The Competition of Recyclers under the Take Back Legislation

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***Abstract*—As the amount ofWaste Electrical and Electronic Equipment (WEEE)increases, the qualified recycler with the high technology and expensive cost have few supply of waste appliances. To solve this situation, China implements a series of take back legislations based on Extended Producer Responsibility. We want to investigate the competition under the take-back legislations. To this end, we make competitive decision under take back legislations with social planner intervention as a two period stage between qualified and unqualified recyclers. Deriving and computing equilibria, the results show that if the subsidy is small, the unqualified monopoly the market. When the subsidy is moderate, the two recyclers are both in the market. When the subsidy is large, the qualified recycler monopoly the market.**

Keywords-EPR; WEEE; reversechannel; competition; game theory

I. INTRODUCTION

With increasing of the e-waste, more and more countries pay their attention on the recycling, disposing of waste and worn electrical appliances. In the EU alone, WEEE grows at a rate of 3-5% per year, about three times faster than average waste[3]. The quantity of end-of-life home electrical appliances per year is more than 50 million. To ease this trouble, the concept who means 'who pollute, who governance' named Extended Producer Responsibility (EPR) is put forward. The countries formulate series of take back legislations based on EPR such as WEEE Directive in EU. China also implements a series of take back legislations. The details is: the government collect fees from the manufacturer for producing electrical appliances involving washing machine, refrigerator, TV and so on. These fees are put in a fund. The fund is used to subsidy the qualified recyclers, which can dispose WEEE with little even no pollution.

There are many papers about the competition in the reverse channel.[1]and Plambeck has reviewed that more and more attention has been paid to the competition closed-loop supply chain.[2] Some researched the competition in reverse channel about manufacturers[3], retailers[4], remanufacturing[5] [6]. Of course, the competition about taking back or recycling attract more and more attention. Some set a return ration or return quantity of the used products from the customers.[4] [7] [8] [3] formulate a model based that the recyclers take back the used products from the cooperative upstream manufacturers or take back a ratio of the used products, where the ratio is set by the social planner. [9] and [10] use a clear strategy to avoid this problem. They formulate a two period model. In the first period, the retailer sell the used products. At the end of the first period, all the used products is handled. Thus, the recycling price is decided by the selling price in the first period. By contrast, in our paper, we choose the direct price competition. The recyclers in our model compete with the recycling price, the demand is increasing if his price increases. In our model, the higher the recycling price is, the recycling quantity is larger, which is different from the before paper.

II. MODEL DESCRIPTION

We formulate a two period model, the first period is the selling the new products, the second period is recycling period.

In the first period, the government give the recycling fee c_d and s, the manufacturer produce one product, it must pay for c_d .With the serious environmental pollution, the government encourage more and more enterprises to efficiently dispose e-waste which make little or no pollution. In this paper, we consider the government set the treatment fee c_d and subsidy s which is exogenous. The government will collect disposal fees if the manufacturer produces one unit electrical appliances and the government will give the qualified recyclers subsidy for dealing with a piece of waste electrical and electronic equipment. The manufacturer decide the price of the new products denoted by p_M . Here, we use a linear model with substitution effects to describe the consumer demand. i.e. $d = a - \beta p_M$, $\beta > 0$, where $a > 0$ is the market size, β is the cross elasticity of demand. It is obvious that the disposal fund is $c_d d$. In the second period, all the products bought by the customers become WEEE, there are three choice to be chosen: selling to qualified recycler denoted by A, selling to unqualified recycler denoted by B or idle at home. Recycler A and B decide the recycling price p_A and p_B respectively. The demand function of recycler Aand Barestated as $d_A = \frac{\tau d}{2} - p_B + p_A$, $d_B = \frac{\tau d}{2} - p_A + p_B$, $0 < \tau < 1$ is the given recycling target. The recyclers can get revenue from disposing e-waste, e.g., the useful parts can be used to remanufacture. We assume the two recyclers can get the same revenue r if they dispose each unit e-waste. But because of different of the technology the two recyclers chose, the cost of recycler A and B disposing each unit e-waste is different. The disposal cost contains the collective cost, the technology and so on.

Obviously, $c_A > c_B$ .Recycler A can get subsidy s by disposing one product but recycler B cannot. Recycler A and B set the recycling p_A and p_B to compete for the market share.

Before our analysis, we first give the following assumption to avoid the trivial case.

Assumption 1： $0 < c_d < \frac{a - \beta c}{\beta}$, $s \geq 0$.

This assumption makes sure that the market is profitable for the manufacturer when the treatment fee is no higher than $\frac{a - \beta c}{\beta}$. In other words,

If the treatment fee is too higher, the manufacturer should increase its price to make it be profitable. Then, the electronic equipment is so expensive that no one want to purchase this production.

III. Model Analysis

As said above, we formulate a two period model, in the first period, the manufacturer decide the price to maximize its profits. In the second period, the two recyclers decide the recycling price to maximize their profits respectively.

A. Manufacturer's Optimal Price

In this section, the manufacturer must decide its price. The manufacturer's project function is stated as:

$$\pi_M(p_M) = (p_M - c_d - c)(a - \beta p_M)$$

We can easily get that

$$\frac{\partial \pi_M}{\partial p_M} = -2\beta p_M + a + \beta(c_d + c)$$

$$\frac{\partial^2 \pi_M(p_M)}{\partial {p_M}^2} = -2\beta < 0$$

Obviously, $\pi_M(p_M)$ is concave in p_M . So, we can get the optimal price that the manufacturer set is as the following:

Theorem 1The optimal price the manufacturer set is $p_M^* = \frac{a + \beta(c_d + c)}{2\beta}$, and based on this optimal price, the demand is $d = \frac{a - \beta(c_d + c)}{2}$, the profit is $\pi_M = \frac{(a - \beta(c_d + c))^2}{4\beta}$.

When the treatment fees is higher, the manufacturer has to raise price to ensure its profits. With the increasing of the price, less customers want to purchase the production. Thus, the profits will decrease. So, the government must not set the treatment so high that the manufacturer will not produce.

B. Recycler's Optimal Strategy

In this section, the two recyclers should respectively decide the optimal recycling price to make his profits maximal with knowing the information of the manufacturer. i.e., the price of a unit product p_M . Here, we use a linear demand model to describe the demand of the customers. i.e., $d_A = \frac{\tau d}{2} - p_B + p_A$, $d_B = \frac{\tau d}{2} - p_A + p_B$. It is obvious that all the used products cannot take back, we let τ be the target collection rate which is mandatory. So, the recycler's optimization problem can be stated as:

$$\max_{p_A} \pi_A(p_A) = (r + s - c_A - p_A)d_A$$

$$\max_{p_B} \pi_B(p_B) = (r - c_B - p_B)d_B$$

We can obtain that

$$\frac{\partial \pi_A}{\partial p_A} = r + s - c_A + p_B - \tau \frac{a - \beta c_d - \beta c}{4} - 2p_A$$

$$\frac{\partial^2 \pi_A}{\partial {p_A}^2} = -2 < 0$$

$$\frac{\partial \pi_B}{\partial p_B} = r - c_B + p_A - \tau \frac{a - \beta c_d - \beta c}{4} - 2p_B$$

$$\frac{\partial^2 \pi_B}{\partial {p_B}^2} = -2 < 0$$

Thus, Π_A and Π_B is concave in p_A and p_B respectively.

Lemma 1 The best response of recycler A and recycler B is the following respectively:

$$p_A^*(p_B) = \begin{cases} p_B + \tau \frac{a - \beta c_d - \beta c}{4}, & p_B \leq -3\tau \frac{a - \beta c_d - \beta c}{4} + r + s - c_A \\ \frac{-\tau \frac{a - \beta c_d - \beta c}{4} + r + s - c_A + p_B}{2}, & p_A - \tau \frac{a - \beta c_d - \beta c}{4} < p_B < p_A + \tau \frac{a - \beta c_d - \beta c}{4} \\ p_B - \tau \frac{a - \beta c_d - \beta c}{4}, & p_B \geq \tau \frac{a - \beta c_d - \beta c}{4} + r + s - c_A \end{cases}$$

and

$$p_B^*(p_A) = \begin{cases} p_A - \tau \frac{a - \beta c_d - \beta c}{4}, & p_A \leq -3\tau \frac{a - \beta c_d - \beta c}{4} + r - c_B \\ \frac{-\tau \frac{a - \beta c_d - \beta c}{4} + r - c_B + p_A}{2}, & p_B - \tau \frac{a - \beta c_d - \beta c}{4} < p_A < p_B + \tau \frac{a - \beta c_d - \beta c}{4} \\ p_A + \tau \frac{a - \beta c_d - \beta c}{4}, & p_A \geq \tau \frac{a - \beta c_d - \beta c}{4} + r - c_B \end{cases}$$

The proof: The proof of the best response of recycler B is similar to the proof of the best response of recycler A. Here, we just give the proof of the best response of recycler A in detail.

Recalling that π_A is concave in p_A , From the First-Order-Condition, we denote $\frac{-\tau \frac{a - \beta c_d - \beta c}{4} + r + s - c_A + p_B}{2}$ which is the local maximize of recycler A. We denote it as $L_A(p_B)$. That is $L_A(p_B)=\dfrac{-\tau\dfrac{a-\beta c_d-\beta c}{4}+r+s-c_A+p_B}{2}$. Thus, the best response of recycler A is stated as

$$p_A^*(p_B)=\min\{\max\{\frac{-\tau\frac{a-\beta c_d-\beta c}{4}+r+s-c_A+p_B}{2},p_B-\tau\frac{a-\beta c_d-\beta c}{4}\},p_B+\tau\frac{a-\beta c_d-\beta c}{4}\}$$

When $p_B\le -3\tau\dfrac{a-\beta c_d-\beta c}{4}+r+s-c_A$, then $\dfrac{-\tau\frac{a-\beta c_d-\beta c}{4}+r+s-c_A+p_B}{2}\ge p_B+\tau\dfrac{a-\beta c_d-\beta c}{4}$, thus $p_A^*(p_B)=p_B+\tau\dfrac{a-\beta c_d-\beta c}{4}$. When $p_A-\tau\dfrac{a-\beta c_d-\beta c}{4}<p_B<p_A+\tau\dfrac{a-\beta c_d-\beta c}{4}$, then

$$p_B+\tau\frac{a-\beta c_d-\beta c}{4}<\frac{-\tau\frac{a-\beta c_d-\beta c}{4}+r+s-c_A+p_B}{2}<p_B+\tau\frac{a-\beta c_d-\beta c}{4}.$$

Thus $p_A^*(p_B)=\dfrac{-\tau\frac{a-\beta c_d-\beta c}{4}+r+s-c_A+p_B}{2}$. When $p_B\ge\tau\dfrac{a-\beta c_d-\beta c}{4}+r+s-c_A$, then $\dfrac{-\tau\frac{a-\beta c_d-\beta c}{4}+r+s-c_A+p_B}{2}<p_B-\tau\dfrac{a-\beta c_d-\beta c}{4}$, thus $p_A^*(p_B)=p_B-\tau\dfrac{a-\beta c_d-\beta c}{4}$. Then, we complete the proof.

Theorem 2The optimal pricing behavior of two recyclers is the following:

1.When $s\le(c_A-c_B)-\tau(a-\beta c_d-\beta c)$, the Equilibrium where recycler B poses price $-3\tau\dfrac{a-\beta c_d-\beta c}{4}+r-c_B$ dominate the market and recycler A quits the market.

2.When $(c_A-c_B)-\tau(a-\beta c_d-\beta c)<s<(c_A-c_B)+\tau(a-\beta c_d-\beta c)$, the Equilibrium where recycler A poses price $r+\dfrac{2s-2c_A-c_B-\tau(a-\beta c_d-\beta c)}{3}$ and recycler B poses price $r+\dfrac{s-c_A-2c_B-3\tau\frac{a-\beta c_d-\beta c}{3}}{3}$.

3. When $s\ge(c_A-c_B)+\tau(a-\beta c_d-\beta c)$, the Equilibrium where recycler A poses price $-\tau\dfrac{a-\beta c_d-\beta c}{2}+r+s-c_A$ dominate the market and recycler B quits the market.

As is shown above, we know that if the subsidy is too little, recycler A can not make up for the inferiority causing by the high cost. So, the recycler B will set the price higher than recycler A to attract all customers to sell their used products to it. Then, the recycler A will leave the market. When the s is too high, recycler A has the ability to set its price to collect all the WEEE from the customers. So, the recycler B can not set its price higher lower to compete for the demand of recycling. Then, it will leave the market. When the subsidy is mediate, there are two recyclers in the market.

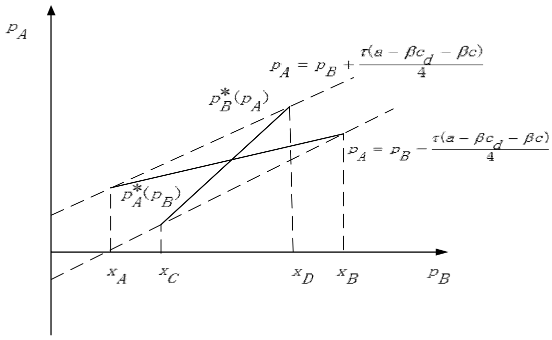

FIGURE I. THE BEST RESPONSE OF RECYCLER A AND B.

The proof: From Figure 1 and Lemma 1, When $s\le(c_A-c_B)-\tau(a-\beta c_d-\beta c)$, i.e., $x_C\ge x_B$, we find the Equilibrium where recycler B poses price $-3\tau\dfrac{a-\beta c_d-\beta c}{4}+r-c_B$ dominate the market and recycler A quits the market. When $(c_A-c_B)-\tau(a-\beta c_d-\beta c)<s<(c_A-c_B)+\tau(a-\beta c_d-\beta c)$, i.e., $x_D>x_A$ and $x_C<x_B$, we find the Equilibrium where recycler A poses price $r+\dfrac{2s-2c_A-c_B-\tau(a-\beta c_d-\beta c)}{3}$ and recycler B poses price $r+\dfrac{s-c_A-2c_B-3\tau\frac{a-\beta c_d-\beta c}{3}}{3}$. When $s\ge(c_A-c_B)+\tau(a-\beta c_d-\beta c)$, i.e., $x_D\le x_A$, we find that the Equilibrium where recycler A poses price $-\tau\dfrac{a-\beta c_d-\beta c}{2}+r+s-c_A$ dominate the market and recycler B quits the market.

Proposition 1 When $(c_A-c_B)-\dfrac{3}{4}\tau(a-\beta c_d-\beta c)<s<c_A-c_B$, then $d_A<d_B$, $\pi_A<\pi_B$

When $c_A - c_B \leq s < (c_A - c_B) + \frac{3}{4}\tau(a - \beta c_d - \beta c)$, then $d_A \geq d_B$, $\pi_A \geq \pi_B$

When the subsidy is lower than $c_A - c_B$, compared to recycler A, recycler B has the advantage to set the price higher to attract more customers to give their used products. So, the profits of recycler B is higher than recycler A. Contrarily, if the subsidy is higher than $c_A - c_B$, the recycler A has the advantage to compete with the recycler B. So, the recycler A can get more used products than the recycler B, thus, the profits of recycler A is higher than recycler B.

IV. Conclusion

In this paper, we use a two period model to investigate the behaviors of recyclers uner the take back legislation based on EPR. We find that if the subsidy is little, the qualified recyclers cannot survive, which is consistent with the phenomenon at present in China. And we find that if the subsidy is large, the qualified can get all the WEEE from the customers. That means the government must enlarge the subsidy.

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