Optimization of the Reverse Logistic System with a Focus on the Consumers' Recycle Willingness and Behavior for Small Home Appliances

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The total recycling of small home appliances in 2020 amounted to only 102,498 tons, which is still far from the government's goal of 140,000 tons in Japan. One of the reasons for the low recycling amount is the higher logistic costs related to the collecting, sorting process, and transportation, which results in lowering authorized recyclers' recycling incentives. However, in the reverse logistics system for small home appliances, consumers are the source stakeholders in the system. Their recycling willingness and behavior have a direct and vital impact on increasing the recycling amount of small home appliances. Therefore, improving the sorting incentives for consumers is crucial for improving the recycling efficiency of small home appliances in this reverse logistic system. This study aims to: (1) develop an optimization model of consumers with a focus on the sorting process (dispose separately from the source) of small home appliances, (2) investigate the impact of the improvement in consumers' incentives for recycling efficiency of small home appliances in the reverse logistic system.

Key Words : *recycle willingness and behavior, signaling game, incentive design, small home appliances, reverse logistic system*

1. INTRODUCTION

According to the Ministry of the Environment and the Ministry of Economy, Trade and Industry, the total amount of small home appliances collection is still far from the government's goal of 140,000 tons (the total amount of small home appliances collection was only 102,498 tons in 2020). In contrast to the successful recycling of specified kinds of home appliances, the recycling of small home appliances has hit a bottleneck, and its implementation status has changed: the cost of recycling small home appliances has increased in recent years, due to the increase in transportation and decomposition costs. This leads to a lack of motivation for authorized recyclers to collect small home appliances and increases the municipality's economic burden. In some cases, the municipality has to pay authorized recyclers a certain fee to incentivize the collection amount of small home appliances.

Although authorized recyclers face uncertainties regarding the low recycling efficiency of small home appliances, for example, the price of metal parts in small home appliances fluctuates wildly, affecting authorized recyclers' profitability. However, as consumers are the source stakeholders in the reverse logistics system of small home appliances, their sorting willingness and behavior to recycle small home appliances are closely related to the authorized recyclers' recycling efficiency. For example, as more and more small home appliances are equipped with storage-type ion-lithium batteries, consumers' improper sorting and disposing of small home appliances directly leads to a significant increase in the transportation and decomposition costs of authorized recyclers.

In Japan, the current recycling methods for all small home appliances are based on free recycling. Consumers hand over small home appliances to recycling locations and recycling containers designated by retailers for free (Fig. 1). There is no corresponding payment for consumers when they illegally discharge or randomly sort small home appliances,

which leads consumers to lose their profitable incentive to discharge and sort separately small home appliances based on regulations and policies from the local municipality. Small appliances are often mixed with combustible and non-combustible municipality solid waste during the discharging and sorting process by consumers, which not only leads to accidents such as explosions and fires during transportation and recycling of small home appliances but also makes it extremely difficult to separate the different parts of small home appliances (e.g., separating the plastic parts from the lithium-ion batteries) and thus leads to an increase in the recycling cost for the authorized recyclers.

Relevant literature mentions that it is crucial for retailers to set reasonable repurchase prices when recycling small home appliances. Appropriate pricing to consumers is influenced by the type of consumer, whether they are cooperative in sorting or not. However, retailers cannot know the type of consumer in advance and will come to know it through the increase in decomposition costs after collection. Therefore, setting the appropriate price under the information asymmetry between consumers and retailers becomes challenging. This study mainly analyzes consumers' willingness to recycle small home appliances and the impact of recycling behavior on the recycling efficiency of small home appliances in the reverse logistics system. As shown in Figure 1, the reverse logistics system for small home appliances is divided into four stages: discharging and sorting, collection, disposal and re-commercialization. The main stakeholders involved in the logistic reverse system are the municipality, consumers, retailers, authorized recyclers, and remanufacturers. This study mainly focuses on the first stage of the reverse logistics system of small home appliances (i.e., the discharge and sorting stage). By formulating and optimizing mathematical models, (1) we will analyze the impact of consumers' recycling willingness and behaviors on the recycling efficiency of small home appliances. (2) analyze the potential elements that affect relevant stakeholders' motivations for small home appliances recycling in the first stage. (3) investigate the impacts of consumers' behavior shift in recycling willingness on other stakeholders' recycling behavior and decision-making in the first stage. According to the three points mentioned above, to improve the consumers' recycling willingness and sorting behavior to improve the recycling efficiency of small home appliances in the reverse logistic system.

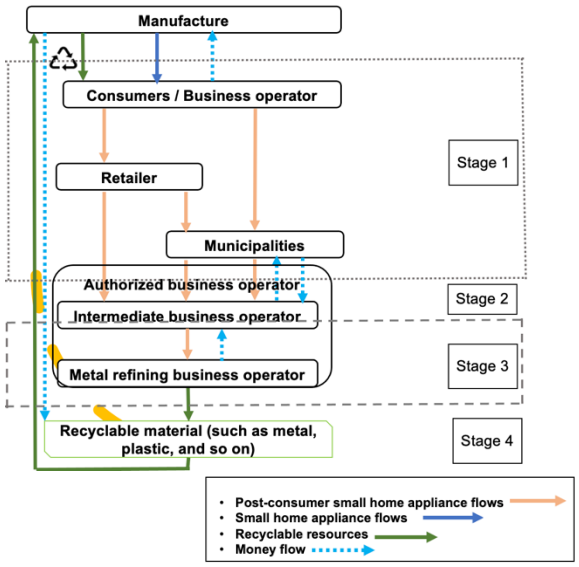


Fig.1 Four stages and relevant stakeholders in reverse logistic system of small home appliances

2. MODEL FORMULATION

(1) Framework

This study will formulate the mathematical models regarding the first stage of the reverse logistics system for small home appliances. The key players in this game are consumers and retailers. Consumers who discharge small home appliances to retailers will receive a buy-back fee, which can be monetary or non-monetary-based. However, the effort and opportunity costs of consumers investing in small home appliances are determined by differences in consumers' elements such as incomes, environmental awareness etc. In our model, consumers are divided into two categories. The first category is low-preference consumers (i.e., they have higher effort and opportunity costs for discharging and sorting small home appliances to recycling containers designated by retailers), which is noted as t_1. The second category is high-preference consumers (i.e., they have lower effort and opportunity costs for discharging and sorting small home appliances to recycling containers designated by retailers), which is noted as t_2. Usually, high-preference consumers charge higher prices for the cost of effort and opportunity of discharging and sorting small home appliances, and vice versa. However, if consumers deliberately hide the information, the retailer's optimal strategy will change, and the interests of the entire reverse logistic system will also be inconsistent. For example, when some consumers have good environmental awareness or can obtain sufficient information about retailers that can recycle different types of small home appliances, this can help them save time and money in discharging and sorting small home appliances. This also means that such

consumers belonging to the category of t_2 will pay lower prices when discharging and sorting with small home appliances and vice versa.

Retailers resell (secondary sales) some of the small home appliances they collect. Suppose that the retailers' decisions are also divided into two categories. The first category is the buyback of small home appliances at low prices, which is noted as p_1, and the second category is the buyback of small home appliances at high prices, which is noted as p_2.

In this game, two categories of consumers signal retailers about their pricing of small home appliances (i.e., request a high or a low recycling price). Then, based on the signals consumers send and retailers' judgments, retailers give repurchase prices that maximize their interests. Then, consumers can ultimately determine their optimal pricing based on the retailer's decision-making.

The game process is shown as follows: (1) the consumers' categories are noted as $T = \{t_1, t_2\}$. When a consumer belong to category of t_1, which means she needs to put higher effort and opportunity costs for discharging and sorting small home appliances to recycling containers designated by retailers (i.e., low-preference consumers). When a consumer belong to category of t_2, which means she just needs to put lower effort and opportunity costs for discharging and sorting small home appliances to recycling containers designated by retailers (i.e., high-preference consumers). The prior probability that retailers know the real categories of consumers, which is noted as $\text{prob}(t_1) = \theta$ (i.e., the probability that knows consumers are belong to high-preference consumers), and which is noted as $\text{prob}(t_2) = 1 - \theta$ (i.e., the probability that knows consumers belong to low-preference consumers). (2) The signal sets for consumers, which is noted as $S = \{s_1, s_2\}$. Consumers are available to select and send signal the from signal sets, which is noted as s_i $(i = 1,2)$ (3) Retailers are available to determine their buyback pricing of collected small home appliances, which is noted as p_i through their decision space, which is noted as $p = \{p_1, p_2\}$ when retailers have observed the signal sent by the consumer. the payoff function for retailers per unit is:

$$u_m(p_j, t_i) = R - m_i - p_j\,, (i, j = 1,2) \qquad (1)$$

R is resell price per unit of collected small home appliances. m_i is the marginal costs of reselling the small home appliances collected from t_i (consumers' categories). Then, the expected payoff per unit when different categories of consumers t_i send the signal s_j is:

$$u_c(s_j, t_i) = r(s_j) - c(t_i, t_j), i = 1,2 \qquad (2)$$

where, $r(s_j)$ is the per unit payoff, when the consumer sends the signal s_j. The $c(t_i, t_j)$ means the marginal costs when t_i personate t_j. When $t_i = t_j$ and $c(t_i, t_j)$ is the marginal cost for t_i (consumers' categories) to discharging and sorting small home appliances to recycling containers designated by retailers, then the personation cost will be none.

Suppose, $P(t_i|s_j)$ is the posterior probability of retailer believe the signal s_j sent by t_i (consumers' categories), which is equivalent to the posterior probability of retailer believe t_i is personate t_j. $P(s_j|t_i)$ is contingent probability of t_i send signal s_j. $P(p_i|s_j)$ is contingent probability of selecting p_i selected by retailers when they receive the signal s_j.

Therefore, the game model with an uncertain cost of discharging and sorting the small home appliances to designated points by consumers is shown as follows:

$$s_1 \le p_1 < R - m_1 < s_2 \le p_2 \le R - m_2 \qquad (3)$$

$$c(t_i, t_j) \le s_j, i \le j, c(t_i, t_i) = c(t_i, t_j), i > j \qquad (4)$$

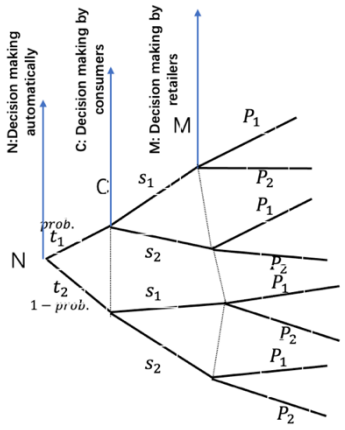


Fig.2 Game trees between retailers and consumers

Note: the prerequisites of the following models works shoud satisfied with conditions (3) and (4).

a) Retailer's Action

The decision making by retailers when they receive the signal s_1. Then, the payoff function per unit if buyback pricing by retailers is set of p_1:

$$u_m(p_1, s_1) = (R - m_1 - p_1)P(t_1|s_1) + (R - m_2 - p_1)P(t_2|s_1) \qquad (5)$$

Then, the payoff function per unit if buyback pricing by retailers is set of p_2:

$$u_m(p_2, s_1) = (R - m_1 - p_2)P(t_1|s_1) + (R - m_2 - p_2)P(t_2|s_1) \quad (6)$$

Accoriding to (4), $p_2 > p_1$, therefore, $u_m(p_1, s_1) > u_m(p_2, s_1)$. This means the optimal buy back pricing for retailers is p_1 when retailers rec eive the signal of s_1 (i.e., $(P_1|s_1)$). Then, we will get the optimal action:

$$P^* = \begin{cases} P^*(p_1|s_1) = 1 \\ P^*(p_2|s_1) = 0 \end{cases} \quad (7)$$

Looking at the recycling framework of small home appliance waste, consumers have two ways to sort small home appliances. One is to discharge them and hand them over to authorized recyclers through the municipalities; the other is for consumers to hand the small home appliances directly to retailers. In this research, we only study the premise that there are only municipalities and consumers.

b) Consumers' Action

Consumers (when consumers' categories belong to t_2: high-preference consumer) determine their own pricing based on the effort and opportunity costs of the small home appliances they invest. If consumer sends signal of s_2, then the payoff function per unit for consumer based on the uncertainty buyback price from retailers (i.e., the uncertainty of p_i):

$$u_c(s_2, t_2) = [p_1 - c(t_2, t_1)]P(p_1|s_2)] + [p_2 - c(t_2, t_2)]P(p_2|s_2) \quad (8)$$

As defined in Eq. (4), $c(t_2, t_1) = c(t_2, t_2)$, Eq. (8) becomes

$$u_c(s_2, t_2) = p_1 P^*(p_1|s_2) + p_2 P^*(p_2|s_2) - c(t_2, t_2) \quad (9)$$

If consumer sends signal of s_1, then the payoff function per unit for consumer:

$$u_c(s_1, t_2) = p_1 - c(t_2, t_2) \quad (10)$$

Due to $p_1 < p_2$, $u_c(s_1, t_2) < u_c(s_2, t_2)$. Therefore, consumers belonging to t_2 category will not to send signal of s_1 due to optimal decision is to send signal of s_2 to retailers (i.e., $(s_2|t_2)$). In this case, $P(s_2|t_2) = 1$, $P(s_1|t_2) = 0$. Then, according to above analysis, the figure 2 could be simplified (Fig.3).

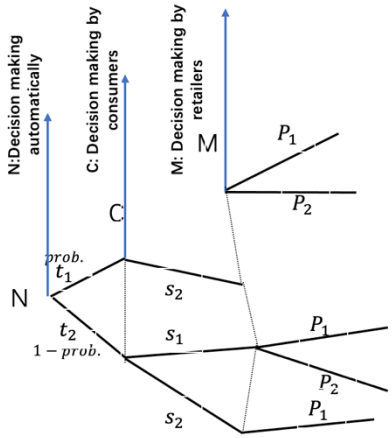


Fig.3 Game trees between retailers and consumers after simplyfied

Then, there are three perfect Bayesian Nash equilibrium: (1) Separating equilibrium: t_1 send the signal of s_1, t_2 send the signal of s_2 (i.e., $(s_1|t_1), (s_2|t_2)$). (2) Pooling equilibrium: both of t_1 and t_2 send the signal of s_2 (i.e., $(s_2|t_1), (s_2|t_2)$). (3) Quasi-separation equilibrium: t_1 send the signal of s_1 or s_2 randomly, t_2 send the signal of s_2 (i.e., $(s_i|t_1)$ $(i = 1,2)$, $(s_2|t_2)$).

3. EQUILIBRIUM ANALYSIS

We examine the three types of equilibirium, (1) sparating equilibrium, (2) pooling equilibrium, (3) Quasi-separation equilibrium. The details and analysis of the three types of equilibrium will be elaborated on the day of the presentation.

4. CONCLUSION

It is difficult for retailers to determine the authenticity of signals sent by different categories of consumers and how to choose the optimal repurchase price for recycling of small home appliances to maximize their own benefits. It is also found that in pooling and quasi-separating equilibrium, low preference-consumers may choose to tell lies and thus threaten the profits of high-preference consumers.

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