# Effect of Government Recycling Fund Policy and Design of Optimal Tax- Subsidy Standard in a Manufacturing-Recycling System

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**Abstract.** In this paper, the Stackelberg game method is used to construct a decision-making model composed of government, a single producer and a single recycler. Considering the WEEE recycling fund policy of the government, the influence of the joint mechanism of tax-subsidy on the production and recycling decisions of relevant stakeholders in the supply chain is discussed. On this basis, this paper discusses the government's optimal tax-subsidy strategy under the current policy of maximizing social welfare, and analyzes the factors that affect the formulation of the optimal tax-subsidy standard. The conclusion shows that, first of all, the tax mainly restrains the production behavior, while the subsidy mainly stimulates the recycling behavior. However, when the manufacturer uses the recycled raw materials for production, the subsidy will also increase the manufacturer's profit. Secondly, from the perspective of social welfare maximization, the optimal government tax is positively correlated with product production cost and environmental damage, while the optimal subsidy is positively correlated with product disassembly rate and recycling environmental benefits.

**Keywords:** WEEE; Recycling fund policy; Extended Producer Responsibility; Closed loop supply chain

## 1 Introduction

The harmfulness and resource nature of electrical and electronic waste (WEEE) make its recycling and disposal become an urgent and necessary issue [1]. In order to standardize the WEEE recycling, China implements the extended producer responsibility system, which emphasizes the responsibility of manufacturers in green production and recycling [2]. Meanwhile, China has issued a series of policies and the main policy is the recycling fund policy. Specifically, the government levies taxes on producers and grants subsidies to recyclers to promote the development of the recycling. The impact of the implementation of this policy on relevant decisions of producers and recyclers is


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worth exploring. At the same time, as WEEE is simply divided into several categories in the recycling catalog, and each category has the same tax and subsidy standard, the implementation effect of the recycling fund policy is not ideal [3]. Therefore, this paper further studies how to determine the best tax-subsidy strategy when the government takes the maximization of social welfare as its decision-making goal, and provides suggestions for the government to improve the utilization efficiency of the recycling tax and promote a virtuous cycle of production and recycling.

There have been many studies exploring the impact of government fiscal policies on the production and recycling of electronic products. Among them, Zhao Xiaomin studied the influence of government subsidies on the cooperation strategy choice and cooperation interval between manufacturers and recyclers [4]. Xia Xiqiang [5] discussed the different effects of different government subsidy strategies in single-channel and dual-channel reverse supply chain. You Jiajing [6] constructed the decision-making model of manufacturers and recycler under the tax policy, and discussed the change of policy effect when the tax collection is balanced. Zhu [7] established a decision-making model between green manufacturers and ordinary manufacturers under the government subsidy policy. Ji Guojun [8] discussed the characteristics of different recycling modes and studied the effect of the lowest recycling rate on the recycling effect.

However, most existing researches only focus on a single tax or subsidy policy, and most of them tend to explore the impact of subsidies on governance. At the same time, most studies regard government regulations or policies as external forces, and rarely discuss the optimal decision-making of the government. Therefore, on the basis of the existing literature, this paper considers the manufacturer ' implementation of detachable environmental design, analyzes the behavior selection characteristics of the manufacturer and recycler under the policy of recycling fund, and establishes the government decision-making model based on the maximization of social welfare, which provides a theoretical reference for the government to optimize the tax-subsidy policy.

## 2 Research hypothesis and conceptual model

For every unit of new products produced by the manufacturer, the government will collect the disposal tax t. For every unit of used products recovered and dismantled by the recycler, the government will give the recycler a subsidy s.

In the product manufacturing stage, the manufacturer decides the selling price of the new product $p_m$. The manufacturer preferentially uses recycled raw materials for production and purchases new materials for production in the insufficient part. Where, the purchase price per unit of recycled raw materials is $v_r$, and the purchase price per of new raw materials is $v_m$, and $v_r < v_m$, otherwise the manufacturer has no power to buy back recycled raw materials for production. In addition, the unit marginal cost of using new raw materials is $c_m = c_0 + v_m$. The manufacturer's production disassembly rate is $e$, the cost of green production is $\eta e^2 / 2$, where $\eta$ is the coefficient of green production cost.

In the sales stage, assuming no repeat purchase behavior and normalizing the market capacity to 1, the inverse demand function of the consumer is $q_m = 1 - p_m$, where $q_m$ is the total consumption of the product.

In the product recycling and treatment stage, the formal recycler will recover the EOL at the price $p_r$ per unit, and the quantity of the recycled product is $q_r = \delta p_r$.Recyclers environmentally disassemble EOL products and obtain $eq_r$ units of recycled raw materials, and sell them to manufacturers at a price per unit $v_r$.During the recycling and dismantling process, the recycler costs $c_d$ per unit of dismantling.

It is assumed that all parties make decisions under the condition of complete information, so backward induction can be used to solve the problem .

According to the above analysis, a bilevel programming game model is established in this section.

The optimal profit decision model of the manufacturer and recycler is as follows, where subscript M stands for manufacturer, and subscript R stands for recycler.

$$\max_{p_m}\Pi_M=(1-p_m)(p_m-c_0-v_m-t)+e\delta p_r(v_m-v_r)-\frac{\eta e^2}{2} \quad (1)$$

$$\max_{p_r}\Pi_R=\delta p_r(ev_r-p_r-c_d+s) \quad (2)$$

For the recycler, the second derivative of the recycling price can be obtained from the profit function of the recycler. It is easy to find that the recycler's profit is a strictly concave function of the recycling price of waste products, that is, the profit maximization problem has a unique solution.

$$\frac{\partial\Pi_r{}^2}{\partial^2 p_r}=-2<0 \quad (3)$$

If the first derivative is 0, the optimal recycling price of the recycler can be obtained as follows:

$$p_r{}^*=\frac{1}{2}(s-c_d+ev_r) \quad (4)$$

Use the same method, the manufacturer's optimal pricing is obtained as:

$$p_m{}^*=\frac{1}{2}(1+t+c_0+v_m) \quad (5)$$

Substituting the above optimal pricing decisions into the profit functions of the manufacturer and the recycler, the optimal profit of the manufacturer and the recycler can be obtained as follows.

$$\Pi_M^*=\frac{1}{4}[2\delta e(v_m-v_r)(-c_d+ev_r+s)+(1-c_m-t)^2-2e^2\eta]^2 \quad (6)$$

$$\Pi_R^*=\frac{1}{4}\delta(ev_r-c_d+s)^2 \quad (7)$$

Analyzing the above content, the following conclusions can be obtained.

**Proposition 1** Under this tax-subsidy policy, there is an upper limit on the tax $t$ collected by the government from the manufacturer. At the same time, the subsidy $s$ given by the government to recycling and processing enterprises has a minimum limit.

**Proof** Under the government recycling tax policy, the optimal pricing of the manufacturer $p_m^*$ need to be positive , which can be deduced to $t < (1 - c_0 - v_m)$.Similarly, the optimal recycling price needs to be positive, so it can be deduced that the government subsidy needs to meet $s > c_d - ev_r$.

**Proposition 2** Under this tax-subsidy policy, the optimal product pricing is positively related to $t$ , but has nothing to do with subsidy $s$ . The optimal recycling price of the recycler and the optimal recycling quantity are positively correlated with $s$ ,but has nothing to do with tax $t$ . The manufacturer's profit is negatively correlated with and positively correlated with. The profit of recycling processor is unrelated to the tax, but positively correlated with the subsidy.

According to Proposition 2, with the increase of tax, the manufacturer's production cost increases, leading to the increase of the price of new products, that is, the manufacturer transfers the economic responsibility of recycling to the consumer through the increase of price. On the other hand, with the increase of subsidies, recyclers can increase the recycling price and attract more consumers to choose formal recycling channels to deliver used electrical and electronic products, so the recycling capacity and recycling profit are improved. At this time, the manufacturer can buy more recycled raw materials, reducing the cost and increasing the profit.

**Proposition 3** When the disassemble rate of the product increases, the recycling price and recycling profit of the recycler both increases. However, for the manufacturer, there is a threshold $e_0$, where the manufacturer's profit increases with the increase of $e$ when $e \le e_0$ and decreases with the increase of $e$ when $e_0 < e < 1$.

$$e_0 = \frac{\delta(v_m - v_r)(s - c_d)}{2[\eta - \delta v_r (v_m - v_r)]} \tag{8}$$

By taking the first derivative of e of the relevant decision variables and profits, the change trend of the relevant variables with the change of the dismantling rate e can be summarized as the following table. Where N represents no correlation, + represents positive correlation, and – represents negative correlation.

**Table 1.** The Change of Optimal Solution and Optimal Profit with the Increase of Parameter e (self-draw)

| Parameter value | $p_m^*$ | $p_r^*$ | $\Pi_m^*$ | $\Pi_r^*$ |
|---|---|---|---|---|
| $0<e<e_0$ | N | + | + | + |
| $e>e_0$ | N | + | - | + |

According to Proposition 3, the increase in the level of disassembly enables the recycler to process and produce more recycled raw materials, thus obtaining higher income through the sale of recycled raw materials. For the manufacturer, when the disassembly rate is lower, the manufacturer's technology cost input is lower, which can be compensated by reducing the production cost by utilizing the recycled raw material. However, it is worth noting that the value of increases with increasing, that is, the government can increase the willingness of manufacturers to produce green products by increasing subsidies, because manufacturers can make profits through green production in the reuse stage.

We next consider the government's optimal tax and subsidy decisions. According to the research of Ji Guojun [8], social welfare also includes the following contents: consumer surplus, the government's tax income and expenditure and the environmental benefit. In summary, the government's social welfare maximization decision model is as follows, where V represents the environmental damage of each unit of new product, and K represents the environmental benefit brought by recycling each unit of WEEE.

$$\max_{t,s\geqslant 0} SW=\Pi_M+\Pi_R+\Pi_c+\Pi_F+\Pi_E=(p_m^*-c_m-t)(1-p_m^*)+(v_m-v_r)(e\delta p_r^*)-\frac{1}{2}\eta e^2+(ev_r-p_r^*-c_d+s)\delta p_r+\int_{p_m^*}^{1}(1-p_m)dp_m+\frac{1}{2}\delta(p_r^*)^2+tq_m^*-sq_r^*-Vq_m^*+Kq_r^* \quad (9)$$

The function is jointly concave with respect to t and s and the equilibrium solution is obtained by setting the first partial derivative equal to 0.

$$t^*=c_0+v_m-1+2V \quad (10)$$

$$s^*=-c_d+2e(v_m-v_r)+2K \quad (11)$$

**Proposition 4** From the perspective of social maximization, there exists an optimal regulation level for the amount of tax and subsidy determined by the government. The optimal tax is positively related to environmental damage V, and the optimal subsidy is positively related to recycling environmental benefit K and product dismantlability rate e.

Proposition 4 shows that under the government policy of restoring tax revenue, there is not a simple linear relationship between the collection of quotas and subsidies and social welfare, and tax revenue and subsidies have their own threshold. Because in the case of maximizing social welfare, the government has the optimal levy and subsidy strategy. When the environmental damage increases, the government will limit the production quantity by raising tax, thus increasing the production cost of the manufacturer, thus stimulating the manufacturer to adopt a more environmentally-friendly design to reduce the environmental damage. When the processing income K increases, the government will encourage recycling and processing companies to disassemble more waste products by increasing subsidies, thus promoting the efficient use of resources.

# 3 Research conclusion and Enlightenment

In this paper, a three-stage sequential game model is established to study the optimal decision-making behavior of the government, manufacturers and recyclers under the government recycling fund policy. The results show that the increase in tax will lead to the increase in the price of the products and the decrease in the quantity of product. The subsidy policy mainly affects the decision-making of recyclers and has an incentive effect on recycling. However, when manufacturers use recycled raw materials at lower prices, the subsidy policy can also provide incentives to manufacturers. This is because the subsidy increases the recycling quantity by increasing the recycling price, which results in more renewable raw materials available for manufacturers to purchase. When manufacturers' green production input is low, they can make up for the high green production cost by using more raw materials. In the end, the profit rises instead, thus achieving a virtuous circle of green production and recycling. In addition, this paper further discusses the government's optimal tax-subsidy strategy under the goal of social welfare maximization. The results show that, contrary to intuition, not the higher the tax and subsidy, the higher the social welfare, both of which have optimal values. Among them, the optimal tax value is positively correlated with environmental damage, and the optimal subsidy value is positively correlated with factors such as recycling environmental benefits and the degree of product disassembly. The conclusion indicates that the government should actively explore new methods to promote manufacturers to carry out green production, and green production at the source is more effective than end-of-life management. In addition, when formulating tax and subsidy, flexible consideration should be given to product characteristics to avoid extensive across-the-board control.

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