_c}{\partial s}>0$ and $\frac{\partial^2\pi}{\partial s^2}<0$, $\frac{\partial b_{mt}}{\partial s}>0$ 、 $\frac{\partial b_{tc}}{\partial s}>0$ 、 $\frac{\partial b_{rc}}{\partial s}>0$ 、 $\frac{\partial b_{mr}}{\partial s}>0$ 、 $\frac{\partial b_{mc}}{\partial s}>0$.

This shows that the higher of the WEEE processing subsidy the government giving to the manufactures, the recycling price and amount of the CLSC member enterprises are higher, and the profit and consumer surplus of the member enterprises increase with the increase of the processing subsidy, but the social welfare shows a trend of decrease after increase first with the increase of the processing subsidy. This also suggests that the member enterprises and the consumers in the supply chain both want the government to improve the processing subsidy, but in terms of the social welfare maximization, it is impossible to improve the processing subsidy again and again.

Conclusion 2 : $\frac{\partial p_m}{\partial h}=\frac{\partial w}{\partial h}>0$, $\frac{\partial p_r}{\partial h}>0$, $\frac{\partial \pi_m}{\partial h}<0$, $\frac{\partial \pi_c}{\partial h}<0$ and $\frac{\partial^2 \pi}{\partial h^2}<0$.

This shows that the WEEE processing fund collected from the manufactures by the government is higher, the wholesale, direct selling price and distribution price of the electric and electronic products are higher, but the profit and consumer surplus of the manufactures and sellers are reduced with the increase of the processing funds, while the social welfare increases first and then reduces with the increase of the funds, besides, the profit of the third party recycling enterprises has nothing with the funds. So the manufactures, distributors and consumers are all want the government to reduce the professing funds.

Conclusion 3: $\frac{\partial G(b_{tc})}{\partial c}>0$ 、 $\frac{\partial G(b_{rc})}{\partial c}>0$ 、 $\frac{\partial G(b_{mc})}{\partial c}>0$, $\frac{\partial b_{mt}}{\partial c}<0$ 、 $\frac{\partial b_{tc}}{\partial c}<0$ 、 $\frac{\partial b_{rc}}{\partial c}<0$ 、 $\frac{\partial b_{mr}}{\partial c}>0$ 、 $\frac{\partial b_{mc}}{\partial c}>0$, $\frac{\partial s}{\partial c}>0$ and $\frac{\partial \pi_t}{\partial c}>0$ 、 $\frac{\partial \pi_r}{\partial c}>0$ 、 $\frac{\partial \pi_m}{\partial c}>0$ 、 $\frac{\partial \pi}{\partial c}>0$ 、 $\frac{\partial \pi_c}{\partial c}>0$.

This suggests that the more the consumers are willing to free deliver WEEE, the WEEE recycled by the various enterprises are more, while the recycling price of the manufactures paid to the third party and the third party and the distributors paid to the consumers will reduce, but the recycling price the manufactures paid to the distributors and consumers will increase, at the same time, the processing subsidy of the government, the profit of the member enterprises, the social welfare and the consumer surplus all will increase.

Conclusion 4 : $\frac{\partial b_{mt}}{\partial d}>0$ 、 $\frac{\partial b_{tc}}{\partial d}>0$ 、 $\frac{\partial b_{rc}}{\partial d}>0$ 、 $\frac{\partial b_{mr}}{\partial d}<0$ 、 $\frac{\partial b_{mc}}{\partial d}<0$, $\frac{\partial s}{\partial d}<0$, $\frac{\partial \pi_r}{\partial d}>0$ 、 $\frac{\partial \pi_m}{\partial d}>0$ 、 $\frac{\partial \pi}{\partial d}>0$ 、 $\frac{\partial \pi_c}{\partial d}>0$.

Conclusion 4 shows that the consumers are more sensitive to the WEEE recycling price, the more WEEE recycled by the enterprises, while the recycling price the manufactures paid to the third party , the third party and the distributors paid to the consumers will increase, but the recycling price the manufactures paid to the distributors and consumers will reduce, at the same time, the processing subsidy of the government will reduce, and the profit of the member enterprises, the social welfare and the consumer surplus all will increase.

Conclusion3 and 4 also suggest, the high environmental awareness as well as the sensitive to the WEEE recycling price of the consumers can help the enterprises to improve the recycling amount of WEEE, and increase the income of the parties involved in CLSC. But there way of promotion is different: the former is from the emotional level of the consumers' quality to directly promote, while the latter is from the rational level of the market economy.

5.CONCLUSION

This article establishes a WEEE-CLSC pricing model under the government regulation, obtaining the optimal strategy for the member enterprises. The study shows that:

（1）the professing funds imposed on the manufactures and subsidy giving to them by the government influence the member enterprises' decision-making through the supply chain conduction effect. Moreover, the higher of the professing funds, the wholesale price, direct selling price and distribution price are higher; the higher of the professing subsidy, the recycling price and amount of the member enterprises are higher. (2) the higher of the consumers' environmental awareness and the more sensitive to the WEEE recycling price, the more helpful for the enterprises to improve the recycling amount of WEEE, at the same time the profitability of the CLSC participants increases.

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