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A Pricing Model and Contract Design for Recycling Used Home Appliances in Accordance with the Retailer's Collecting Method

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Abstract: Using the price for recycling used home appliances as a variable in the decision-making process, this paper studies the pricing decision-making process of the home appliances enterprises when a wholesale and retail price for the green home appliances have already been determined in advance. Considering the influences of the effective recycle behavior of the used home appliances to the whole supply chain, a game model about the recycle pricing for the used home appliances is presented in accordance with the retailer's collecting method. Then a revenue and expense-sharing contract is designed to coordinate the supply chain so as to improve the performance of the green supply chain in terms of the recycle of the used home appliances.

Keywords: green supply chain, green supply chain management; game model; pricing decision-making, revenue and expense-sharing contract, home appliances industry

1. INTRODUCTION

In recent years, the urgency and importance of integrating home appliances industry with the green supply chain management has gained more attention all over the world, due to the fact that discarded used or recycled home appliances become hazardous substances and are harmful to the environment if disposing them by traditional means. In China, how to take back used home appliances and improve the consumption of the green home appliances could be with great significance for the development of home appliances industry in the following years, which will depend on the price strategies to a large extent.

Comparing with the traditional one, the pricing problems of the green supply chain for home appliances industry are more complicated due to its operational objectives and in consideration of its economic efficiency, social and environmental impact as well as its unique characteristics. Meanwhile, there are many difficulties about how to make pricing decisions in home appliances industry when considering the influences of the effective recycle behavior of the used home appliances to the whole supply chain and the specific characteristics concerned with coordination.

Therefore, it is necessary to study the pricing issues of the green supply chain for home appliances industry, especially the recycle pricing strategies.

2. LITERATURE REVIEW

Green supply chain is also called Environmentally Conscious Supply Chain (ECSC) or Environmentally Supply Chain (ESC), which has its roots in both environment management and supply chain management literature. Adding the "green" component to supply chain management involves addressing the influence and relationships between supply chain management and natural environment.

There are a growing number of research papers on green supply chain management that use game theory to model pricing decisions. The present research results include some studies about the pricing problems for the green supply chain management itself and some studies about the pricing problems for the closed-loop supply

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chain with product remanufacturing focusing on the effective utilization of resources, with the latter as a majority.

Savaskan et al [1] use game theory to present the optimal closed-loop supply chain structures and to study the pricing and recycle strategies based on three reverse channel formats. Ray et al [2] were interested in looking for the optimal pricing and trade-in strategies for durable, recyclable products by focusing on the replacement customers who are only interested in trade-ins. In another study, Gu et al [3]-[5] analyzed the price decision process for reverse supply chain based on game theory. Wang et al [6][7] conducted several studies to systematically examined the pricing strategies of the closed-loop supply chain management and came up with a set of models based on game theory. Ge et al [8], Guo et al [9], Qiu and Huang [10], Sun and Da [11], Shi and Chen [12] have studied the pricing and coordination problems of the closed-loop supply chain management base on game theory too. Guo et al[13], Huang et al [14] and Chen et al [15] have studied the coordination issues about the close-loop supply chain based on third party collecting.

Some scholars studied price-making decision and the coordination mechanism in the green supply chain, such as Jiao et al [16], Shen and Wang [17], Li [18], Liu and Ma [19], Zhu and Dou [20], Cao et al [21], etc. Xu and Zhou [22] proposed a portfolio pricing model for the Green Supply Chain of home appliances industry based on retailer collecting. Xu and Gao [23] proposed a portfolio pricing model for the Green Supply Chain of home appliances industry based on manufacturer collecting. Xu and Zhou [24] also proposed a game model for the pricing of recycling used home appliances in accordance with the manufacturer's collecting method.

So far researches about the pricing model of the green supply chain for home appliances industry, especially game models for the pricing of recycling used home appliances, are still very limit. Therefore, considering the influences of the effective recycle behavior of the used home appliances to the whole supply chain, this paper will propose a game model about the recycle pricing for the used home appliances in accordance with the retailer's collecting method to try to determine the optimal pricing decision about the recycle price for the used home appliances when a wholesale and retail price for the green home appliances have already been determined in advance. Revenue and expense-sharing contracts will be designed to coordinate the supply chain so as to improve the performance of the green supply chain in terms of the recycle of the used home appliances.

3. MODEL NOTATIONS AND ASSUMPTIONS

3.1 Notations

We use the following notation throughout the paper:

C_m will denote the unit cost of manufacturing a new green home appliance, C_r will denote the unit cost of remanufacturing a returned home appliance into a new one, and C_s will denote the unit cost of selling a new home appliance for the retailer. P is the retail price of the green home appliance and W is the unit wholesale price. In this model, P and W for the green home appliances have already been determined in advance. P_c will denote the unit recycle price for the used home appliances from the consumer to the retailer, and P_r will denote the unit transfer price for the used home appliances from the retailer to the manufacturer. S_b will denote the unit subsidy or penalty that manufacturer obtained from governments. $D(P)$ is the basic demand for the new green home appliance in the market as a function of retail price, and $D'(P_c)$ is the derivative demand for the new green home appliance created by recycling used home appliance as a function of recycle price. $\prod_i^{j-R}$ will denote the profits function for channel member i in recycle model j. R indicates the model is a recycle pricing model. $\prod_i^{*j-R}$ will denote the optimal profit correspondingly. The subscript i will take M, R and vacancy, which will denote the manufacturer, the retailer, and the centralized manufacturer, respectively. Superscript j will take values C and R, which will denote the centrally coordinated and the retailer's collecting method, respectively. P_c^{*j-R} and P_r^{*j-R} will denote the optimal recycle price and optimal transfer price, respectively.

3.2 Assumptions

The primary goal of this paper is to construct a pricing model so as to make optimal strategy about the recycle price for the used home appliances as well as the total channel profits. Hence, we consider the following scenario and make the following modeling assumptions.

Suppose that the manufacturer has incorporated a remanufacturing process for used home appliances into her original production system, so that she can manufacture a new home appliance directly from raw materials, or remanufacture part or whole of a returned unit into a new product. We assume that the home appliances produced by using used products are the same as a new one by using raw materials in terms of quality and functions, and will be sold at the same wholesale price.

(1) We consider a two-echelon green supply chain and model a bilateral monopoly between a single manufacturer and a single retailer. It is the retailer who is responsible for collecting the used home appliances.

(2) While optimizing their objective functions, all supply chain members have access to the same information.

(3) We consider the manufacturer has sufficient channel power over the retailer to act as a Stackelberg leader. The Stackelberg structure for the solution of similar games has been widely used in the supply chain management literature.

(4) The pricing decisions are considered in a single-period setting.

(5) Producing a new green home appliance by using a used product is less costly than manufacturing a new one, i.e., $C_r<C_m$, and the cost saving is denoted by Δ, i.e., $\Delta=C_m-C_r$.

(6) r denotes the fraction of the recycled used home appliance that will be put into remanufacturing and the other fraction 1-r will be put into other places, e.g., raw materials regeneration, i.e. $0\leq r\leq 1$. We assume that the unit residual value of used home appliances is S（$S\leq\Delta$）.

From Assumptions (5) and (6), the average unit revenue from recycling used home appliances can be written as $\Delta'=r\Delta+(1-r)S$.

(7) We assume that the recycling quantity A is only dependent on the recycle price for used home appliances, i.e., $A(P_c)=g+hP_c$, where g and h are parameters by a value greater than zero. Parameter g reflects the consumers' awareness of environmental protection and h indicates the level of sensitivity of the consumers to the recycle price P_c.

(8) We assume that part of recycling quantity will translate into new demand for the green home appliances particularly when taking some means and measures, such as cash incentives from government for older home appliances that are traded in for new green ones. We characterize the conversion rate by τ, i.e., $D'(P_c)=\tau(g+hP_c)$ and $0\leq\tau\leq 1$. The conversion rate τ can be influenced by appropriate subsidy from the governments to the consumers in practice. $D'(P_c)$ is a derivative demand from the recycle of the used home appliances.

(9) We consider dedicated cost of recycling used home appliances is function of recycling quantity, i.e., $C(P_c)=LA^2(P_c)$ and $L>0$, where L is a parameter of recycling cost.

4. A PRICING MODEL FOR RECYCLING USED HOME APPLIANCES

In this section, we will present a game model about the recycle pricing for the used home appliances based on the model that it is the retailer who is responsible for colleting the used home appliances. As a benchmark case, the Centrally Coordinated Model is analyzed to highlight inefficiencies resulting from decentralization of decision making, and is later used for deriving the channel coordinating pricing scheme.

4.1 Centrally coordinated model (Model C)

The centrally coordinated model provides a benchmark scenario to compare the decentralized models with respect to the supply chain profits. Because there is a single decision maker, the wholesale price W is irrelevant to the formulation of the objective function. Hence, the total supply chain profits connected with the recycle of the used home appliances is shown as follows:

$$\begin{aligned}\prod^{C-R} &= D'(P_c)\cdot(P-C_m-C_s+S_b)+A(P_c)\cdot(\Delta'-P_c)-C \\ &= \tau(g+hP_c)(P-C_m-C_s+S_b)+(g+hP_c)(\Delta'-P_c)-L(g+hP_c)^2\end{aligned} \tag{1}$$

To simplify the expression, we make:

$$X = P-C_m-C_s+S_b \tag{2}$$

The simultaneous solution of the first-order conditions results and the profits of the green supply chain are listed in Table 1. The optimal pricing under centrally coordinated system is $P_c^{*C\text{-}R}$.

4.2 Decentralized pricing model in accordance with the retailer's collecting method (Model R)

In this model, P and W for the green home appliances have already been determined by other methods in advance. To take the used home appliances back, the manufacturer pays a transfer price P_r per unit returned to her from the retailer. The retailer is responsible for the promotion and collection of used home appliances and decides the recycle price P_c for the used home appliances. The manufacturer decides the transfer price P_r.

The profits of the retailer, manufacturer and the total supply chain profits connected with the recycle of the used home appliances are given by following equations, respectively.

$$\begin{aligned}\prod_R^{R-R} &= D'(P_c)\cdot(P-W-C_s)+A(P_c)\cdot(P_r-P_c)-C \\ &= \tau(g+hP_c)(P-W-C_s)+(g+hP_c)(P_r-P_c)-L(g+hP_c)^2\end{aligned} \tag{3}$$

$$\begin{aligned}\prod_M^{R-R} &= D'(P_c)\cdot(W-C_m+S_b)+A(P_c)\cdot(\Delta'-P_r) \\ &= \tau(g+hP_c)(W-C_m+S_b)+(g+hP_c)(\Delta'-P_r)\end{aligned} \tag{4}$$

$$\begin{aligned}\prod^{R-R} &= \prod_R^{R-R}+\prod_M^{R-R} \\ &= \tau(g+hP_c)(P-C_m-C_s+S_b)+(g+hP_c)(\Delta'-P_c)-L(g+hP_c)^2\end{aligned} \tag{5}$$

To simplify the expressions, we make:

$$\begin{aligned}Y &= W-C_m+S_b \\ Z &= P-W-C_s \\ X &= Y+Z\end{aligned} \tag{6}$$

The optimal recycle pricing strategy under decentralized decision-making with the retailer responsible for collecting is （$P_r^{*R\text{-}R}$, $P_c^{*R\text{-}R}$） which is listed in Table 1 together with the optimal profits of the retailer, manufacturer and the total supply chain.

Table 1. Comparison of equilibrium results of recycle pricing game models under Model C and Model R

	Model C	Model R
P_c^{*j-R}	$\dfrac{h\Delta'-g-2Lgh+\tau hX}{2h(1+Lh)}$	$\dfrac{h\Delta'-3g-4Lgh++\tau hX}{4h(1+Lh)}$
P_r^{*j-R}	N/A	$\dfrac{h\Delta'-g-\tau h(P-C_s+C_m-S_b)+2\tau hW}{2h}$
$\prod_M^{*j-R}$	N/A	$\dfrac{(h\Delta'+g+\tau hX)^2}{8h(1+Lh)}$
$\prod_R^{*j-R}$	N/A	$\dfrac{(h\Delta'+g+\tau hX)^2}{16h(1+Lh)}$
$\prod^{*j-R}$	$\dfrac{(h\Delta'+g+\tau hX)^2}{4h(1+Lh)}$	$\dfrac{3(h\Delta'+g+\tau hX)^2}{16h(1+Lh)}$

It can be proved that the total supply chain profits connected with the recycle of the used home appliances under centrally coordinated model is less than the one under the decentralized circumstance, which shows that there are inefficiencies resulting from decentralization of decision making due to double marginalization in the channel. Therefore, the profits of the total supply chain can be further improved by designing appropriate contract so that the pricing game effects can be improved correspondingly.

5. A REVENUE AND EXPENSE-SHARING CONTRACT MODEL

As we know that the overall performance of supply chain can be improved significantly through effective contracts and the collaborative relationships between supply chain members are also assured by supply chain contracts. Even if supply chain contracts cannot achieve the best coordination effect, there will be possible Pareto optimal solution, which means that each member's profit will be not less than the original one without coordination [25]. Therefore, we will design a revenue and expense-sharing contract model so as to improve the game effects of the recycle pricing decision making.

Since there will be a derivative demand from the recycle of the used home appliances, the retailer could increase its sale and improve its profits as a result. However, it's retailer who undertake the total cost concerning with the recycle of the used home appliances. It is obvious that the retailer will have no enough enthusiasm to recycle the used home appliances. Therefore, it is necessary to allocate the revenue and expense fairly. In this paper, considering the characteristics of the green supply chain for home appliances industry, all the increased revenue, subsidy from the governments, the recycle revenue and all the cost connected with the recycle of the used home appliances will be allocated between the manufacturer and the retailer, so that the overall performance of the whole supply chain will be improved.

We assume that the manufacturer and the retailer sign a revenue and expense-sharing contract before the sale period. At the end of sale period, the increased sales revenue connected with the recycle of the used home appliances, the subsidy from the governments and the recycle revenue will be allocated between the manufacturer and the retailer, with the retailer accounted for θ ($0\le\theta\le1$) percent and the manufacturer accounted for 1- θ. At the same time, all recycling costs will be allocated too, with the retailer accounted for θ ($0\le\theta\le1$) percent and the manufacturer accounted for 1- θ.

Here we characterize the superscript "-RES" to the notations to denote the optimal results of the game equilibrium.

The profits of the retailer, manufacturer and the total supply chain profits connected with the recycle of the used home appliances are given by following equations, respectively.

$$\begin{aligned}\prod_R^{R-R(RES)} &= \theta\cdot\tau(g+hP_c)(P+S_b)-\tau(g+hP_c)(W+C_s)\\ &\quad+\theta\cdot[(g+hP_c)(\Delta'-P_c)-L(g+hP_c)^2]+P_r(g+hP_c)\end{aligned} \tag{7}$$

$$\begin{aligned}\prod_M^{R-R(RES)} &= (1-\theta)\cdot\tau(g+hP_c)(P+S_b)+\tau(g+hP_c)(W-C_m)\\ &\quad+(1-\theta)[(g+hP_c)(\Delta'-P_c)-L(g+hP_c)^2]-P_r(g+hP_c)\end{aligned} \tag{8}$$

$$\begin{aligned}\prod^{R-R(RES)} &= \prod_R^{R-R(RES)}+\prod_M^{R-R(RES)}\\ &= \tau(g+hP_c)(P-C_m-C_s+S_b)+(g+hP_c)(\Delta'-P_c)-L(g+hP_c)^2\end{aligned} \tag{9}$$

The best responses are determined by the following equation (10).

$$P_c^{*R-R(RES)}=\frac{\theta[h\Delta'-g-2Lgh+\tau h(P+S_b)]-\tau h(W+C_s)+P_r h}{2h\theta(1+Lh)} \tag{10}$$

In order to make the game result reach the efficiency of the centrally coordinated model, the condition $P_c^{*R-R(RES)}=P_c^{*C-R}$ must be satisfied, and we will get the equation (11).

$$P_r^{*R-R(RES)}=\tau(W+C_s)-\tau\theta(C_m+C_s) \tag{11}$$

It can be found that equation (10) and (11) show the optimal recycle pricing strategy under decentralized decision-making with the retailer responsible for the collection, i.e., ($P_c^{*R-R(RES)}$, $P_r^{*R-R(RES)}$).

In this circumstance, the optimal profits of the retailer, manufacturer and the total supply chain are given by following equations, respectively.

$$\prod_R^{*R-R(RES)} = \theta \cdot \prod^{*C-R} = \theta \cdot \frac{(h\Delta' + g + \tau hX)^2}{4h(1+Lh)} \tag{12}$$

$$\prod_M^{*R-R(RES)} = (1-\theta) \cdot \prod^{*C-R} = (1-\theta) \cdot \frac{(h\Delta' + g + \tau hX)^2}{4h(1+Lh)}$$

$$\prod^{*R-R(RES)} = \prod^{*C-R} = \frac{(h\Delta' + g + \tau hX)^2}{4h(1+Lh)} \tag{13}$$

Form the above equation (12) and (13), it can be found that the profits of the supply chain members will depend on the value of θ. The conditions driving the manufacturer and the retailer to accept the contract are that the profits of the supply chain members will be as least not lower than the profits before signing the contract, i.e.,

$$\frac{1}{4} \le \theta \le \frac{1}{2} \tag{14}$$

In general, the green supply chain can be coordinated by this revenue and expense-sharing contract. The gaming and decision process is as follows: the home appliances manufacturer determine the ratio θ according to the constraint shown in equation (14) and the recycle price P_c from the consumers. According to this recycle pricing strategy, both the manufacturer and the retail will improve their profits and the total supply chain profits connected with the recycle of the used home appliances can reach the optimal level of centrally coordinated system.

6. A NUMERICAL EXAMPLE

Here the models proposed in this paper will be analyzed by numerical examples with specific data. The home appliance designated here is the Freon-free and inverter air-conditioner manufactured by Gree Electric Appliances, Inc. of Zhuhai. Assumption of the basic parameters for Gree Freon-free and inverter air-conditioner are list in Table2. At the same time, we assume that the the retail price of the green home appliance P is 3000 RMB and the unit wholesale price W is 2500 RMB.

Table 2. Assumption of the basic parameters for GREE freon-free and inverter air-conditioner

C_m	C_r	r	S	Δ'	C_s	g	h	τ	S_b	L	α	β
2400	1500	0.6	100	580	300	40	0.2	0.4	300	0.0005	4725	1.5

6.1 Equilibrium results of the recycle pricing in Model C and Model M

The gaming equilibrium under centrally coordinated model and decentralized model with the retailer responsible for collecting the used home appliances are listed in Table 3.

Table 3. Equilibrium results of the recycle pricing for used GREE air-conditioner under Model C and Model M

	Model C	Model M
P_c*(RMB /unit)	310	55
A（g+hP_c）(million unit)	102	51
P_r^*(million unit)	N/A	230
$\prod_M^*$ (million RMB)	N/A	26007

$\prod_R^*$ (million RMB)	N/A	13004
$\prod^*$ (million RMB)	52015	39011
Efficiency loss（%）	N/A	25

From Table 3, it can be seen that, the recycle price from the consumers P_c in Model M is lower than the one in Model C, which will affect the consumer's decision to replace his or her used home appliance and result in a decline of the recycle quantity. As a result the quantity translated into the new demand will decrease too. From the perspective of social welfares, the decrease of the recycle price will reduce the enthusiasm of consumers to return their used home appliances and affect the effective recycle of the used home appliances, which will decrease the environmental and social benefit.

It can also be seen that the total supply chain profits connected with the recycle of the used home appliances is less than the profits of centralized model, having lost 25 percent efficiency, i.e., 13004 million RMB.

6.2 Improvements of the recycle pricing by a revenue and expense-sharing contract

Here we will observe the improvements of the recycle pricing by a revenue and expense-sharing contract. According to the equation (14), the value of θ is between 0.25 and 0.5. Then according to the equation (12), we can calculate the profits of the retailer are 52015 θ and the profits of the manufacturer are (1- θ) 52015. Profits of the manufacturer and the retailer under different sharing ratio θ are listed in Table 4.

Table 4. Profits of the manufacturer and the retailer under different sharing ratio θ

θ	$\prod_M^*$（million RMB）	$\prod_R^*$（million RMB）	$\prod^*$（million RMB）
0.25	39011	13004	52015
0.30	36410	15604	52015
0.35	33810	18205	52015
0.40	31209	20806	52015
0.45	28608	23407	52015
0.50	26007	26007	52015

It can be seen that the effects of the recycle pricing game between the manufacturer and retailer have been improved by the revenue and expense-sharing contract, with an increase in the profits of the supply chain members compared with the decentralized decision making. The total supply chain profits connected with the recycle of the used home appliances has reached the level of centralized system and eliminated the double marginalization. The exact allocation result of the profits will depend on the value of θ, which will be affected by the negotiation ability. The greater the θ is, the more profits the retailer will gain and the less profits the manufacturer will gain, but profits level of both the retailer and the manufacturer have been improved compared with the circumstance without the contract.

7. CONCLUSIONS

In consideration of the impact of the recycle quantity of the used home appliances on the demand for the green home appliances, a recycle pricing model of the green supply chain for home appliances industry is presented based on the model that it is the retailer who is responsible for colleting the used home appliances, which is mainly about the decision-making of the recycle price for used home appliances. As a benchmark case, the Centrally Coordinated Model is also analyzed to highlight inefficiencies resulting from decentralization of decision making, and is later used for deriving the channel coordinating pricing scheme. The analysis shows that there exists double marginalization and the pricing game effects should be further improved. Then a revenue and expense-sharing contract model is designed which will be able to allocate resources properly, thus maximizing the profits and effectiveness of the supply chain as a whole. At last, using Gree Electric Appliances, Inc. of Zhuhai as a case study, this paper applies its recycle pricing models to one of its green products, namely, the freon-free and inverter air-conditioner, and has proved the rationality and feasibility.

This paper proposes an alternative model to solve the recycle pricing problems of the complicated supply chain operations, especially the green supply chain management. The recycle pricing models presented in this paper for the green supply chain of home appliances industry provides a practical and theoretical guidance for home appliances enterprises in making recycle pricing decisions and supply chain contracts. It is also of significance in improving the effectiveness and efficiency of the whole supply chain.

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