Pricing Models for Dual-channel Reverse Supply Chain Considering Regional Differences under “Internet Recycling” Mode in China

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Abstract. In recent years, the Internet technology has been deeply influencing recycling industry to make it more intelligent and interconnected. However, most existing papers on “Internet Recycling” neglected the problem of pricing strategy under online and offline channels for different levels of recyclers. Moreover, the effect of regional differences has been emphasized a lot in dual-channel forward supply chain, but recycling field has seldom been concerned about it. In this paper, a recycling system consisting of one recycling center and several third-party recyclers (TPR) was investigated based on traditional mode and dual-channel mode. The dual-channel reverse supply chain model is transformed from traditional mode by the introduction of online channel. It involves two recycling modes, as recycling centre for online recovery and “Recycling center+TPR” for offline recovery. By establishing pricing strategies based on Stackelberg game model, the impacts of regional differences were analysed. Finally, numerical analysis was given to illustrate the effectiveness of the pricing mechanisms and strategies.

Keywords. Dual-channel reverse supply chain, regional differences, Internet Recycling, Stackelberg game model.

1. Introduction
WEEE (Waste of Electric and Electronic Equipment) is introduced by online channel of internet, which can improve the recycling efficiency, recycling quality of waste products and recycling awareness of residents. This mode has been widely used gradually in china. Based on the recycling of dual-channel mode (online and offline channel), an important problem of Reverse Supply Chain Management (RSCM) is the decision of proper recycling pricing in the process of the introduction of online channel. Generally speaking, different pricing strategies of recycling channel mainly studies on the gambling among channels (Savaskan, 2004), the comparison of recovery cost (Atasu, 2013) and the proportion of makethare (Choi, 2013). Besides it, some scholars point out that online and offline channel management has effects on regional differences. There still exists an obscure receptivity differences in different regions, especially in China (Sheng, 2010). It is an important question for scholars to solve on how to conduct a differential pricing properly in the process of RSCM in different regions.
This thesis mainly analyzes online channel acceptance in different regions and the differences of logistics cost that have effect on pricing strategy of dual recycling channels. Firstly, we have established a mathematical model of regional differences on the basis of Reverse Supply Chain Management. Secondly, we got the optimum pricing strategy of recycling center and the third-party recycler by game theory. Finally, we tested the model by a numerical example.

2. Model assumptions and notations
This thesis studies the TPR in one recycling center and two different cities (city A and city B), aiming at helping recycling center and TPR make proper pricing decision to maximize their revenue. In traditional offline channels, consumers first recycle WEEE to TPR in local areas, and then TPR in two different cities recycle WEEE to the larger recycling center. The recycling center and two TPR separately abide by the stackelberg game theory. In dual-channel mode, in addition to offline recycling model mentioned before, there still exists online recycling channel of internet. In such a channel, consumers can directly recycle WEEE to the recycling center by mail or by way of going to the store. Besides it, the regional differences between two cities all have effect on pricing strategies of recycling center and TPR, such as, channels acceptance and logistics cost.

Take Savaskan for reference (2006), we have made assumptions on study in the following aspects, decision framework, channel costs and regional differences.

Hypothesis 1: Although many kinds of WEEE can be studied, to be brief, WEEE is still one kind of recycling in our studies and they have the same recycling efficiency.

Hypothesis 2: As the major player of Stackelberg, recycling center has enough channel rights comparing to TPR and make the optimal decision by observing the reactions of TPR.

Hypothesis 3: In reality, many factors all have effects on the consumers’ choice of online or offline channel, such as, recycling price, service convenience, environmental psychology, and etc. In this study, the consumers’ choices are attributed to the recycling price and recycling channel acceptance.

Hypothesis 4: the relationship between the quantity of recycling and the price of recycling is linear.

Hypothesis 5: The electronic channel acceptance $\theta_i$ and logistics cost $c_i$ in different cities only have relevant to regional development in such a city and isn’t influenced by recovery price and etc.

We have studied the recycling center of Reverse Supply Chain Management and the pricing strategy of TPR by using mathematical model. Firstly, we described the symbols used in modeling.
| Symbol | Definition |
|--------|------------|
| \(d_{oi}\) | The amount of waste products collected in offline channel |
| \(d_{oi}\) | The amount of waste products collected in online channel |
| \(\vartheta\) | Index of the acceptance of online channel |
| \(c_i\) | Logistics costs of online channels |
| \(P_0\) | Unit income recycling center get from waste product |
| \(P_o\) | Unit offline channel recovery price transferred from consumers to TPR |
| \(P_e\) | Unit online channel recovery price transferred from consumers to recycling center |
| \(W_i\) | Unit recovery price transferred from TPR to recycling center |
| \(\alpha_i\) | Index of basic market size(a \(i>0\)) |
| \(\beta_i\) | Sensitivity of consumers to the recycle price in the channel of their own(\(\beta_i>0\)) |
| \(\gamma_i\) | Sensitivity of consumers to the recycle price of the opposite channel(\(\beta_i>\gamma_i>0\)) |
| \(\Pi_{iw}\) | Profit of recycling center |
| \(\Pi_{i}\) | Profit of TPR |

\[ i(i=1,2) \] standing for city A and city B in different cities in the table.

3. Model formulation and solution

3.1. Traditional mode

Fig one, in the only traditional mode of offline recycling channel, TPR in different cities recycle WEEE from consumers at a unit price of \(P_o\) each, and then TPR transfer WEEE to the recycling center at a price of \(W_i\) after a simple cleaning. WEEE will be decomposed and demounted by recycling center, then the parts and materials will be reproduced or resold.

![Fig.1 Depiction of the reverse supply chain in two cities](image)

Recycling center and different pricing strategies of TPR have been studied by Stackelberg game theory. Due to the dominant role of recycling center, the maximal profit and optimal pricing of TPR should be first analyzed based on backward induction. Revenue function of TPR can be express as follows:

\[
\Pi_i = (w_i - p_i)d_{oi} = (w_i - p_i)(\alpha_i + \beta_i p_i) = -\beta_i p_i^2 + (w_i \beta_i - \alpha_i) p_i + w_i \alpha_i
\]
As the objective function $\Pi_i$ is always concave with $r_i$, set $r_i^\ast$ as the optimal recycling price of TPR, when $\frac{\partial \Pi_i}{\partial r_i} = 0$, $r_i^\ast = \frac{w_i\beta_i - \alpha_i}{2\beta_i}$, $\Pi_i$ reach to the maximum value. As the dominant player of Stackelberg, the recycling center optimize its own pricing strategy after observing the two pricing strategies of TPR in different regions in order to get maximum profits. The profit of recycling center can be expressed as:

$$\Pi_m = \sum_{i=1}^{2}(p_b - w_i)d_i = \sum_{i=1}^{2}(p_b - w_i)(\alpha_i + \beta_i r_i^\ast)$$  \hspace{1cm} (2)

Similar to $\Pi_i$, $\Pi_m$ is always concave with $w_i$. Set $w_i^\ast$ as the optimal recycling price of TPR in different regions, then set $\frac{\partial \Pi_m}{\partial w_i} = 0$, the solution is $w_i^\ast = \frac{p_b\beta_i - \alpha_i}{2\beta_i}$. Substitute $w_i^\ast$ into $r_i^\ast = \frac{w_i\beta_i - \alpha_i}{2\beta_i}$ in the above two formulas (1) and (2), the solutions can be obtained:

The maximal profit of recycling center is:

$$Max_{\Pi_m} = \sum_{i=1}^{2} (\alpha_i + p_b\beta_i)^2$$  \hspace{1cm} (3)

The optimal price $P_i^\ast$ is:

$$P_i^\ast = \frac{p_b\beta_i - \alpha_i}{2\beta_i} = \frac{p_b\beta_i - 3\beta_i}{4\beta_i}$$  \hspace{1cm} (4)

The maximal profit of TPR is:

$$Max_{\Pi_i} = \frac{\left(\beta_i P_p + \alpha_i\right)^2}{16\beta_i}$$  \hspace{1cm} (5)

3.2. Dual-channel mode

![Fig.2 Depiction of the dual-channel reverse supply chain in two cities](image)

On the basis of traditional recycling mode, an introduction of online channel is listed as Fig2. Different from traditional mode, recycling center in this mode not only recycles waste products from consumers but also directly recycles from consumers at the price of $P_2$ through the network. Therefore, the relationship between recycling center and TPR is not only up and down stream relationship of supply chain but also becomes competitors. Comparing to TPR, online channel of
recycling center has advantages over off line channel in the aspects of recycling price, quantity, efficiency and environmental protection. Then, with the increasing of residents’ environmental awareness, these advantages can improve the consumers’ acceptance and selection of online channel.

To sum up, the function \( d_u \) and \( d_o \) in dual-channel mode can be separately expressed as \( d_u = \theta \alpha_i + \beta_i p_i - \gamma_i p_i \), \( d_o = \alpha_i + \beta_o p_o - \gamma_o p_o \). Similarly, the revenue function of TPR in different regions should be first studied on the basis of backward induction:

\[
\Pi_i = (w_i - p_i)d_u = (w_i - p_i)[(1 - \theta)\alpha_i + \beta_i p_i - \gamma_i p_i] \\
= -\beta_i p_i^2 + [w_i(1 - \theta)\alpha_i + \gamma_i p_i]p_i + [w_i(1 - \theta)\alpha_i - w_i\gamma_i p_i] \\
\text{(6)}
\]

As the objective function \( \Pi \) is always concave with \( p_i \), set \( \frac{\partial \Pi}{\partial p_i} = 0 \), the optimum pricing of TPR with \( p_i \) is expressed as:

\[
p_i^* = \frac{w_i\beta_i + \gamma_i p_i - (1 - \theta)\alpha_i}{2\beta_i} \\
\text{(7)}
\]

Now the profit of TPR reaches to the maximum value. The recycling center has made the pricing decision contrapuntally. The profit function of recycling center is listed as follows:

\[
\text{Max } \Pi_c = \sum_{i=1}^{3} (p_i - p_i - c_i)d_u + (p_i - w_i)d_o \\
= \sum_{i=1}^{3} (p_i - p_i - c_i)(\theta \alpha_i + \beta_i p_i - \gamma_i p_i) + (p_i - w_i)[(1 - \theta)\alpha_i + \beta_i p_i^* - \gamma_i p_i^*] \\
\text{(8)}
\]

As the objective function \( \Pi_c(p_i,w_i,w_2) \) is always concave, set \( \frac{\partial \Pi_c}{\partial w_i}, \frac{\partial \Pi_c}{\partial w_2}, \text{ and } \frac{\partial \Pi_c}{\partial w_3} \) all to be zero, we can get the optimum \( w_i^*, w_2^* \) and \( p_i^* \) in order to make the profit of recycling center reach the maximum value.

\[
p_i^* = \frac{\sum_{i=1}^{3} (p_i - p_i - \alpha_i\beta_i - \beta_i \gamma_i - \alpha_i(1 - \theta)\beta_i - \beta_i \gamma_i - \beta_i \gamma_i)}{2\beta_i} \\
\text{(9)}
\]

\[
w_i^* = \frac{c_i\beta_i + p_i\beta_i + \gamma_i p_i^* - \alpha_i(1 - \theta) - p_i\gamma_i}{2\beta_i} \\
\text{(10)}
\]

Substitute formula (9) and (10) into (6) and (7), the final optimal recycling pricing of TPR is expressed as \( p_i^* = \frac{w_i\beta_i + \gamma_i p_i^* - (1 - \theta)\alpha_i}{2\beta_i} \) and the maximal profit is expressed as \( \Pi_c = -\beta_i p_i^2 + [w_i\beta_i - (1 - \theta)\alpha_i + \gamma_i p_i^*]p_i^* + [w_i(1 - \theta)\alpha_i - w_i\gamma_i p_i^*] \). Then the maximal profit of recycling center can be solved by substituting it into (8):

\[
\text{Max } \Pi_c = \sum_{i=1}^{3} (p_i - p_i - c_i)(\theta \alpha_i + \beta_i p_i^* - \gamma_i p_i^*) + (p_i - w_i)[(1 - \theta)\alpha_i + \beta_i p_i^* - \gamma_i p_i^*] \\
\text{(11)}
\]
4. Numerical analysis

To sum up, in the reverse supply chain of due-channel mode, the $\theta$ and $c$ of e-channel both have effects on the optimal pricing strategy and maximum profits of recycling center or the TPR. Because most countries all have the uneven development problems including china, the baseline value or the change rate of $\theta$ and $c$ all have obscure differences in different regions. Therefore, the pricing strategy needs to be modified properly after the recycling center is led into online channel. Based on the previous studies, we have made a calculation analysis of $\theta$ and $c$ changes. Suppose $\theta = 1500$ (not general), $\alpha_i = \alpha = 2000$, $\beta = \beta = 6$, $\gamma_1 = \gamma_2 = 4$, then we should first keep $c_1 = c_2 = 10$ as fixed value, assume that $\theta = 0.3$ is stable, $\theta$ increases from 0.3 to 0.7, we get Table2 by simulation with Matlab. Besides it, we keep $\theta = \theta = 0.3$ as fixed value, assume that $c_1 = \theta = 67$ is stable, $c_2$ increases from 14 to 6, then we get table3 by simulation with Matlab.

The calculation results show that $\theta$ and $c$ in city B make changes, which not only have effects on the recycling center and the profits, optimal pricing of TPR in this city but also have effects on the TPR’s decision of city A. When $\theta$ increases, the TPR’s demands in city A should decrease by $p_1$; when $c_2$ decreases, the TPR’s demand in city a increases by $p_1$ relatively. Meanwhile, recycling center still needs to make adjustments to the TPR’s recycling price in city A.

| $\theta$ | $p_1$ | $w_1$ | $w_2$ | $p_1$ | $p_2$ | $\Pi_1$ | $\Pi_2$ | $\Pi_m$ |
|---------|-------|-------|-------|-------|-------|--------|--------|--------|
| 0.3     | 515.00| 480.00| 480.00| 295.00| 295.00| 205350.00 | 205350.00 | 7158900.00 |
| 0.4     | 510.00| 476.67| 493.33| 291.67| 316.67| 205353.70 | 187263.13 | 7187914.30 |
| 0.5     | 505.00| 473.33| 506.67| 288.33| 338.34| 205346.30 | 170020.03 | 7218906.40 |
| 0.6     | 500.00| 470.00| 520.00| 285.00| 360.00| 205350.00 | 153600.00 | 7259190.00 |
| 0.7     | 495.00| 466.67| 533.33| 281.67| 381.67| 205350.00 | 138013.63 | 7316762.80 |

| $c_2$ | $p_2$ | $w_1$ | $w_2$ | $p_1$ | $p_2$ | $\Pi_1$ | $\Pi_2$ | $\Pi_m$ |
|-------|-------|-------|-------|-------|-------|--------|--------|--------|
| 14    | 514.75| 478.50| 481.17| 294.17| 295.50| 203872.67 | 206836.38 | 7158913.92 |
| 12    | 515.24| 478.83| 480.83| 294.50| 295.50| 203876.35 | 206094.37 | 7163950.06 |
| 10    | 515.75| 479.17| 480.50| 294.84| 295.50| 203876.35 | 205350.00 | 7168962.65 |
| 8     | 516.24| 479.49| 480.16| 295.16| 295.49| 203868.98 | 204610.67 | 7173977.51 |
| 6     | 516.74| 479.83| 479.83| 295.50| 295.50| 203876.35 | 203876.35 | 7179038.99 |

5. Conclusion

The author in this article studies the pricing strategy model in a dual-channel reverse supply chain with the consideration of “Internet Recycling” model and regional differences. Several conclusions can be obtained: Firstly, as online recycling channel is introducing, we find if the acceptation or logistic costs of online channel changes in one city, the pricing and profits of the recycling center and TPRs will all be affected. Secondly, through the calculation and simulation of the game model, we can see how members of the supply chain should adjust their pricing strategies to maximize their profits or reduce their losses when the environment of the reverse supply chain is changed. Based on the above conclusions, the author provides guidelines for recycling center and TPRs to make pricing decisions to gain more profits and develop recycling industry better.
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