Choice of Government’s Mechanism in Closed-loop Supply Chain by Considering Customer’s Awareness of Environmental Protection Under Asymmetric Information

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Keywords: Asymmetric information, Customer’s awareness of environmental protection, Reward-penalty mechanism, Reward-penalty and subsidy mechanism, Tax-subsidy mechanism.

Abstract. Environmental consciousness has become very important in theory and practice, the recycling and reusing of waste electrical and electronic equipment (WEEE) can effectively improve the efficiency of resource utilization. In the paper, based on the customer’s awareness of environmental protection, we compare the impact of different government mechanisms on reducing the carbon emission and improving the effectiveness of the recovery quantity under asymmetric information. We build three different decision-making models by using the dynamic game theory. We analyze the optimal decision in four decision-making models and explain the feature of different government mechanisms. Lastly, we analyze the impact of the customer’s awareness of environmental protection on the optimal decision making models. The result shows that (1) The government’s carbon emission reward-penalty mechanism can improve the wholesale price for new product and improve the buy-back price for the WEEE in manufacturer. (2) The government’s unit carbon tax for manufacturer is larger than the degree of the carbon emission reward-penalty for manufacturer, the manufacturer’s cost of production can increase. The unit sale price of retailer can improve with the increasing of the manufacturer’s wholesale price for new product. (3) The government’s unit carbon tax for manufacturer is larger than the degree of the carbon emission reward-penalty for manufacturer, the manufacturer’s cost of production can increase.

Introduction

There are more and more waste electrical and electronic equipment (WEEE) due to the rapid development of economy and the shortening product life cycle, moreover, manufacturers always produce so many electronic products that meet the various needs of customers. According to incomplete statistics, the number of WEEE all over the world will reach 65 million tons by 2017, which increases by about 33% compared to 49 million tons in 2012. The above numbers show that the number of WEEE is increasing year by year and the recycling of WEEE is harder. On the other hand, it takes retailer much more money and time to build the recycling channel. Moreover, the environmental problem caused by the WEEE is becoming more and more serious, there are more than seven hundreds kinds of chemical components in WEEE, and most of them are harmful for human body. On the other hand, the WEEE has great economic value, and it can also improve the firm’s social image. Thus, more and more scholars and firms pay more attention to recycling of the WEEE.

Shen and Xiong (2013) suggested that the coordination of closed-loop supply chain could be achieved through the collection and remanufacture of patented products, and they proposed the revenue and expense sharing contract to control the sharing ratio through negotiations. Zhang et al. (2014) analyzed a signaling game in closed-loop supply chain when the collection effect cost was the retailer’s private information. Wang et al. (2015) studied responsibility sharing in the WEEE collection between the manufacturer and the collector, and identified a reward-penalty mechanism for government to motivate industry’s recycling endeavor. Jafar et al. (2017) considered a two-level
closed-loop supply chain with one manufacturer and one retailer and discussed the government role in improving coordination supply chain through tax exemption and subsidy. Hou et al. (2017) analyzed the coordination of decentralized supply chain with the Leader-follower game, and determined that the revenue sharing contract could achieve the closed-loop supply chain coordination problem.

We discuss the following questions:
(1) With the asymmetric information, how does the manufacturer design the information screening contract to identify the type of the retailer and so that it promotes the retailer to recycling more WEEE?
(2) Which kinds of government’s mechanism is more advantage to retailer’s recycling of WEEE and to manufacturer’s reducing of carbon emission under asymmetric information?
(3) How does the customer’s awareness of environmental protection, the reward-penalty mechanism, the reward-penalty and subsidy mechanism and tax-subsidy mechanism impact on the decision variables in different decision-making models?

Theoretical Model and Variables Description

Assumption

(1) The recovery fixed cost of the WEEE in retailer is \( I (1 - \beta q^2) \), \( \beta \) is the recovery difficulty coefficient, \( q \) is the recovery quantity of the WEEE;

(2) In generally, the production cost in manufacturer of using the recycling WEEE material is lower than the production cost in manufacturer of using the new material. Thus, we assume that manufacturers produce the new products of using the WEEE material at first, then, they use the new materials to produce until the WEEE material is used out. The production cost of using new materials is \( c_m \), and the production cost of using WEEE materials is \( c_r \). To guarantee the economic significance of the model, there should be the following equations: \( c_w < c_y + c_r + w + c_{mp} \) and \( c_m - c_r = \Delta \);

(3) The manufacturer acts as the channel leader; the retailer acts as the channel follower;

(4) The remanufacturing rate in manufacturer is one hundred percent;

(5) The unit carbon emission in two manufacturers is the same which can express \( \alpha_0 \).
Table 1. Variables description.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>$c_r$</td>
<td>Manufacturer’s production cost of using WEEE materials</td>
</tr>
<tr>
<td>$c_m$</td>
<td>Manufacturer’s production cost of using new materials</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>Unit saving cost is expressed as $\Delta = c_m - c_r$, differences of production cost of new materials or recycled components</td>
</tr>
<tr>
<td>$I_i$</td>
<td>The recovery fixed cost of retailer, generally, the larger of the retailer’s recycling quantity, the larger of the retailer’s recovery fixed cost, $I_i = \beta_i q_i$, $\beta_i$ is the recovery difficulty coefficient, $i \in {H, L}$, $I_H$ expresses high recovery fixed cost</td>
</tr>
<tr>
<td>$p_r$</td>
<td>Unit sale price of retailer when the retailer’s recovery fixed cost is in $i$-level, $i \in {H, L}$</td>
</tr>
<tr>
<td>$w_i$</td>
<td>Unit wholesale price for new product of manufacturer when the retailer’s recovery fixed cost is in $i$-level, $i \in {H, L}$</td>
</tr>
<tr>
<td>$b_i$</td>
<td>The buy-back price of manufacturer when the retailer’s recovery fixed cost is in $i$-level, $i \in {H, L}$</td>
</tr>
<tr>
<td>$c_i$</td>
<td>Unit recovery cost of retailer when the retailer’s recovery fixed cost is in $i$-level, $i \in {H, L}$</td>
</tr>
<tr>
<td>$d_i$</td>
<td>The market demand of retailer when the retailer’s recovery fixed cost is in $i$-level, $i \in {H, L}$, $d = \alpha - p_i$, $\alpha$ can express the basic market demand</td>
</tr>
<tr>
<td>$q_0$</td>
<td>Target recovery quantity designed by the government</td>
</tr>
<tr>
<td>$e_0$</td>
<td>Target carbon emission designed by the government</td>
</tr>
<tr>
<td>$f$</td>
<td>The reward-penalty intensity of the carbon emission for manufacturer established by government</td>
</tr>
<tr>
<td>$k$</td>
<td>The reward-penalty intensity of the unit recovery quantity for retailer established by government</td>
</tr>
<tr>
<td>$s$</td>
<td>The government’s unit recycling quantity subsidy for retailer</td>
</tr>
<tr>
<td>$g$</td>
<td>The government’s unit carbon emission tax for manufacturer</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>Consumer’s awareness of environmental protection</td>
</tr>
<tr>
<td>$\pi^m(j)$</td>
<td>The manufacturer’s profit function under the situation $j$</td>
</tr>
<tr>
<td>$\pi^r(j)$</td>
<td>The retailer’s profit function under the situation $j$</td>
</tr>
<tr>
<td>$\pi^r_0$</td>
<td>The retailer’s reserved profit</td>
</tr>
</tbody>
</table>

Game Model of Different Government’s Mechanism in Closed-Loop Supply Chain

Case 1: Decision-making Model without Government’s Mechanism

In this case, the government does not implement any mechanism for manufacturer’s carbon emission and for retailer’s recovery quantity. The manufacturer’s profit function can express that:

$$
\pi^m = \rho - \rho_0 j\left(\lambda + \nu r - \rho_0 j\right) + \rho \left(\lambda + \nu r - \rho_0 j\right) + \rho_0 j\left(\lambda + \nu r - \rho_0 j\right)
$$

The retailer’s profit function can express that:

$$
\pi^r = \rho - \rho_0 j\left(\lambda + \nu r - \rho_0 j\right) + \rho \left(\lambda + \nu r - \rho_0 j\right) + \rho_0 j\left(\lambda + \nu r - \rho_0 j\right)
$$

Constraint can be expressed as:

$$
\begin{align*}
&\rho - \rho_0 j\left(\lambda + \nu r - \rho_0 j\right) + \rho \left(\lambda + \nu r - \rho_0 j\right) + \rho_0 j\left(\lambda + \nu r - \rho_0 j\right) \\
&\rho - \rho_0 j\left(\lambda + \nu r - \rho_0 j\right) + \rho \left(\lambda + \nu r - \rho_0 j\right) + \rho_0 j\left(\lambda + \nu r - \rho_0 j\right) \\
&\rho - \rho_0 j\left(\lambda + \nu r - \rho_0 j\right) + \rho \left(\lambda + \nu r - \rho_0 j\right) + \rho_0 j\left(\lambda + \nu r - \rho_0 j\right) \\
&\rho - \rho_0 j\left(\lambda + \nu r - \rho_0 j\right) + \rho \left(\lambda + \nu r - \rho_0 j\right) + \rho_0 j\left(\lambda + \nu r - \rho_0 j\right)
\end{align*}
$$

Proposition 1 In game model with government’s carbon emission reward-penalty mechanism and recovery ratio reward-penalty mechanism, manufacturer’s optimal wholesale price for the new product $w^0_{ij}$ and buy-back price for the WEEE $b^0_{ij}$. Retailer’s the unit sale price $p^0_{ij}$, $p^0_{ij}$ and the unit recovery price of retailer $r^0_{ij}$. The manufacturer’s profit $\pi^m(j)$ and the retailer’s profit $\pi^r(j)$ can express that:
\[ x_{w}^{(1)} = \frac{(1 + \beta_u)(2z_u - c_u - \lambda) + \lambda}{\beta_u - \beta_L} \]  

(4)

\[ n_{w}^{(1)} = \frac{(1 + \beta_u)(2 + \lambda) + \lambda + \lambda_0}{2\beta_u + 1}(2 + \beta_u) + \beta_u + \beta_L) \]  

(5)

\[ h_{w}^{(1)} = \frac{(1 + \beta_u)(2 + \lambda) + \lambda + \lambda_0}{2\beta_u + 1}(2 + \beta_u) + \beta_u + \beta_L) \]  

(6)

\[ \delta = \frac{(1 + \beta_u)(2 + \lambda) + \lambda + \lambda_0}{2\beta_u + 1}(2 + \beta_u) + \beta_u + \beta_L) \]  

(7)

\[ p_{w}^{(1)} = \frac{(1 + \beta_u)(2z_u - c_u - \lambda) + \lambda}{\beta_u - \beta_L} \]  

(8)

\[ r_{w}^{(1)} = \frac{(1 + \beta_u)(2z_u - c_u - \lambda) + \lambda}{\beta_u - \beta_L} = \frac{(1 + \beta_u)(2z_u - c_u - \lambda) + \lambda}{(2 + \beta_u)} \]  

(9)

\[ p_{r}^{(2)} = \frac{1}{2}(\beta_u - \beta_L) \]  

(10)

\[ r_{r}^{(2)} = \frac{(c_u + \lambda + \lambda_0)(2 + \beta_u) + \lambda + \lambda_0}{(2 + \beta_u)} \]  

(11)

### Case 2: Decision-making Model with Government’s Carbon Emission Reward-penalty Mechanism

#### Mechanism and Recovery Quantity Reward-penalty Mechanism

In this case, the government designs the emission carbon reward-penalty mechanism for manufacturer and recovery ratio reward-penalty mechanism for retailer. The total amount of the reward-penalty intensity for carbon emission in manufacturer can express as:

\[ 0 = \mathcal{F}(\Delta q_{w} - q_0). \]  

(12)

The manufacturer’s profit function can express that:

\[ \Delta \mathcal{F}(\Delta q_{w} + q_0). \]  

(13)

Constraint can be expressed as:

\[ \Delta q_{w} - q_0 \leq 0, \Delta q_{w} - q_0 \leq 0, \Delta q_{w} - q_0 \leq 0. \]  

(14)

Proposition 2 In game model with government’s carbon emission reward-penalty mechanism and recovery ratio reward-penalty mechanism, manufacturer’s optimal wholesale price for the new product \( w_{w}^{(2)} \) and buy-back price for the WEEE \( \delta_{w}^{(2)} \). Retailer’s the unit sale price \( p_{r}^{(2)} \) and the unit recovery price of retailer \( r_{r}^{(2)} \). The manufacturer’s profit \( x_{w}^{(2)} \) and the retailer’s profit \( x_{r}^{(2)} \) can express that:

\[ x_{w}^{(2)} = \frac{(1 + \beta_u)(2z_u - c_u - \lambda) + \lambda}{\beta_u - \beta_L} \]  

(15)

\[ x_{r}^{(2)} = \frac{(1 + \beta_u)(2z_u - c_u - \lambda) + \lambda}{\beta_u - \beta_L} \]  

(16)
In this case, the government designs the carbon emission reward-penalty mechanism for manufacturer and recovery ratio subsidy mechanism for retailer. The total amount of the reward-penalty intensity for carbon emission in manufacturer can express as \( M = f[\Delta r_m - \Delta c] \). The unit recycling subsidy for retailer can express as \( s (x > 0) \), thus, the total amount of reward-penalty intensity for the recovery quantity in retailer can express as \( (x + r) \). The manufacturer’s profit can express as:

\[
r_1^{(2)} = [(s_2 - \Delta c_k + \Delta c_{k-1}) + s_2 - \Delta c_{k-1}] + (s_2 - \Delta c_{k-1}) - \Delta c_{k-1}
\]

\(
= (s_2 - \Delta c_{k-1}) + s_2 - \Delta c_{k-1} + s_2 - \Delta c_{k-1}
\]

The retailer’s profit can express as:

\[
r_2^{(2)} = [(s_2 - \Delta c_k + \Delta c_{k-1}) + s_2 - \Delta c_{k-1}] + (s_2 - \Delta c_{k-1}) - \Delta c_{k-1}
\]

\[
= (s_2 - \Delta c_{k-1}) + s_2 - \Delta c_{k-1} + s_2 - \Delta c_{k-1}
\]

Constraint can be expressed as:

\[
\alpha
\]

\[
\beta
\]

Proposition 3 in game model with government’s carbon emission reward-penalty mechanism and recovery ratio reward-penalty mechanism, manufacturer’s optimal wholesale price for the new product \( p_{w}^{(0)} \) and buy-back price for the WEEE \( p_{h}^{(0)} \). Retailer’s the unit sale price \( p_{s}^{(0)} \) and the unit recovery price of retailer \( r_{r}^{(0)}, r_{r}^{(1)} \). The manufacturer’s profit \( p_{w}^{(0)} \) and the retailer’s profit \( p_{r}^{(0)} \) can express that:

\[
\rho_{w}^{(0)} = \frac{(1 + \beta_{w})(c_{w} - \gamma_{w} + \alpha_{w} - \gamma_{w})}{\alpha_{w} - \beta_{w}}
\]

\[
\rho_{r}^{(0)} = \frac{(1 + \beta_{r})(c_{r} + \alpha_{r} - \gamma_{r})}{\alpha_{r} - \beta_{r}}
\]

\[
\rho_{r}^{(1)} = \frac{(1 + \beta_{r})(c_{r} + \alpha_{r} - \gamma_{r})}{\alpha_{r} - \beta_{r}}
\]

\[
\rho_{w}^{(1)} = \frac{(1 + \beta_{w})(c_{w} - \gamma_{w} + \alpha_{w} - \gamma_{w})}{\alpha_{w} - \beta_{w}}
\]

\[
\rho_{r}^{(1)} = \frac{(1 + \beta_{r})(c_{r} + \alpha_{r} - \gamma_{r})}{\alpha_{r} - \beta_{r}}
\]
Comparing the Result between Different Decision-Making Models

In this section, we compare the results between different decision-making models, and we can get the following conclusions:

Proposition 5 The wholesale price for new product, the buy-back price for the WEEE in manufacturer, the unit sale price in retailer in Case 1 are lower than that in Case 2. However, the unit recovery price in retailer in Case 1 is higher than that in Case 2.

Proof: From the optimal decision in case 1 and the optimal decision in case 2, we know that:

\[ w_1^{(1)} - w_1^{(2)} = (1 + \beta_2) \left( k - s \right) \frac{(1 + \beta_2) \left( k - s \right)}{\hat{p}_H - \hat{p}_k} \], when \( s > k, w_1^{(1)} > w_1^{(2)} ; s < k, w_1^{(2)} < w_1^{(1)} \).

Proposition 5 shows that the government’s carbon emission reward-penalty mechanism can improve the wholesale price for new product and improve the buy-back price for the WEEE in manufacturer. Because the main purpose of the government’s carbon emission reward-penalty mechanism is to reduce the manufacturer’s carbon emission. Manufacturer should reduce the carbon emission by using advanced technology, this can increase the cost of manufacturer’s production. Thus, the wholesale price for new product and the buy-back price for the WEEE in manufacturer can be improved. On the other hand, the unit sale price in retailer can increase with the increasing of the wholesale price for new product. The purpose of the government’s recovery quantity reward-penalty is to improve the retailer’s recovery quantity, thus, the retailer’s recovery price for the WEEE can be reduced.

Proposition 6 When the degree of the recovery quantity subsidy is higher than the degree of the recovery ratio reward-penalty, the unit sale price in retailer, the wholesale price for new product in manufacturer in case 3 is higher than that in case 2. What is more, the buy-back price for the WEEE in manufacturer in case 3 is higher than that in case 2. However, the unit recovery price in retailer in case 3 is higher than that in case 2 under any conditions.

Proof: \( w_2^{(3)} - w_2^{(1)} = \frac{(1 + \beta_2) \left( k - s \right)}{\hat{p}_H - \hat{p}_k} \), when \( s > k, w_2^{(3)} > w_2^{(1)} ; s < k, w_2^{(1)} < w_2^{(3)} \).

\[ \rho_1^{(1)} = \frac{a (\beta_2 - \beta_k) + (1 + \beta_k)(2c + c_m f - a) + (1 + \beta_k)(c_{ref} - \hat{c} + \hat{c})}{2(\beta_2 - \beta_k)} \] (31)

\[ d_1^{(1)} = \frac{\{(1 + \beta_2) \left( k - s \right) + (1 + \beta_k) \left( k - s \right) \} - \rho_1^{(1)} \left( k - s \right) - \rho_1^{(2)} \left( k - s \right)}{4(\beta_2 - \beta_k)(\beta_2 - \beta_k)} \] (32)

\[ d_1^{(1)} = \frac{\{(1 + \beta_2) \left( k - s \right) + (1 + \beta_k) \left( k - s \right) \} - \rho_1^{(1)} \left( k - s \right) - \rho_1^{(2)} \left( k - s \right)}{4(\beta_2 - \beta_k)(\beta_2 - \beta_k)} \] (33)
Proposition 6 shows that for the retailer, the recovery quantity subsidy mechanism is much better than the recovery ratio reward-penalty mechanism under the same carbon emission reward-penalty mechanism. The retailer’s recovery price under the recovery quantity subsidy mechanism is higher than that under the recovery ratio reward-penalty mechanism. Although, the retailer’s recovery price can be increased, the recovery quantity can be decreased, retailer’s losses can be compensated by the government’s subsidy. The carbon emission reward-penalty mechanism can make the manufacturer’s cost of production increase. Thus, the wholesale price for the new product can increase, the retailer’s sale price for new product can increase.

Conclusions

In this paper, based on the customer’s awareness of environmental protection, we build three different decision-making models and solve these decision-making models by using Lagrange method, and compare the optimal decision variables. Then, we analyze the impact of customer’s awareness of environmental protection, the reward-penalty mechanism, the reward-penalty and subsidy mechanism and the tax-subsidy mechanism on the optimal decision variables. We can get the following conclusions:

The main contributions in this article are as follows: we assume that the asymmetric information is existence between the manufacturer and the retailer, the retailer’s private information is divided into two types which includes the high cost and the low cost; we discuss the impact of different government mechanisms on reducing the carbon emission and improving the effectiveness of the recovery quantity under asymmetric information. Lastly, we analyze the optimal decision in different decision-making models and explain the advantages and disadvantages of different government mechanisms. Moreover, we analyze the impact of customer’s awareness of environmental protection on the optimal decision making.

The research can be extended in several directions: we only discuss the impact of customer’s awareness of environmental protection on the optimal decision variables in closed-loop supply chain which includes one manufacturer and one retailer. In the future, we can discuss it in closed-loop supply chain distribution network which includes one manufacturer and multi-retailers. Moreover, we only assume that the recovery fixed cost is the asymmetric information between manufacturer and retailer. In the future, we will consider other asymmetric information.

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