Effectiveness of Consumer-Paid Deposit-Refund System in Closed-Loop Supply Chain

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Abstract

In order to explore the effectiveness of consumer-paid deposit-refund system (DRS) in a closed-loop supply chain, this paper used game theory to analyze the equilibrium strategies and compare the equilibrium outcomes for each stakeholder under consumer-paid DRS and no consumer-paid DRS. The finding is that the recycling quantity of used products and the social welfare in the consumer-paid DRS both are bigger than that in no consumer-paid DRS. Therefore, the consumer-paid DRS is effective for promoting the used products recycling and the social welfare.

Keywords

Consumer-paid deposit-refund system, closed-loop supply chain, effectiveness.

1. Introduction

In consumer-paid deposit-refund system, consumers need to pay a deposit when purchasing products and receive a refund when returning used products [1]. Consumer-paid DRS has an optimal cost structure and cost efficiency, which is an effective environmental economic policy. As early as the 1970s, DRS has appeared in the United States as a method of recycling waste packaging. Later, many scholars (e.g., Potter [2], Fullerton et al. [3], Bohm [4], Hicks et al. [5]) conducted academic researches on it. Many studies established a general equilibrium model from total supply and total demand to design optimal DRS in closed-loop supply chain (e.g., Onuma et al. [6], Uwasu et al. [7], Sigman [8]). However, Atasu [9] considered that operational management analysis method can integrate economic models and system sciences effectively, so that it can be applied to research on recycling policies in different backgrounds. In recent years, there are many researches used game theory to study recycling policy (e.g. Zhong et al., [10], Xie Tianshuai et al., [11, 12], Numata [13], Ino et al. [14]).

Therefore, this paper uses game theory to establish two closed-loop supply chain models under consumer-paid DRS and no consumer-paid DRS. By studying the equilibrium strategies and comparing the equilibrium outcomes, we obtain the optimal deposit and the role of consumer-paid DRS.

2. Model and Hypothesis

2.1 Model without Consumer-Paid DRS

We assume that there is a single product closed-loop supply chain, which includes a producer (also a recycler) and some consumers. In this closed-loop supply chain, first the producer sells products to consumers and gets sales price of the product. Then when the product lifecycle ends, consumers return used products to producer and receive recycling price of the used product.

Consumers: we assume that consumers willing to pay for the product is $X \sim U[0, P_X]$ (P_X is the maximum willingness) and cost to return for the waste is $Y \sim U[0, P_Y]$ (P_Y is the maximum cost). Given the sales price of the product p_s, a consumer with willingness to pay X' buys the product if $X' \geq p_s$. So we can get the total quantity sold:

$$q_s = 1 - \frac{p_s}{P_X} \tag{1}$$

Given the recycling price of the used product p_r, a consumer with cost Y' to return the used product if $Y' \leq p_r$. So we can get the total quantity recycled:

$$q_r = \frac{q_s}{P_Y} p_r = \frac{(P_X - p_s) p_r}{P_X P_Y} \tag{2}$$

The consumers surplus in products sales market:

$$\Pi_{CS} = \frac{(P_X - p_s)^2}{2P_X} \tag{3}$$

The returning profit of consumers in used products recycling market:

$$\Pi_{CR} = q_r \left(p_r - \frac{q_s p_r^2}{2P_Y} \right) = \frac{p_r^2 (P_X - p_s)\left(2P_X P_Y - p_r (P_X - p_s)\right)}{2P_X^2 P_Y^2} \tag{4}$$

the total profit of consumers in closed-loop supply chain is $\Pi_C = \Pi_{CS} + \Pi_{CR}$.

Producer： we assume that producer chooses the sales price to maximize his sales profit and chooses recycling price to maximize his recycling profit. The cost of producing per unit product is μ and the profit of handling per unit used product is g_r. The producer maximizes his sales profit:

$$\Pi_{MS}(p_s) = q_s (p_s - \mu) = \frac{-p_s^2 + (P_X + \mu) p_s - \mu P_X}{P_X} \tag{5}$$

and maximizes his recycling profit:

$$\Pi_{MR}(p_r) = q_r (g_r - p_r) = \frac{p_r (g_r - p_r)(P_X - p_s)}{P_X P_Y} \tag{6}$$

the total profit of producer in closed-loop supply chain is $\Pi_M = \Pi_{MS} + \Pi_{MR}$.

Environmental benefits: we assume the environmental cost of not recycling a used product is given by ε, then:

$$\Pi_E = -\varepsilon (q_s - q_r) = -\frac{\varepsilon (P_X - p_s)(P_Y - p_r)}{P_X P_Y} \tag{7}$$

Social welfare: the total welfare in the economy consists of consumers profit, producer profit and environmental benefit, i. e., $W = \Pi_C + \Pi_M + \Pi_E$.

The sequence of events is as follows: First, the producer sets sales price (p_s). Then given the sales price, consumers buy the products. A two-party two-stage dynamic game is formed at this time. After entering recycling market of used products, the producer sets recycling price (p_r) first. Then given the recycling price, consumers return used products, another two-party two-stage dynamic game is formed. Actually, these two games are independent of each other, but only in time sequence. We assume that all games are complete information.

2.2 Model with Consumer-Paid DRS

In consumer-paid DRS, first the government sets the deposit (t). Then consumers pay the deposit when purchasing products (the deposit can be collected by producer) and receive the refund when returning used products (the refund can be returned by producer).

Consumers: we assume that the deposit does not affect consumers' purchase decision, so p_s is still equation (1) and Π_{CS} is still equation (3). When the product lifecycle ends, given the deposit t and the recycling price p_r, a consumer with cost Y' to return the used product if $Y' \le p_r + t$. So we can get the total quantity recycled:

$$q_r = \frac{q_s}{P_Y}(p_r + t) = \frac{(P_X - p_s)(p_r + t)}{P_X P_Y} \quad (8)$$

when t is higher than or equal to P_Y, all used products can be returned at $p_r = 0$. However, if consumers do not return the used products, they will lost their deposits $t(q_s - q_r)$. The returning profit of consumers in recycling market:

$$\Pi_{CR} == q_r\left(p_r - \frac{q_s(p_r+t)^2}{2P_Y}\right) - t(q_s - q_r) = \frac{(P_X - p_s)(p_r+t)\left(2P_X P_Y p_r - (P_X - p_s)(p_r+t)^2\right)}{2P_X^2 P_Y^2} - \frac{t(P_X - p_s)(P_Y - p_r - t)}{P_X P_Y} \quad (9)$$

the total profit of consumers in closed-loop supply chain is $\Pi_C = \Pi_{CS} + \Pi_{CR}$.

Producer: the sales profit Π_{MS} is still equation (5). The recycling profit:

$$\Pi_{MR}(p_r) = q_r(g_r - p_r) = \frac{(P_X - p_s)(p_r + t)(g_r - p_r)}{P_X P_Y} \quad (10)$$

the total profit in closed-loop supply chain is $\Pi_M = \Pi_{MS} + \Pi_{MR}$.

Environmental benefits:

$$\Pi_E = -\varepsilon(q_s - q_r) = -\frac{\varepsilon(P_X - p_s)(P_Y - p_r - t)}{P_X P_Y} \quad (11)$$

Government: The deposits of non-returned used products can be recognized as the revenue of the government:

$$\Pi_G = t(q_s - q_r) = \frac{t(P_X - p_s)(P_Y - p_r - t)}{P_X P_Y} \quad (12)$$

Social welfare: the total welfare consists of consumers profit, producer profit, environmental benefit and government revenue, i.e., $W = \Pi_C + \Pi_M + \Pi_E + \Pi_G$. The government chooses the deposit to maximize the social welfare.

The sequence of events is as follows: First the producer sets the sales price (p_s).Then given the sales price, consumers buy products, a two-party two-stage dynamic game is formed. After entering the recycling market, the government sets the deposit (t) first. Given the deposit, the producer sets the recycling price (p_r). Then given the recycling price, consumers return the used products, a three-party three-stage dynamic game is formed. These two games are independent of each other, but only in time sequence. We assume that all games are complete information.

3. Model Analysis without Cousumer-Paid DRS

3.1 Equilibrium Strategies

We use backward induction to solve the equilibrium strategies. Since the two dynamic games in the sales market and recycling market are independent of each other, we can solve them separately.

PROPOSITION 1. The optimal sales price is $p_s^* = \frac{P_X + \mu}{2}$.

PROOF. The optimal response function of consumers about sales prices has been given by the equation (1). The producer's sales profit function is the equation (5). Substituting q_s into equation (5):

$$\Pi_{MS}(p_s) = \frac{-p_s^2 + (P_X + \mu)p_s - P_X \mu}{P_X} \quad (13)$$

get optimal sales price $p_s = \frac{P_X + \mu}{2}$.

PROPOSITION 2. If $g_r \le 2P_Y$, the optimal recycling price is $p_r^* = \frac{g_r}{2}$; If $g_r \ge 2P_Y$, the optimal recycling price is $p_r^* = P_Y$.

PROOF. The optimal response function of consumers about recycling price has been given by the equation (2). The producer's recycling profit function is equation (6). Substituting q_r into equation (6):

$$\Pi_{MR}(p_r) = \frac{(P_X - p_s)(-p_r^2 + g_r p_r)}{P_X P_Y} \tag{14}$$

If $g_r \le 2P_Y$, we get the optimal recycling price $p_r^* = \frac{g_r}{2}$; If $g_r \ge 2P_Y$, we get the optimal recycling price $p_r^* = P_Y$.

Proposition 2 shows that when handling profit per unit used product is low ($g_r \le 2P_Y$), recycling price $p_r^* = g_r / 2$ can only attract a portion of consumers to return the used products. If handling profit per unit used product is sufficient high ($g_r \ge 2P_Y$), recycling price $p_r^* = P_Y$ can attract all consumers to return the used products.

3.2 Equilibrium Outcomes

According to the optimal sales price of proposition 1 and the optimal recycling price of proposition 2, we can get sales quantity, recycling quantity, consumers profit, producer profit, environmental benefit and social welfare. The equilibrium outcomes are shown in Table 1.

Table 1. Equilibrium outcomes without consumer-paid DRS

	$g_r \le 2P_Y$	$g_r \ge 2P_Y$
p_s^*	$\frac{P_X + \mu}{2}$	$\frac{P_X + \mu}{2}$
p_r^*	$\frac{g_r}{2}$	P_Y
q_s^*	$\frac{P_X - \mu}{2P_X}$	$\frac{P_X - \mu}{2P_X}$
q_r^*	$\frac{g_r(P_X - \mu)}{4P_X P_Y}$	$\frac{P_X - \mu}{2P_X}$
Π_C^*	$\frac{(P_X - \mu)(8P_X P_Y^2(P_X - \mu) - g_r^3(P_X - \mu) + 8g_r^2 P_X P_Y)}{64P_X^2 P_Y^2}$	$\frac{(P_X - \mu)(P_X^2 - P_X\mu + 3P_X P_Y + \mu P_Y)}{8P_X^2}$
Π_M^*	$\frac{(P_X - \mu)(g_r^2 + 2P_X P_Y - 2\mu P_Y)}{8P_X P_Y}$	$\frac{(P_X - \mu)(P_X - \mu + 2g_r - 2P_Y)}{4P_X}$
Π_E^*	$\frac{\varepsilon(P_X - \mu)(g_r - 2P_Y)}{4P_X P_Y}$	0
W^*	$\frac{(P_X - \mu)(8P_X P_Y^2(3P_X - 3\mu - 4\varepsilon) - g_r^3(P_X - \mu) + 16g_r P_X P_Y(\varepsilon + g_r))}{64P_X^2 P_Y^2}$	$\frac{(P_X - \mu)(P_X(3P_X - 3\mu + 4g_r) - P_Y(P_X - \mu))}{8P_X^2}$

Table 1 shows that recycling quantity and recycling price will increase as handling profit per unit used product increases. When handling profit per unit used product is sufficient high ($g_r \ge 2P_Y$), all waste will be returned to the producer. Besides, consumers profit, producer profit, environmental benefit and social welfare have been maximized. Therefore, the precondition for the implementation of consumer-paid DRS in used products recycling should be $g_r \le 2P_Y$. The analysis of the next chapter is conditional on $g_r \le 2P_Y$.

4. Model Analysis with Consumer-Paid DRS

We use the backward induction to solve the equilibrium strategies. Since the two dynamic games in sales market and recycling market are still independent of each other, we solve them separately.

4.1 Equilibrium Strategies of Producer

PROPOSITION 3. The optimal sales price is $p_s^* = \frac{P_X + \mu}{2}$.(The proof is same as proposition 1.)

PROPOSITION 4. The optimal recycling price is shown in Table 2.

Table 2 Optimal recycling price with cosumer-paid DRS

	$g_r \le P_Y$			$P_Y \le g_r \le 2P_Y$		
	$t < g_r$	$g_r \le t < P_Y$	$t \ge P_Y$	$t < 2P_Y - g_r$	$2P_Y - g_r \le t < P_Y$	$t \ge P_Y$
p_r^*	$\frac{g_r - t}{2}$	0	0	$\frac{g_r - t}{2}$	$P_Y - t$	0

PROOF. The optimal response function of consumers about recycling price has been given by the equation (8). The producer's recycling profit function is equation (10). Substituting q_r into equation (10):

$$\Pi_{MR}(p_r) = \frac{(P_X - p_s)(p_r + t)(g_r - p_r)}{P_X P_Y} \tag{15}$$

get optimal recycling price $p_r = \frac{g_r - t}{2}$. After analysis, the optimal recycling price is shown in Table 2.

Table 2 shows that the recycling price decreases as the deposit increases. If $g_r \le P_Y$, once the deposit exceeds the handling profit per unit used product ($t \ge g_r$), the recycling price becomes $p_r = 0$, i. e., the producer does not have to pay the recycling price to consumers. If $P_Y \le g_r \le 2P_Y$, once the deposit exceeds the consumer's maximum returning cost ($t \ge P_Y$), the recycling price becomes $p_r = 0$ too.

4.2 Equilibrium Strategies of Government

PROPOSITION 5. If $g_r \le 2P_Y$, the optimal deposit is $t^* \in [P_Y, +\infty)$; If $g_r \ge 2P_Y$, the optimal deposit is $t^* \in [2P_Y - g_r, +\infty)$.

PROOF. According to the optimal sales price of proposition 3 and the optimal recycling price of proposition 4, we can obtain the total profit of each stakeholder and futher obtain the social welfare. Then we use derivative method to solve the optimal deposit for maximum social welfare. The optimal deposit is given by proposition 5.

Proposition 5 shows that the optimal deposit related to the handling profit per unit used product g_r and consumer's maximum returning cost P_Y. If $g_r \le P_Y$, the optimal deposit is $t^* \in [P_Y, +\infty)$. At this time, the producer's recycling capacity is weak due to the low handling profit which caused the government to set a high deposit to ease the recycling pressure of the producer. If $P_Y \le g_r \le 2P_Y$, the sufficient high handling profit shares the government's recycling pressure, so that the optimal minimum deposit is reduced to $2P_Y - g_r$.

4.3 Equilibrium Outcomes

According to the optimal sales price of proposition 3, the optimal recycling price of proposition 4 and the optimal deposit of proposition 5, we can get the sales quantity, recycling quantity, consumers profit, producer profit, environmental benefit, government revenue and social welfare. The equilibrium outcomes are shown in Table 3.

Table 3. Equilibrium outcomes with consumer-paid DRS

	$g_r \le P_Y$	$P_Y \le g_r \le 2P_Y$
p_s^*	$\frac{P_X+\mu}{2}$	$\frac{P_X+\mu}{2}$
p_r^*	0	$\left[0, P_Y - t^*\right]$
q_s^*	$\frac{P_X-\mu}{2P_X}$	$\frac{P_X-\mu}{2P_X}$
q_r^*	$\frac{P_X-\mu}{2P_X}$	$\frac{P_X-\mu}{2P_X}$
t^*	$\left[P_Y, +\infty\right)$	$\left[2P_Y - g_r, +\infty\right)$
Π_C^*	$\frac{(P_X-P_Y)(P_X-\mu)^2}{8P_X^2}$	$\frac{(P_X-\mu)\left(P_X\left(P_X-\mu-4t^*\right)+P_Y\left(3P_X+\mu\right)\right)}{8P_X^2}$
Π_M^*	$\frac{(P_X-\mu)(P_X-\mu+2g_r)}{4P_X}$	$\frac{(P_X-\mu)\left(P_X-\mu+2g_r-2P_Y+2t^*\right)}{4P_X}$
Π_E^*	0	0
Π_G^*	0	0
W^*	$\frac{(P_X-\mu)\left(P_X\left(3P_X-3\mu+4g_r\right)-P_Y\left(P_X-\mu\right)\right)}{8P_X^2}$	$\frac{(P_X-\mu)\left(P_X\left(3P_X-3\mu+4g_r\right)-P_Y\left(P_X-\mu\right)\right)}{8P_X^2}$

Table 3 shows that the recycling quantity, recycling price, consumers profit, producer profit, environmental benefit, government revenue and social welfare are all influenced by consumer-paid DRS. If $g_r \le P_Y$, Π_C^*, Π_M^*, Π_E^*, Π_G^* and W^* are all fixed values under the optimal consumer-paid DRS. If $P_Y \le g_r \le 2P_Y$, consumers profit is inversely proportional to the deposit, and producer profit is proportional to the deposit. As the deposit increases, the total loss of the consumers profit is equal to the growth of the producer profit. Thus the social welfare is still a fixed value. Beyond that, the high handling profit per unit used product not only reduces the optimal deposit, but also brings higher social welfare.

5. Comparision

In order to be easy to express, we add the subscript $Null$ and DRS to the equilibrium outcomes in Table 2 and table 4 respectively, e. g., p_{s-Null}^* indicates the sales price without consumer-paid DRS, p_{s-DRS}^* indicates the sales price with consumer-paid DRS.

PROPOSITION 6. If the optimal deposit is sufficient high ($t^* \in \left[P_Y, +\infty\right)$ or $t^* \in \left[2P_Y - g_r, +\infty\right)$), there are $p_{s-Null}^* = p_{s-DRS}^*$, $q_{s-Null}^* = q_{s-DRS}^*$, $p_{r-Null}^* > p_{r-DRS}^*$, $q_{r-Null}^* < q_{r-DRS}^*$.

Proposition 6 shows that consumer-paid DRS will not affect the sales price and sales quantity, but it will reduce the recycling price and increase recycling quantity. Because the high deposit encourages consumers to participate in the returning of used products. Even if the recycling price is low, the recycling quantity is still high and equal to the sales volume, achieving complete recycling. Therefore, the implementation of consumer-paid DRS can improved the recycling of used products.

PROPOSITION 7. If the optimal deposit is sufficient high ($t^* \in \left[P_Y, +\infty\right)$ or $t^* \in \left[2P_Y - g_r, +\infty\right)$), there are $\Pi_{C-Null}^* > \Pi_{C-DRS}^*$, $\Pi_{M-Null}^* < \Pi_{M-DRS}^*$, $\Pi_{E-Null}^* < \Pi_{E-DRS}^*$, $W_{Null}^* < W_{DRS}^*$.

Proposition 7 shows that a sufficient high deposit will reduce the consumers profit, but will increase the producer profit, environmental benefit and social welfar because the waste is fully returned at a high deposit. Therefore, the implementation of DRS can improved the social welfare.

6. Numerical Simulation

To more directly verify the role of consumer-paid DRS, we use mathematical 9.0 for numerical simulation. When $g_r \le P_Y$, the simulation value are $P_X = 12$, $P_Y = 5$, $\mu = 10$, $g_r = 2$, $\varepsilon = 3$. When $P_Y \le g_r \le 2P_Y$, the simulation value are $P_X = 12$, $P_Y = 5$, $\mu = 10$, $g_r = 7$, $\varepsilon = 3$. The equilibrium outcomes without consumer-paid DRS are shown in Table 4. The equilibrium outcomes with optimal consumer-paid DRS (if $g_r \le P_Y$, $t^* \in [5, +\infty)$; if $P_Y \le g_r \le 2P_Y$, $t^* \in [3, +\infty)$) are shown in Table 5. r is the recycling rate which is recycling quantity divided by sales quantity.

Table 4. Equilibrium outcomes without DRS

	$g_r \le P_Y$	$P_Y \le g_r \le 2P_Y$
p_s^*	11	11
p_r^*	1	3.5
q_s^*	0.083	0.083
q_r^*	0.017	0.058
r^*	0.205	0.699
Π_C^*	0.058	0.240
Π_M^*	0.1	0.288
Π_E^*	–0.2	–0.075
Π_G^*	0	0
W^*	–0.042	0.452

Table 5. Equilibrium outcomes with DRS

	$g_r \le P_Y$	$P_Y \le g_r \le 2P_Y$
p_s^*	11	11
p_r^*	0	$[0, 5 - t^*]$
q_s^*	0.083	0.083
q_r^*	0.083	0.083
r^*	1	1
Π_C^*	0.024	$0.441 - 0.083t^*$
Π_M^*	0.25	$0.25 + 0.083t^*$
Π_E^*	0	0
Π_G^*	0	0
W^*	0.274	0.691

First, the comparison result between Table 4 and Table 5 intuitively reflects that consumer-paid DRS has improved recycling rate from both 0.205 and 0.699 to 1. That is, DRS achieves complete used products recycling with a low recycling price and a high deposit. When handling profit per unit used product is low ($g_r \le P_Y$), the recycling quantity with DRS has increased by 4 times. But when handling profit per unit used product is high ($P_Y \le g_r \le 2P_Y$), the recycling quantity with DRS has only increased by 0.4 times. That is because a high handling profit has enabled the producer to have stronger recycling capacity to recycle more used products. Actually, both the high handling profit and the high deposit improve the recycling of used products.

Second, the comparison result between Table 4 and Table 5 also intuitively reflects that consumer-paid DRS has improved the benefits of producer, environment and society. In particular, the environmental benefits have been changed from negative to zero, avoiding environmental pollution. Although consumers profit in DRS is lower than that in no DRS, total social welfare is still higher than that in no DRS due to higher producer profit and higher environmental benefit.

Therefore, by comparing equilibrium outcomes of numerical simulation, the results show that recycling rate of the waste and the social welfare in DRS are bigger than that in no DRS. Therefore, the DRS is effective for promoting the recycling quantity and social welfare.

7. Conclusion

From the perspective of protecting the environment, the used products can always be fully returned when the deposit is sufficient high, thus improving the environment to the greatest extent. From the perspective of social economy, a sufficient high deposit will increase social welfare. Therefore, the implementation of consumer-paid DRS can not only promote the recycling of the used products, but also bring a higher social welfare. So the consumer-paid deposit-refund system is effective.

References

[1] T.S. Xie, J. Zhang: Analysis Framwork on Deposit-refund System for E-waste Management in China, Science and Technology Management Research, Vol. 35(2015) NO. 17, p.40-46. (in Chinese)

[2] R.C. Porter: A Social Benefit-Cost Analysis of Mandatory Deposits on Beverage Containers, Journal of Environmental Economics and Management, Vol. 5(1978) NO. 4, p.351-375.

[3] D. Fullerton, A. Wolverton: Two Generalizations of a Deposit-Refund Systems, American Economic Review, Vol. 90(2000) NO. 2, p.238-242.

[4] P. Bohm: *Deposit-refund systems: Theory and applications to environmental, conservation, and consumer policy* (Resources for the Future, America 1981), p.42-70.

[5] C. Hicks, R. Dietmar and M. Eugster: The recycling and disposal of electrical and electronic waste in China—legislative and market responses, Environmental Impact Assessment Review, Vol. 25(2005) NO. 5, p.459-471.

[6] A. Onuma, T. Saito: Some Effects of Depoisit-Refund System on Producers and Consumers, Keio Economic Society Discussion Paper, Vol. 3(2003), p.1-22.

[7] M. Uwasu, T. Naito, H. Yabar, et al: Assessment of Japanese Recycling Policies for Home Electric Appliance: Cost-Effectiveness Analysis and Socioeconomic and Technological Implications, Environmental Development, Vol. 6(2013) NO. 1, p.21-33.

[8] H.A. Sigman: A Comparison of Public Policies for Lead Recycling, The RAND journal of Economics, Vol. 26(1995) NO. 3, p.452-478.

[9] A. Atasu, L. N. Wassenhove: An Operations Perspective on Product Take - Back Legislation for E - Waste: Theory, Practice, and Research Needs[J]. Production & Operations Management, 2012, 21(3): 407-422.

[10] H. Zhong, C. Zhao: *E-waste Deposit system under EPR in China: A view from closed-loop supply chain* (Service Systems and Service Management (ICSSSM)-9th International Conference on. IEEE, 2012), 2012, p.239-243.

[11] T.S. Xie, X.Y. Li: Goal of E-Waste Recycling Policy: Social Welfare vs Environmental Rcycling Rate (Forecasting), Vol. 35(2016) NO. 3, p.56-62. (in Chinese)

[12] T.S. Xie, J. Zhang and F.X. Wang: Decision-Making Models and Effects of Deposit-refund System for E-Waste in China (Operations Research and Management Science), Vol. 26(2017) NO. 1, p.182-189. (in Chinese)

[13] D. Numata: Economic Analysis of Deposit–Refund Systems with Measures for Mitigating Negative Impacts on Suppliers (Resources Conservation & Recycling), Vol. 53(2009) NO. 4, p.199-207.
[14] H. Ino: Optimal Environmental Policy for Waste Disposal and Recycling when Firms are not Compliant (Journal of Environmental Economics & Management), Vol. 62(2010) NO. 2, p.290-308.