

Closed-loop Supply Chain Model Analysis of Home Appliances based on Promotional Effort and Recycling Effort

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ABSTRACT

Nowadays, a large number of home appliances have entered the node of renewal, if they can be properly disposed of and utilised, used home appliances can also be converted into renewable resources to achieve the economic cycle, and at the same time, green living and circular economy are increasingly accepted by the public. Recycling of used home appliances has both economic and social benefits. At the same time, promotional efforts invested in the market for home appliances have an obvious effect on increasing their market demand. Therefore, it is necessary to study the closed-loop supply chain of home appliances based on promotion and recycling efforts. In this paper, we use literature analysis, mathematical analysis and Stackelberg game analysis to construct a closed-loop supply chain model for home appliances based on promotional and recycling efforts after determining who is the promoter among manufacturers and retailers, and then compare and analyse the decisions and benefits of the supply chain members, taking into account their centralised and decentralised decision-making. The results of this paper show that: (1) when home appliance manufacturers, retailers and third-party recyclers of used home appliances make decentralised decisions, there is a double marginal effect, i.e., the supply chain members only consider their own benefits while ignoring the benefits of the supply chain as a whole, which results in the failure of this closed-loop supply chain system of home appliances to be coordinated. (2) When the retailer's promotional effort is greater, both the retail price and the retailer's profit are lower. (3) The greater the recycling effort of the third-party recycler of used home appliance products, the higher its recycling price, i.e., the consequent increase in recycling costs, leading to a decrease in its profit.

KEYWORDS

Promotional Effort; Recycling Effort; Closed-loop Supply Chain

1. INTRODUCTION

Recycling and reuse of household appliances is one of the most important ways to achieve sustainable use of resources. As the service life of appliances increases, some old appliances may no longer be able to meet the needs of modern life, so recycling and reuse can turn these old appliances into useful resources for the production of new products. For example, some old appliances can be dismantled into useful components for the production of new appliances. In addition, some home appliances can be technologically upgraded and modified to regain their use value. The recycling and reuse of home appliances can not only reduce the waste of resources, but also reduce environmental pollution. Household appliances will produce a large amount of waste and pollutants in the process of production and use, if these waste and pollutants are not effectively treated and recycled, it will cause great damage to the environment. Therefore, the recycling and reuse of home appliances is of great significance, which not only reduces the waste of resources, but also reduces environmental pollution and realises the sustainable use of resources.

Netessine and Rudi, who were among the first to study retailers' promotional effort decisions, demonstrated the impact of decisions in the supply chain on profitability by integrating manufacturers and retailers, introducing rebate contracts and proposing a programme to harmonise the supply chain. Taylor's findings suggest that when promotional effort affects product demand, a well-designed target rebate and return contract is required to achieve a win-win situation for both the manufacturer and the retailer and to achieve supply chain coordination. In addition, the provision of return services enhances the incentives of promotional efforts to retailers. Wang and Song included promotional effort, selling price and green level as decision variables in their constructed dual-channel supply chain based on demand uncertainty, and on this basis, with the objective of profit maximisation, they established profit models for manufacturers and retailers under three different decision-making scenarios, namely centralised decision-making, decentralised decision-making and collaborative decision-making, respectively, and compared and analysed optimal decision-making under the three models, which were subject to sensitivity analysis in order to further test the results.

In this paper, we will discuss the benefits of the closed-loop supply chain of home appliances under different decisions based on the promotional efforts of home appliance retailers and the recycling efforts of third-party recyclers of used home appliances.

2. MODEL DESCRIPTION AND UNDERLYING ASSUMPTIONS

2.1. Model Description

In this paper, we will construct a closed-loop supply chain that includes a home appliance manufacturer, a home appliance retailer, and a third-party recycler of used home appliance products. At this point, the operation flow of this supply chain is that the home appliance manufacturer produces home appliance products at a unit cost of raw materials of c . After the products are produced, it sells the home appliance products to the retailer at a certain wholesale price per unit of w , and the retailer puts the products into the market at a price of retail per unit of p for consumers to choose to buy them. At the same time, the manufacturer of home appliances will preferentially purchase recycled materials available after recycling from a third-party recycler of used home appliances at a recycling transfer price of h_1 , and then purchase brand-new raw materials at a price of c from an upstream supplier when the recycled materials cannot satisfy the production, and the relationship between the prices of the two satisfies $c > h_1$. The third-party recycler recovers used home appliances from consumers at the recycling price of h_2 , and the recycling quantity is N .

2.2. Underlying Assumption

Assumption 1: Market demand is affected by price and level of promotional effort, and market demand increases with the level of promotional effort made by the promotional agent. Excluding other factors, the market demand for home appliances is:

$$D = a - \alpha p + \beta e \quad (1)$$

Where a denotes the basic market demand of home appliances, α is the elasticity coefficient of the sales price of home appliances to the market, and β is the elasticity coefficient of the promotional effort level of the promotion subject to the market demand. α and β are constants and are greater than 0.

Assumption 2: It is assumed that the cost of promotional effort of the promotional subject as a function of the level of promotional effort is given in the equation:

$$F(e_i) = \frac{1}{2} k e_i^2 \quad (2)$$

e_i is the effort level, where $i=1$ denotes the level of promotional effort of the retailer and $i=2$ denotes the level of recycling effort of the third-party recycler of used home appliance products.

Assumption 3: The recycling volume of used and end-of-life household appliances is affected by the recycling price and the level of recycling effort. As the level of recycling effort of third-party recyclers of used and end-of-life appliances increases, the amount of recycling increases. Without considering other factors, the recycling of used home appliances is:

$$N = b + \gamma h_2 + \delta e_2 \quad (3)$$

Assumption 4: The subjects in the supply chain are perfectly rational and will make decisions based on their own profit-maximising objectives.

Assumption 5: The members of this home appliance supply chain are consistent with the Stackelberg game, where the leader makes decisions before the followers do. In this home appliance supply chain, the manufacturer is the leader.

Assumption 6: Recycled materials recovered by the manufacturer from a third-party recycler of used household appliances are functionally identical to brand new raw materials purchased from an upstream supplier, and the market cannot tell the difference between the two;

Assumption 7: There is no shortage loss in the whole supply chain, and communication costs are not considered when participating in the contract;

Assumption 8: To ensure that all members of the supply chain benefit, there is $p > w > c > h_1 > h_2 > 0$.

3. CLOSED-LOOP SUPPLY CHAIN DECISION ANALYSIS OF HOME APPLIANCES UNDER DIFFERENT MODELS

This chapter will discuss the benefits of a closed-loop supply chain for home appliances under different decisions based on the promotional efforts of retailers of home appliances and the recycling efforts of third-party recyclers of used and end-of-life home appliances.

3.1. Decision Analysis of a Closed-loop Supply Chain for Home Appliances in a Centralised Model

In the centralised model, the appliance manufacturer, the retailer and the third-party recycler of used and end-of-life appliances in the closed-loop supply chain of home appliances are viewed as a single entity, and all members make decisions together to maximise the profit of that supply chain.

The profit function of the appliance manufacturer is:

$$\Pi_M = wD - h_1N - c(D - N) \quad (4)$$

The profit function for a retailer of home appliances is:

$$\Pi_R = (p - w)D - \frac{1}{2}k_1(e_1)^2 \quad (5)$$

The profit function for third-party recyclers of used appliance products is:

$$\Pi_H = (h_1 - h_2)N - \frac{1}{2}k_2(e_2)^2 \quad (6)$$

At this point, the overall profit of the closed-loop supply chain for the appliance is:

$$\Pi_T = \Pi_M + \Pi_R + \Pi_H \quad (7)$$

At this point, the first-order and second-order derivatives of the overall profit of the closed-loop supply chain with respect to the recovery price h_2 , the retail price p , the level of promotional effort e_1 , and the level of recovery effort e_2 are obtained, respectively:

$$\frac{\partial \Pi_T}{\partial h_2} = c\gamma - \delta e_2 - 2\gamma h_2 - b \quad (8)$$

$$\frac{\partial \Pi_T}{\partial p} = c\alpha - 2\alpha p + \beta e_1 + a \quad (9)$$

$$\frac{\partial \Pi_T}{\partial e_1} = \beta p - c\beta - k_1 e_1 \quad (10)$$

$$\frac{\partial \Pi_T}{\partial e_2} = c\delta - \delta h_2 - k_2 e_2 \quad (11)$$

Therefore, by making Eqs. (8), (9), (10) and (11) equal to 0 and joining them, the optimal recycling price h_2^* , the optimal retail price p^* , the optimal level of promotional effort e_1^* , and the optimal level of effort e_2^* of the closed-loop supply chain of home appliance products at the time of centralised decision-making can be obtained, and they are, respectively:

$$h_2^* = \frac{c\gamma k_2 - c\delta^2 - bk_2}{2\gamma k_2 - \delta^2} \quad (12)$$

$$p^* = \frac{c\alpha k_1 - c\beta^2 + ak_1}{2\alpha k_1 - \beta^2} \quad (13)$$

$$e_1^* = \frac{\beta(a - c\alpha)}{2\alpha k_1 - \beta^2} \quad (14)$$

$$e_2^* = \frac{\delta(c\gamma + b)}{2\gamma k_2 - \delta^2} \quad (15)$$

Then, the maximum profit of a closed-loop home appliance supply chain under centralised decision-making is:

$$\Pi_T^* = \frac{((2c^2\alpha^2\gamma + (2c^2\gamma^2 - 4c(a - b)\gamma + 2b^2)\alpha + 2a^2\gamma)k_2 - \delta^2(a - c\alpha)^2)k_1 - \beta^2 k_2 (c\gamma + b)^2}{2(\beta^2 - 2\alpha k_1)(\delta^2 - 2\gamma k_2)} \quad (16)$$

3.2. Decision Analysis of a Closed-loop Supply Chain for Home Appliances in a Decentralised Model

This chapter constructs a closed-loop supply chain consisting of a home appliance manufacturer, a home appliance retailer, and a third-party used appliance recycler, with the retailer acting as the promotional agent responsible for home appliance promotions, the third-party used appliance recycler responsible for recycling used appliances from consumers, and the home appliance manufacturer obtaining recycling materials from the third-party used appliance recycler.

The closed-loop supply chain of this home appliance product is subjected to a Stackelberg game, in which the manufacturer is the leader and the order of the game is as follows:

Stage 1: Manufacturers act first, setting wholesale prices and recycling transfer prices for appliances;

Stage 2: retailers and third-party recyclers of used and end-of-life appliances observe the manufacturer's decisions and set retail prices, promotional effort levels, recycling prices, and recycling effort levels of home appliances to maximise their profits.

The solution process adopts the reverse induction method to analyse the optimal decision-making behaviours of each member in the closed-loop supply chain of home appliance manufacturing.

First, find the first-order and second-order partial derivatives of the profit of the retailer of home appliances with respect to the retail price and the level of promotional effort, respectively, for Eq. (5), and make the first-order partial derivatives equal to 0. There are:

$$\frac{\partial \Pi_R}{\partial p} = a - \alpha p + \beta e_1 - (p - w)\alpha = 0 \quad (17)$$

$$\frac{\partial \Pi_R}{\partial e_1} = (p - w)\beta - k_1 e_1 = 0 \quad (18)$$

$$\frac{\partial^2 \Pi_R}{\partial p^2} = -2\alpha < 0 \quad (19)$$

$$\frac{\partial^2 \Pi_R}{\partial e_1^2} = -k_1 < 0 \quad (20)$$

$$\begin{vmatrix} \frac{\partial^2 \Pi_R}{\partial p^2} & \frac{\partial^2 \Pi_R}{\partial p \partial e_1} \\ \frac{\partial^2 \Pi_R}{\partial e_1 \partial p} & \frac{\partial^2 \Pi_R}{\partial e_1^2} \end{vmatrix} = 2k_1\alpha - \beta^2 > 0 \quad (21)$$

Since equations (19) and (20) are less than 0, Π_R is a convex function with respect to (p, e) when $2k_1\alpha > \beta^2$, so there exists a unique set of optimal values (p^f, e_1^f) that maximise the profit Π_R of the home appliance retailer. Therefore, the optimal retail price p^f and the optimal level of promotional effort e_1^f of the home appliance retailer at decentralised decision making can be obtained by associating Eq. (17) with Eq. (18), respectively:

$$p^f = \frac{\alpha w k_1 - \beta^2 w + \alpha k_1}{2\alpha k_1 - \beta^2} \quad (22)$$

$$e_1^f = \frac{\beta(a - w\alpha)}{2\alpha k_1 - \beta^2} \quad (23)$$

At the same time, the third-party used home appliance recycler also determines its own recycling price and recycling effort level based on the recycling transfer price proposed by the manufacturer. To find the first-order and second-order derivatives of the profit of the third-party used and end-of-life appliances recycler with respect to the recycling price and the recycling effort level, respectively, for equation (6), and to make its first-order derivatives equal to 0, there are:

$$\frac{\partial \Pi_H}{\partial h_2} = (h_1 - h_2)\gamma - \delta e_2 - \gamma h_2 - b = 0 \quad (24)$$

$$\frac{\partial \Pi_H}{\partial e_2} = (h_1 - h_2)\delta - k_2 e_2 = 0 \quad (25)$$

$$\frac{\partial^2 \Pi_H}{\partial h_2^2} = -2\gamma < 0 \quad (26)$$

$$\frac{\partial^2 \Pi_H}{\partial e_2^2} = -k_2 < 0 \quad (27)$$

$$\begin{vmatrix} \frac{\partial^2 \Pi_H}{\partial h_2^2} & \frac{\partial^2 \Pi_H}{\partial h_2 \partial e_2} \\ \frac{\partial^2 \Pi_H}{\partial e_2 \partial h_2} & \frac{\partial^2 \Pi_H}{\partial e_2^2} \end{vmatrix} = 2k_2\gamma - \delta^2 > 0 \quad (28)$$

Since equations (26) and (27) are less than 0, Π_H is a convex function with respect to (h_2, e_2) when $2k_2\gamma > \delta^2$, so there exists a unique set of optimal values (h_2^f, e_2^f) that maximise the profit of the third-party used home appliance product recycler, Π_H . Therefore, the optimal recycling price h_2^f and the optimal level of promotional effort e_2^f of the third-party used home appliance recycler at decentralised decision-making can be obtained by associating Eq. (24) with Eq. (25), respectively:

$$h_2^f = \frac{\gamma h_1 k_2 - \delta^2 h_1 - b k_2}{2\gamma k_2 - \delta^2} \quad (29)$$

$$e_2^f = \frac{\delta(\gamma h_1 + b)}{2\gamma k_2 - \delta^2} \quad (30)$$

Substituting Eqs. (22), (23), (29), and (30) into Eq. (4) and finding the first-order and second-order partial derivatives of the profit of the manufacturer of home appliances with respect to the wholesale price and the recycling and transfer price, respectively, and making their first-order partial derivatives equal to 0, we have:

$$\frac{\partial \Pi_M}{\partial w} = -\frac{\alpha((c - 2w)\alpha + a)k_1}{\beta^2 - 2\alpha k_1} = 0 \quad (31)$$

$$\frac{\partial \Pi_M}{\partial h_1} = \frac{\gamma k_2((2h_1 - c)\gamma + b)}{\delta^2 - 2\gamma k_2} = 0 \quad (32)$$

$$\frac{\partial^2 \Pi_M}{\partial w^2} = \frac{2k_1\alpha^2}{-2k_1\alpha + \beta^2} < 0 \quad (33)$$

$$\frac{\partial^2 \Pi_M}{\partial h_1^2} = \frac{2k_2\gamma^2}{-2k_2\gamma + \delta^2} < 0 \quad (34)$$

$$\begin{vmatrix} \frac{\partial^2 \Pi_M}{\partial w^2} & \frac{\partial^2 \Pi_M}{\partial w \partial h_1} \\ \frac{\partial^2 \Pi_M}{\partial h_1 \partial w} & \frac{\partial^2 \Pi_M}{\partial h_1^2} \end{vmatrix} = \frac{4k_1 k_2 \alpha^2 \gamma^2}{(-2k_1\alpha + \beta^2)(-2k_2\gamma + \delta^2)} > 0 \quad (35)$$

Since Eq.s (33) and (34) are less than 0 and (35) is greater than 0, Π_M is a concave function with respect to (w, h_1) , so there exists a unique set of optimal values (w^f, h_1^f) that maximise the profit Π_M of home appliance manufacturers. Therefore, the optimal retail price w^f and the optimal level of promotional effort h_1^f for the home appliance retailer at decentralised decision making can be obtained by associating Eq. (31) with Eq. (32), respectively:

$$w^f = \frac{a + c\alpha}{2\alpha} \quad (36)$$

$$h_1^f = \frac{c\gamma - b}{2\gamma} \quad (37)$$

So there:

$$p^f = \frac{(\beta^2 c - 3\alpha k_1)\alpha + a\beta^2 - \alpha^2 c k_1}{2\alpha(\beta^2 - 2\alpha k_1)} \quad (38)$$

$$e_1^f = \frac{\beta(a - c\alpha)}{4\alpha k_1 - 2\beta^2} \quad (39)$$

$$h_2^f = \frac{(c\delta^2 + 3bk_2)\gamma - b\delta^2 - \gamma^2 ck_2}{2\gamma(\delta^2 - 2\gamma k_2)} \quad (40)$$

$$e_2^f = \frac{\delta(c\gamma + b)}{4\gamma k_2 - 2\delta^2} \quad (41)$$

Proposition 1: Compared to centralised decision making, decentralised decision making is less profitable in terms of retail price of home appliances, level of promotional effort, recycling price of used home appliances and the entire closed-loop supply chain of home appliances. That is, $p^f < p^*$, $e_1^f < e_1^*$, $h_2^f < h_2^*$, $e_2^f < e_2^*$, $\Pi_T^f < \Pi_T^*$.

Proof: $p^* - p^f = \frac{\alpha ck_1 - \beta^2 c + \alpha k_1}{2\alpha k_1 - \beta^2} - \frac{\alpha wk_1 - \beta^2 w + \alpha k_1}{2\alpha k_1 - \beta^2} = \frac{(\beta^2 - \alpha k_1)(c - w)}{2\alpha k_1 - \beta^2} > 0$, $e_1^* - e_1^f = \frac{\beta(a - c\alpha)}{2\alpha k_1 - \beta^2} - \frac{\beta(a - w\alpha)}{2\alpha k_1 - \beta^2} = \frac{\beta\alpha(c - w)}{\beta^2 - 2\alpha k_1} > 0$, $h_2^* - h_2^f = \frac{c\gamma k_2 - c\delta^2 - bk_2}{2\gamma k_2 - \delta^2} - \frac{\gamma h_1 k_2 - \delta^2 h_1 - bk_2}{2\gamma k_2 - \delta^2} = \frac{(\delta^2 - \gamma k_2)(c - h_1)}{\delta^2 - 2\gamma k_2} > 0$, $e_2^* - e_2^f = \frac{\delta(c\gamma + b)}{2\gamma k_2 - \delta^2} - \frac{\delta(\gamma h_1 + b)}{2\gamma k_2 - \delta^2} = -\frac{\delta\gamma(c - h_1)}{\delta^2 - 2\gamma k_2} > 0$, $\Pi_T^* - \Pi_T^f = \frac{1}{4}\Pi_T^* > 0$.

Proposition 1 illustrates that the retail price of home appliances, the level of promotional effort of the retailer, the recycling price of the third-party used and end-of-life home appliance recycler, and the level of his recycling effort are all lower than the values at the time of the centralised decision-making, respectively, so that the members in the closed-loop supply chain of home appliances make a higher total profit of the system at the time of the centralised decision-making than at the level of the decentralised decision-making. This is because, when home appliance manufacturers, retailers and third-party recyclers of used and end-of-life home appliance products make decisions in a decentralised manner, each participant may seek to maximise its own profit more often, while ignoring the overall efficiency of the entire supply chain system. In this case, the double marginal effect of the supply chain leads to an uncoordinated system.

4. ARITHMETIC AND NUMERICAL SIMULATION ANALYSIS

4.1. Arithmetic Analysis

From the above analysis, it can be concluded that the decision-making results of the closed-loop supply chain system for home appliances based on promotional effort and recycling effort at centralised and decentralised decision-making are shown in Table 1.

Let $(\beta^2 c - 3\alpha k_1)\alpha + a\beta^2 - \alpha^2 ck_1 = B$,

$(c\delta^2 + 3bk_2)\gamma - b\delta^2 - \gamma^2 ck_2 = J$,

$(\beta^2 - 2\alpha k_1)(\delta^2 - 2\gamma k_2) = S$.

Table 1 Results of Different Decisions

Results of decision-making	Centralised decision-making	Decentralised decision-making
Manufacturer's Optimal Wholesale Prices w	—	$\frac{a + c\alpha}{2\alpha}$
Retailer Optimal Retail Price p	$\frac{c\alpha k_1 - c\beta^2 + ak_1}{2\alpha k_1 - \beta^2}$	$\frac{B}{2\alpha(\beta^2 - 2\alpha k_1)}$
Manufacturer's Optimal Recycling Prices h_1	—	$\frac{c\gamma - b}{2\gamma}$
Optimal Recycling Prices from Third Party Recyclers h_2	$\frac{c\gamma k_2 - c\delta^2 - bk_2}{2\gamma k_2 - \delta^2}$	$\frac{J}{2\gamma(\delta^2 - 2\gamma k_2)}$

Table 2 Results of Different Decisions (continued)

Results of decision-making	Centralised decision-making	Decentralised decision-making
Optimal Promotional Efforts e_1	$\frac{\beta(a - c\alpha)}{2\alpha k_1 - \beta^2}$	$\frac{\beta(a - c\alpha)}{4\alpha k_1 - 2\beta^2}$
Optimal Recycling Efforts e_2	$\frac{\delta(c\gamma + b)}{2\gamma k_2 - \delta^2}$	$\frac{\delta(c\gamma + b)}{4\gamma k_2 - 2\delta^2}$
Manufacturer's Optimal Profit Π_M	—	$\frac{A}{4S}$
Optimal Profitability for Retailers Π_R	—	$\frac{k_1(-c\alpha + a)^2}{16\alpha k_1 - 8\beta^2}$
Optimal Profits for Third-party Recyclers Π_H	—	$\frac{k_2(c\gamma + b)^2}{-8\delta^2 + 16\gamma k_2}$
System Optimum Profit Π_T	$\frac{A}{2S}$	$\frac{3A}{8S}$

Now assume that the relevant parameters are $c=600$, $a=10000$, $\alpha=16$, $\beta=4$, $b=1500$, $\gamma=300$, $\delta=10$, and under this assumption, in order to ensure that $k_1 \in (0,1]$, $k_2 \in (0,1]$ and to satisfy that $p > w > c > h_1 > h_2 > 0$, so that $k_1 \in (0.5,1]$, $k_2 \in (0.34,1]$, and within this range, the Take $k_1=0.6$ and $k_2=0.5$.

Based on the model results and assumed parameters, the following results can be obtained, as shown in Table 3.

Table 3 Decision Values for Different Decisions

Results of decision-making	Centralised decision-making	Decentralised decision-making
Manufacturer's Optimal Wholesale Prices w	—	612.50
Retailer Optimal Retail Price p	675.00	650.00
Manufacturer's Optimal t Recycling Prices h_1	—	297.50
Optimal Recycling Prices from Third Party Recyclers h_2	146.25	70.63
Optimal Promotional Efforts e_1	500.00	250.00
Optimal Recycling Efforts e_2	9075.00	4537.50
Manufacturer's Optimal Profit Π_M	—	2.06×10^7
Optimal Profitability for Retailers Π_R	—	3750.00
Optimal Profits for Third-party Recyclers Π_H	—	1.03×10^7
System Optimum Profit Π_T	4.12×10^7	3.09×10^7

Note: Results are retained to two decimal places.

4.2. Numerical Simulation Analysis

Without changing other parameters, in order to further verify the validity of the above conclusions, numerical simulation is used in this section for the analysis.

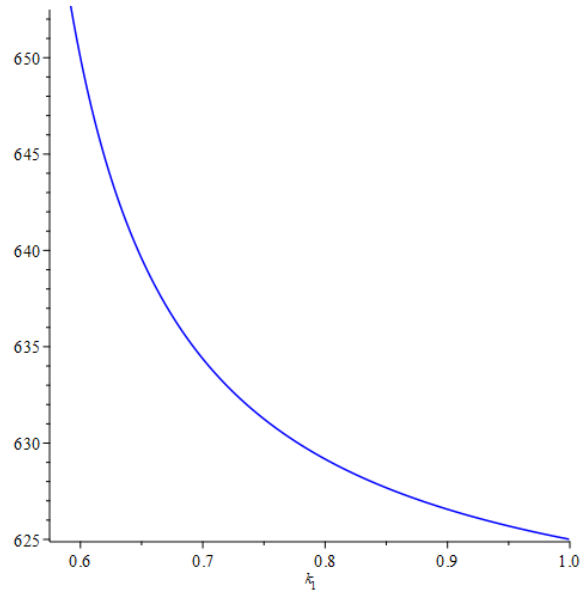


Figure 1 Influence of k_1 on retail price p

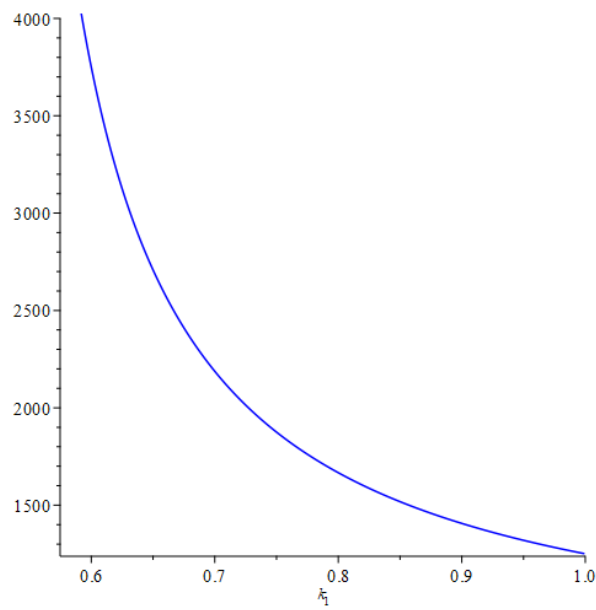


Figure 2 Influence of k_1 on retail profit Π_R

As can be seen in Figures 1 and 2, the higher the retailer's promotional effort, the lower the retail price and the retailer's profit. Within the upside of promotional effort, the decrease in profit affects the retailer's promotional motivation and makes the retailer reluctant to make promotional efforts.

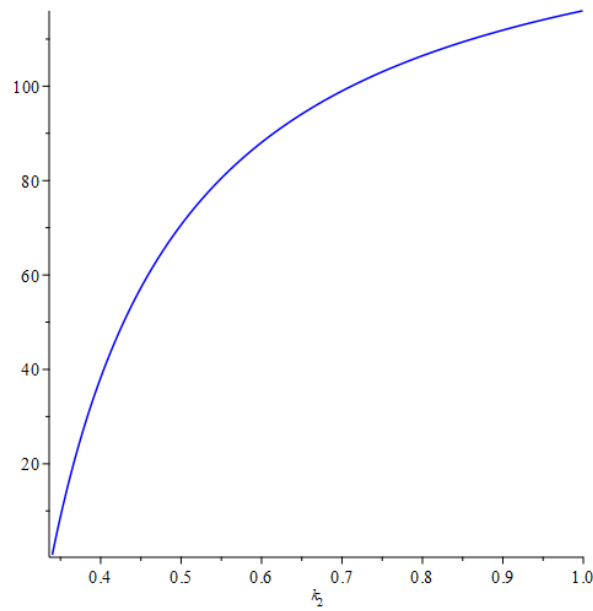


Figure 3 Influence of k_2 on recovery price h_2 of third-party recyclers of used household appliances

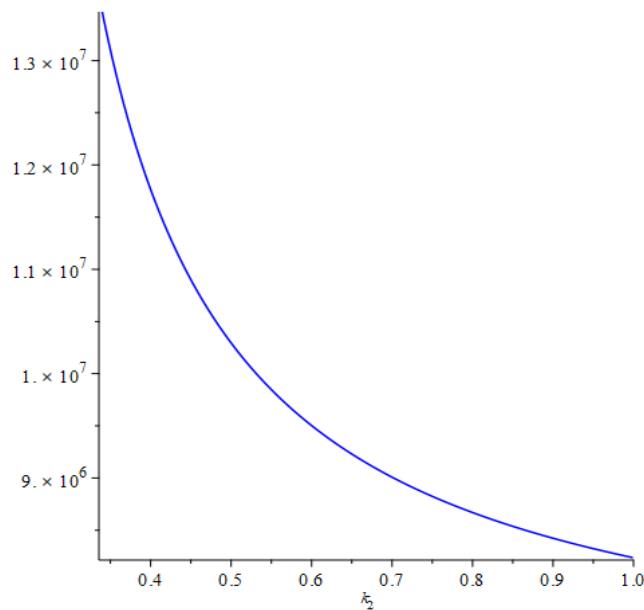


Figure 4 Influence of k_2 on profit Π_R of third party recyclers of used household appliances

As can be seen in Figures 3 and 4, the greater the recycling effort of third-party used household appliance product recyclers, the higher their recycling price increases, i.e., the recycling cost increases subsequently, resulting in a decrease in their profit. Within the rising space of recycling effort, the decrease in profit affects the recycling motivation of the third-party used home appliance recycler, making the third-party used home appliance recycler reluctant to make recycling efforts.

5. SUMMARY

A comparative analysis of the return values of the closed-loop supply chain of home appliances in the centralised and decentralised decision-making states reveals that the retail price of home appliances, the level of promotional effort of the retailer, the recycling price of the third-party used and end-of-life appliances recycler, and the level of his recycling effort in the decentralised decision-

making state are significantly lower than the values in the centralised decision-making state. This is because when home appliance manufacturers, retailers and third-party used and end-of-life appliance recyclers make decentralised decisions, each participant may pursue their own profit maximisation more and ignore the overall efficiency of the whole supply chain system. In this case, the double marginal effect of the supply chain leads to an uncoordinated system.

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