A Portfolio Pricing Model and Contract Design of the Green Supply Chain for Home Appliances Industry Based on Retailer Collecting

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Abstract: From the perspectives of the operational objectives of the green supply chain management and in consideration of its economic efficiency, social and environmental impact as well as its unique characteristics, this paper examines the pricing issues of the green supply chain for home appliances industry by using game theory and contract coordination theory. Considering the influences of the effective recycle behavior of the used home appliances to the whole supply chain, the paper proposes a game model for the portfolio pricing for the wholesale, retail and recycle price based on retailer recycling model. Then a revenue and expense-sharing contract model is designed to improve the game effects, by allocating both total revenues and expenses related to the manufacturing, retailing and recycling operations in the green supply chain among all participating players, thus maximizing the profits and effectiveness of the supply chain as a whole. The pricing models presented in this paper provide a practical and theoretical guidance for home appliances enterprises in making pricing decisions and supply chain contracts.

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

1. INTRODUCTION

Since the beginning of the 21st century, supply chain management has become an important means to gain the competitive advantage. The pricing problems of supply chain management have been widely recognized in the literature and in practice. Scholars from home and abroad have made many studies in this field and constructed many pricing models, which have enhanced the coordination between enterprises along the supply chain and improved the overall effectiveness of the supply chain. However, with the rise of green supply chain management, the pricing problems of supply chain management are facing new difficulties and challenges.

As a result, 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 recent years, many countries in the world formulate more strict environmental protection laws and regulations to strengthen the environmental protection and management, e.g., WEEE directive 2002/96/EC (Waste Electrical and Electronic Equipment directive 2012/96/European Community, as amended by 2003/108/EC) and RoHS directive 2002/95/EC (Restriction of Hazardous Substances directive 2002/95/European Community). In addition, European Union started to implement a series of new directives that contain more restrict requirements for recycling used home appliances on August 15, 2012. Furthermore, it has already reached a peak of recycling used home appliances in China since 2003 and the growing speed of electrical trash is triple the household refuse. 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

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appliances industry of China, 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 problems of the green supply chain for home appliances industry. More specifically, we address the following research questions:

(1) How to make portfolio pricing strategy of the wholesale price and the retail price for the green home appliances, and the recycle price for the used home appliances as well as the total channel profits under the circumstance that manufacturer contracting the collection of used products to the retailer?

(2) How to improve the total channel profits by designing appropriate contract model?

2. LITERATURE REVIEW

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 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. They discussed how the wholesale price and the retail price as well as the total channel profits are affected by the choice of the reverse channel structure and how the closed-loop supply chain structures influence the incentives to invest in used-product collection and the product return rates. Ray et al [2] studied the optimal pricing and trade-in strategies for durable, remanufacturable products by focusing on the scenario where the replacement customers are only interested in trade-ins. They characterized the roles that the durability of the product, the extent of return revenues, the age profile of existing products in the market, and the relative size of the two customer segments play in shaping the optimal prices and the amount of trade-in rebates offered. Gu et al [3]-[5] have made an analysis about the price decision for reverse supply chain based on game theory. Jiao et al [6] studied multi-product price-making decision and the coordination mechanism in the single-period supplier-manufacturer green supply chain in such a market that the common and green products coexist and can replace each other because of different customer preferences. The research papers of Wang et al [7]-[11] from the year of 2006 to 2010 have systemically studied the pricing strategies of the closed-loop supply chain management and constructed a set of models by using game theory. Ge et al [12] studied the pricing and coordination problems of the closed-loop supply chain management base on game theory too. Shen and Wang [13] studied the manufacturer's evolutionary strategy in the green supply chain with evolutionary game based on a product differentiation model with linear demand functions, and analyzed the efficiency of government's allowance on green product. Guo et al [14] considered a two level closed-loop supply chain which enables the retailer to be engaged in the promotion and collection of used products in addition to distributing new products and a situation with stochastic demand, and developed a joint decision profit model to analyze how the enterprises determine order quantity and collection price. Guo et al [15] also made one coordination research for closed-loop supply chain management based on the third party. Li [16] used cooperative game model and non-cooperative game model to study the pricing decision of the node enterprises in the green supply chain and proposed the coordination mechanism for pricing correspondingly. Liu and Ma [17] have constructed a profit model between manufacturer and retailer for both cooperative game and non-cooperative game in the green supply chain and discussed the coordination mechanism for the internal price. Qiu and Huang [18] studied the coordination of closed-loop supply chain with product recycling in stochastic demand. Based on considering two recycling channels covering both manufactures and sellers, they have developed a Stackelberg game model for closed-loop supply chain where the manufacturers and sellers play the roles of leader and follower respectively. They have pointed out that a two-part tariff contract signed by both parties can simply make the closed-loop supply chain coordinative so as to ensure that both manufacturers and sellers in the supply chain gain their own rational profits. Huang et al [19] discussed the pricing decision problems of the closed-loop supply chain management with remanufacture based on third-party collecting and analyzed the efficiency of the supply chain under different decision structure. Guo et al [20] classified the discarded products into two kinds, namely the remanufactured product and non-rebirth product, and set up the centralization decision-making model and the decentralization decision-making model in the closed-loop supply chain to discuss the optimal price and order quantity strategies by considering the stimulation effect of the government to the manufacturer as well as designed a revenue and expense-sharing contract to coordinate the supply chain. Chen et al [21] studied the price decision-making and coordination with contract in the Stackelberg closed-loop supply chain with product remanufacturing composed of manufacturer, retailer and third-party logistics provider based on game theory. Li et al [22], Sun and Da [23]-[24], Shi and Chen [25] and Chen et al [26] have studied the pricing coordination problems by using revenue-sharing contracts. Zhu and Dou [27] established a three-stage game model by considering products' green degree and government subsidies . The first stage is that the government determines the subsidies coefficient; the second stage is that manufacturers with various green strategies in supply chain determine their own products' green degree; the third stage is that manufacturers in supply chain determine their own products' prices . In view of the consumer demand caused by product's utility diversity, and taking the initial stage of green market's development as research background, Cao et al [28] have proposed two coordination strategies based on the Stackelberg game and cooperative decision-making separately. Based on the latter, they use Nash coordination approach to propose a nonlinear pricing model, which can achieve a Pareto improvement of the members' Stackelberg-equilibrium profits.

So far no literature exists about the pricing model of the green supply chain for home appliances industry. 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 for the portfolio pricing based on retailer colleting model to try to determine the optimal pricing decision about the wholesale price and the retail price for the green home appliances, and the recycle price for the used home appliances. Revenue and expense-sharing contract model will be designed respectively to improve the game effects, by allocating both total revenues and expenses related to the manufacturing, retailing and recycling operations in the green supply chain among all participating players, thus maximizing the profits and effectiveness of the supply chain as a whole.

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. 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. $\prod_i^j$ will denote the profits function for channel member i in supply chain model j and $\prod_i^{*j}$ 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 retailer collecting models, respectively. P^{*j}, W^{*j}, P_c^{*j} and P_r^{*j} will denote the optimal prices, respectively.

3.2 Assumptions

The primary goal of this paper is to construct a portfolio pricing model so as to make optimal strategies about the wholesale price and the retail price for the green home appliances, and 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.

This enables us to explore the implications of assigning a dual role to a forward channel member. Specifically, if the retailer undertakes the collection effort, he not only determines the quantity demanded in the market by setting the retail price of the home appliances, but also influences the recycle amount by setting the recycle price of the used home appliances.

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

This assumption enables us to control for inefficiencies and risk-sharing issues resulting from information asymmetry [29].

(3) We consider the manufacturer has sufficient channel power over the retailer to act as a Stackelberg leader.

This assumption states that in determining the outcome of the game played between the manufacturer and the retailer, the manufacturer uses her foresight about the retailer's reaction functions in her decision making. The Stackelberg structure for the solution of similar games has been widely used in the supply chain management literature [30].

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

We assume the previous existence of the home appliances in the market. Those home appliances sold in the previous periods can be returned to the manufacturer for reuse. Hence, the focus of analysis is on the average supply chain profits per period when similar home appliances are introduced to the market repeatedly.

(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) We characterize the availability of the used home appliances by r, the remanufacturing rate of the recycled used home appliances. 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. $0\le r\le 1$. We also assume that the unit residual value of used home appliances is S（$S\le\Delta$）.

From Assumptions (5) and (6), the average unit revenue from recycl 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., $A(P_c)=g+hP_c$, which shows that the recycling quantity is an increasing function of the recycle price P_c, where g and h are parameters and both of them are greater than zero, i.e., $g,h>0$. Parameter g reflects the consumers' awareness of environmental protection, in other words, there are a number g of consumers will be willing to return their used home appliances even for free. Parameter 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, which denotes the fraction of recycled quantity of the used home appliances to the new market demand, i.e., $D'(P_c)=\tau(g+hP_c)$ and $0\leq\tau\leq1$. The conversion rate τ can be influenced by appropriate subsidy from the governments to the consumers in practice. When subsidy from the governments is increased, consumers will be more willing to replace their used home appliances with new green ones in advance. $D'(P_c)$ 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. L can be understood as recycle difficulties, which means that the more the recycle difficulties are, the more the recycling cost will occur. L is normally related to the characteristics of the home appliances.

(10) We assume the basic demand function is $D(P)=\alpha-\beta P$, with α and β being positive parameters.

We assume a downward sloping linear demand function. Lee and Staelin [31] have shown that the vertical interaction between the channel members and the optimality of the channel strategies depend on the convexity of the demand functions. Therefore, we make this assumption for the analysis of the pricing problems of the green supply chain for home appliances industry, and the analysis to nonlinear demand functions is a question of future research.

From Assumptions (8) and (10), the total demand for green home appliances are composed of the basic demand and the derivative demand from the recycle of the used home appliances and can then be written as $D(P)+D'(P_c)=\alpha-\beta P+\tau(g+hP_c)$.

(11) We assume that fraction λ_1 of the unit manufacturing cost are those cost concerning to meet the requirements or standards of the green home appliances, and the other fraction 1- λ_1 are other kind of manufacturing cost, i.e., $0\leq\lambda_1\leq1$. Similarly, We assume that fraction λ_2 of the unit retail cost are those cost concerning to the promotion of the green home appliances, and the other fraction 1- λ_1 are other kind of retail cost, i.e., $0\leq\lambda_2\leq1$.

4. A PORTFOLIO PRICING MODEL BASED ON RETAILER COLLECTING

In this section, we will present a portfolio pricing model of the green supply chain for home appliances industry 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 and the transfer price P_r are irrelevant to the formulation of the objective function. Hence, the profits function of the whole supply chain is shown as follows:

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

The simultaneous solution of the first-order conditions results and the profits of the green supply chain are listed in Table 1. The optimal portfolio pricing strategies under centrally coordinated system is (P^{*C}, P_c^{*C}).

4.2 Decentralized pricing model based on retailer collecting (Model R)

In this model, the retailer also engages in the promotion and collection of used home appliances in addition to distributing new green home appliances. To take the used home appliances back, the manufacturer pays a transfer price P_r per unit returned to her from the retailer. In this model, the retailer decides the retail price P, and the recycle price P_c for used home appliances. The manufacturer decides the whole sale W and the transfer price P_r.

The profits of the retailer, manufacturer and the total supply chain are given by following equations, respectively.

$$\begin{aligned}\Pi_R^R &= [D(P)+D'(P_c)]\cdot(P-W-C_s)+A(P_c)\cdot(P_r-P_c)-C \\ &= \left[\alpha-\beta P+\tau(g+hP_c)\right](P-W-C_s)+(g+hP_c)(P_r-P_c)-L(g+hP_c)^2\end{aligned} \tag{2}$$

$$\begin{aligned}\Pi_M^R &= [D(P)+D'(P_c)](W-C_m+S_b)+A(P_c)(\Delta'-P_r) \\ &= \left[\alpha-\beta P+\tau(g+hP_c)\right](W-C_m+S_b)+(g+hP_c)(\Delta'-P_r)\end{aligned} \tag{3}$$

$$\begin{aligned}\Pi^R &= \Pi_R^R+\Pi_M^R = [\alpha-\beta P+\tau(g+hP_c)](P-C_m-C_s+S_b)+(g+hP_c)(\Delta'-P_c) \\ &\quad -L(g+hP_c)^2\end{aligned} \tag{4}$$

Because the objective function is jointly concave in P and P_c, the best responses can be determined from the first-order conditions. And then Given P^{*R} and P_c^{*R}, the manufacturer will optimize the optimal value of her profits function. From the first-order conditions, the best responses will are determined and the results are shown in Table 1. The optimal portfolio pricing strategies under decentralized decision-making with the retailer responsible for collecting is (W^{*R}, P_r^{*R}, P^{*R}, P_c^{*R}). In this circumstance, the optimal profits of the retailer, manufacturer and the total supply chain are also given in Table 1.

It can be proved that the total supply chain profits of centrally coordinated model is less than the one of decentralized circumstance, which shows that there is 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.

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

	Model C	Model R
W^{*j}	N/A	$\frac{\alpha+\beta(C_m-C_s-S_b)}{2\beta}$
P^{*j}	$\frac{\alpha+\beta(C_m+C_s-S_b)+\tau A}{2\beta}$	$\frac{3\alpha+\beta(C_m+C_s-S_b)+2\tau A_R}{4\beta}$
P_c^{*j}	$\frac{2\beta(h\Delta'-g-2Lgh)+\tau h[\alpha-\beta(C_m+C_s-S_b)+\tau g]}{4\beta h(1+Lh)-\tau^2h^2}$	$\frac{2\beta(h\Delta'-3g-4Lgh)+\tau h[\alpha-\beta(C_m+C_s-S_b)+2\tau g]}{8\beta h(1+Lh)-2\tau^2h^2}$
P_r^*	N/A	$\frac{h\Delta'-g}{2h}$
A/A$_R$	$\frac{2\beta(h\Delta'+g)+\tau h[\alpha-\beta(C_m+C_s-S_b)]}{4\beta(1+Lh)-\tau^2h}$	$\frac{2\beta(h\Delta'+g)+\tau h[\alpha-\beta(C_m+C_s-S_b)]}{8\beta(1+Lh)-2\tau^2h}$
D	$\frac{\alpha-\beta(C_m+C_s-S_b)+\tau A}{2}$	$\frac{\alpha-\beta(C_m+C_s-S_b)+2\tau A_R}{4}$
Π_M^*	N/A	$\frac{A_R(h\Delta'+g)}{2h}+\frac{B^2+2\tau A_RB}{8\beta}$
Π_R^*	N/A	$\frac{A_R(h\Delta'+g)}{4h}+\frac{B^2+2\tau A_RB}{16\beta}$
Π^*	$\frac{A(h\Delta'+g)}{2h}+\frac{B^2+\tau AB}{4\beta}$	$\frac{3A_R(h\Delta'+g)}{4h}+\frac{3B^2+6\tau A_RB}{16\beta}$

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 [32]. Therefore, we will design a revenue and expense-sharing contract model so as to improve the game effects of the pricing decision making.

In the existing research papers about recycle of the used products, it is usual that only sales revenue and fixed costs for collecting are allocated between the supply chain members. In this paper, considering the characteristics of the green supply chain for home appliances industry, all those revenues including not only sales but also subsidy from the governments, and all those costs including not only costs regarding the recycling but also the costs concerned with the green production and relevant promotion, will be allocated between the manufacturer and the retailer.

We assume that the manufacturer and the retailer sign a revenue and expense-sharing contract before the sale period. The manufacturer will sell the home appliances to the retailer at a wholesale price lower than the unit manufacturer cost. At the end of sale period, sales revenue and subsidy from the governments will be allocated between the manufacturer and the retailer, with the retailer accounted for φ ($0 \le \varphi \le 1$) percent and the manufacturer accounted for $1-\varphi$. At the same time, costs will be allocated too, including the recycling costs and costs concerned with green production and relevant promotion, with the retailer accounted for φ ($0 \le \varphi \le 1$) percent and the manufacturer accounted for $1-\varphi$.

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 are given by following equations, respectively.

$$\begin{aligned}\Pi_R^{R-RES} &= \varphi\left[\alpha - \beta P + \tau(g + hP_c)\right](P - \lambda_1 C_m - \lambda_2 C_s + S_b) \\ &\quad + (g + hP_c)P_r - \left[\alpha - \beta P + \tau(g + hP_c)\right][W + (1-\lambda_2)C_s] \\ &\quad - \varphi[(g + hP_c)P_c + L(g + hP_c)^2]\end{aligned} \tag{5}$$

$$\begin{aligned}\Pi_M^{R-RES} &= (1-\varphi)\left[\alpha - \beta P + \tau(g + hP_c)\right](P - \lambda_1 C_m - \lambda_2 C_s + S_b) \\ &\quad + \left[\alpha - \beta P + \tau(g + hP_c)\right][W - (1-\lambda_1)C_m] + (g + hP_c)(\Delta' - P_r) \\ &\quad - (1-\varphi)[(g + hP_c)P_c + L(g + hP_c)^2]\end{aligned} \tag{6}$$

$$\begin{aligned}\Pi^{R-RES} &= \Pi_R^{R-RES} + \Pi_M^{R-RES} = [\alpha - \beta P + \tau(g + hP_c)](P - C_m - C_s + S_b) \\ &\quad + (g + hP_c)(\Delta' - P_c) - L(g + hP_c)^2\end{aligned} \tag{7}$$

Because the objective function is jointly concave in P and P_c from the first-order conditions, the best responses are determined by the following equation (8).

$$\begin{aligned}P^{*R-RES} &= \frac{\varphi[\alpha + \beta(\lambda_1 C_m + \lambda_2 C_s + S_b) + \tau(g + hP_c) + \beta[W + (1-\lambda_2)C_s]}{2\beta\varphi_2} \\ P_c^{*R-RES} &= \frac{hP_r - \varphi(g + 2Lgh) + \varphi\tau h(P - \lambda_1 C_m - \lambda_2 C_s + S_b) - \tau h[W + (1-\lambda_2)C_s]}{2h(1 + Lh)}\end{aligned} \tag{8}$$

In order to make the game result reach the efficiency of the centrally coordinated model, the condition $P^{*R-RES} = P^{*C}$ and $P_c^{*R-RES} = P_c^{*C}$ must be satisfied, and we will get the equation (9).

$$\begin{aligned}W^{*R-RES} &= \varphi(1-\lambda_1)C_m - (1-\varphi)(1-\lambda_2)C_s \\ P_r^{*R-RES} &= \varphi\Delta'\end{aligned} \tag{9}$$

It can be found that equation (8) and (9) show the optimal portfolio pricing strategies under decentralized decision-making with the retailer responsible for collecting i.e., (P^{*R-RES}, P_c^{*R-RES}, W^{*R-RES}, P_r^{*R-RES},).

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

$$\prod_R^{*R-RES} = \varphi \prod^{*C} = \varphi(\frac{A(h\Delta'+g)}{2h} + \frac{B^2+\tau AB}{4\beta}) \tag{10}$$

$$\prod_M^{*R-RES} = (1-\varphi)\prod^{*C} = (1-\varphi)(\frac{A(h\Delta'+g)}{2h} + \frac{B^2+\tau AB}{4\beta})$$

$$\prod^{*R-RES} = \frac{A(h\Delta'+g)}{2h} + \frac{B^2+\tau AB}{4\beta} \tag{11}$$

Form the above equation (10) and (11), it can be found that the profits of the supply chain members will depend on the value of φ. The conditions driving the manufacturer and the retail 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. From Table 1, according algebra, equation "$A=2A_R$" must be workable, therefore the following condition can be given.

$$\frac{1}{4} \le \varphi \le \frac{1}{2} \tag{12}$$

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 φ according to the constraint shown in equation (12), then the manufacturer determine the wholesale price W and recycle price from the retailer P_r, and the retailer determine the retail price P as well as the recycle price P_c from the consumers. According to this portfolio pricing strategies, both the manufacturer and the retail will improve their profits and the total profits of the green supply chain 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.

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 portfolio pricing in Model C and Model R

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

Table 3. Equilibrium results of the portfolio pricing for GREE freon-free and inverter air-conditioner in Model C and Model R

	Model C	**Model R**
W*(RMB /unit)	N/A	2475
P*(RMB /unit)	2787	2969
P_c*(RMB /unit)	267	34
A（g+hP_c）(million unit)	93	47
P_r*(RMB /unit)	N/A	190
D (million unit)	581	291
$\prod_M^*$ (million RMB)	N/A	127205
$\prod_R^*$ (million RMB)	N/A	63603
$\prod^*$ (million RMB)	254410	190808
Efficiency loss（%）	--	25

As we have stated that the total demand depends on the basic demand and the derivative demand from recycling the used home appliances. The basic demand depends on the retail price, the lower the retail price is, the more the basic demand will be. The derivative demand depends on the recycle price from the consumers, the greater the recycle price is, the more the derived demand will be.

From Table 3, it can be seen that the retail price in Model R is greater than the one in Model C, which will result in a decline in the basic demand of the green home appliances. Meanwhile, the recycle price from the consumers P_c is much 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 by roughly half. 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.

As the result of the increased retail price and the decreased recycle price, the total demand for GREE freon-free and inverter air-conditioner is only a half of the demand in Model C, which is the main reason of the efficiency loss. It can be seen that the total profits of the supply chain is much less than the profits of centralized model, having lost 25 percent efficiency. This has proved that there exists a double marginalization.

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

Here we will observe the improvements of the portfolio pricing by a revenue and expense-sharing contract with an assuming of λ_1=0.4 and λ_2=0.3. According the equation (12), the value of φ is between 0.25 and 0.5. Then according to the equation (10), we can calculate the profits of the retailer are 236353φ and the profits of the manufacturer are (1-φ) 236353. Profits of the manufacturer and the retailer under different sharing ratio φ are listed in Table 4.

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

φ	Π_M^* (million RMB)	Π_R^* (million RMB)	Π^* (million RMB)
0.25	190808	63603	254410
0.3	178087	76323	254410
0.35	165367	89044	254410
0.4	152646	101764	254410
0.45	139926	114485	254410
0.50	127205	127205	254410

It can be seen that the effects of the 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 profits of the supply chain have reached the level of centralized system and eliminated the double marginalization. The exact allocation result of the profits will depend on the value of φ, which will be affected by the negotiation ability. The greater the φ 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 new demand function is proposed in this paper. A portfolio 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 portfolio pricing for the wholesale, retail price of the green home appliances and 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 models is designed which will be able to allocate resources properly in accordance with the different cost factors such as green manufacture, retail and marketing expenses as well as cost of collecting and recycling, 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 pricing models to one of its green products, namely, the freon-free and inverter air-conditioner, and has proved the rationality and feasibility.

Connecting the recycling of the used home appliances with the sale of the green home appliances and making a portfolio pricing strategies from the perspective of the whole supply chain, will be helpful to recycle the used home appliances effectively so as to relieve the pressure of the recycling for the used home appliances in China. At the same time, this can induce consumers to choose green home appliances when they return their used home appliances back, and reduce the bad influences of the home appliances to the environments during the usage as well as improve the environmental benefits.

This paper proposes an alternative model to solve the pricing problems of the complicated supply chain operations, especially the green supply chain management. The 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 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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