Decentralized Decision-Making Model for Closed-Loop Supply Chain with Remanufacturing Considering Premium & Penalty Mechanism of Government

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Abstract. Taking a typical closed-loop supply chain (CLSC) system which consists of a single supplier and retailer as the research objective, this study intends to find optimal decisions for all companies in CLSC system under premium & penalty mechanism of government working on the reverse logistics enterprises. A decentralized decision model is established based on the game theory, which simultaneously determines the optimal decision of all parties mentioned and shows the influence of premium & penalty mechanism of government on the closed-loop supply chain. The conclusions are as follows: (1) The premium & penalty mechanism of government contributes to increasing retailers' profit; (2) Whether the premium & penalty mechanism of government positively influence the recycling rate of reverse logistics enterprise or not depends on the interaction of premium & penalty coefficient k and recycling fixed cost coefficient C0. (3) If fixed cost recovery coefficient meets certain conditions, the efficiency of the closed-loop supply chain will be improved. So, reducing the recovery cost is essential to promote the efficient of closed-loop supply chain. The results of this paper not only have a practical effect on promoting the efficiency of CLSC with remanufacturing, but also provide a decision-making reference for the government to make recycling and reusing policy of renewable resources.

Keywords: Closed-Loop Supply Chain; Remanufacturing; Premium & Penalty Mechanism; Decentralized Decision-Making Model

1 Introduction

With the shortening of product life cycle and increasing environmental problems caused by the rapid development of industrial system, people pay attention to sustainable development and recycling economy, so as the remanufacturing industries and the related policies. Many countries, including America, Britain and Japan, have developed incentive policies to promote the development of remanufacturing (Thierry et al., 1995)[1]. The WEEE (Waste Electrical and Electronic Equipment) promulgated by the US requires the original equipment manufacturer (OEM) to recycle waste products (Zhao et al., 2004)[2]. China has also formulated rules that electrical product manufacturers must be responsible for the recycling of waste products since 2003. Nowadays more and more enterprises incorporate the closed-loop supply chain into their strategic system in order to survive in the changing policy environment and meet the customers' needs. Thus the design models for closed-loop supply chain with remanufacturing have became a hot research objective.

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Compared to the traditional supply chain, Closed Loop Supply Chain (CLSC) has an additional material flow called reverse feedback process or reverse supply chain (Krikkle et al., 2011)[3]. Forward supply chain is a process of material supply, production, distribution and consumption in the traditional sense. Correspondingly, reverse supply chain includes collection, inspection, separation, reproducing, discarding and re-distribution (Fleischmann, 1997)[4].

The exiting academic researches on CLSC mainly focus on pricing decision-making models (Ferrer and Swaminathan,2006)[5], profit distribution (Shi,2009)[6], incentives mechanism[7] and production plan optimization models (Inderfurth and Teunter,2001)[8], whose aims are to improve the efficiency of CLSC and increase the profits of companies. From the perspective of research method, principal-agent theory and game theory are commonly used in related studies. For example, Ji Guo-jun et al. (Ji and Huang, 2010) consider the constraints of take-back laws and establish decision-making model for remanufacturing supply chain using game theory[9]. Wang Wen-bin et al. (Wang and Da, 2007) formulate a model based on generalized stochastic Petri nets[10]. Savaskan et al. (Savaskan et al., 2004) take several kinds of recycling channels into consideration by analyzing CLSC models with product remanufacturing[11]. With the development of CLSC theory, there is a tendency of employing newsboy model, the non-cooperative game theory and cooperative game theory to solve the problems of joint pricing and profit distribution policy making. As a result, optimization models for CLSC under the conditions of centralized decision-making and decentralized decision-making have gradually emerged (Hou et al., 2004; Ge et al., 2008; Wang et al., 2006; Yao et al., 2003)[12-15]. However, most of these studies consider a two-stage supply chain model consisting of only manufacturers and retailers, while fail to take reverse logistics enterprise as a third party in supply chain operation and decision-making.

In recent years, the worldwide implement of recycling regulations have attracted scholars' attention on the influence of premium & penalty mechanism of government. The premium & penalty mechanism of government is an important function of government to standardize the market order and promote healthy economic development. The premium & penalty mechanism of government is that the company will be punished if it fails to meet the government's requirements; conversely, it will get corresponding reward from the government. Wang Wenbin discusses the decision-making results and its application scope in centralized and decentralized closed-loop supply chains involving the premium and penalty mechanism based on recycling rate and recycling quantity (Wang and Da,2011)[16]; Xiong ZhongJie compares three closed-loop remanufacturing-based supply chain models under government reimbursement policies: products recycled by manufacturers, retailers, and the third party (Xiong and Huang,2011)[17]; Nie Jiajia studies the decision of pricing and recycling in manufactured take-back closed-loop supply chain with premium & penalty mechanism (Nie et al., 2011)[18]. However, the existing studies only discuss such kind of government incentive mechanisms that acting on the supplier or retailer, while ignore the possibility that it may act on other node companies. Wang Wenbin proves that government incentive mechanisms show better effect on recyclers compared to the manufacturer incentive mechanisms in the CLSC consisting of one manufacturer and one recycler. The conclusion mentioned above provides a reliable academic basis for exploring the role of premium & penalty mechanism of government working on reverse companies and lays theoretical foundation for our study.

Set in the research background of closed-loop supply chain with remanufacturing consisting of single supplier, single retailer and one reverse logistics enterprise, this paper assumes that premium & penalty mechanism of government is acting on reverse logistics enterprise recycling, and discusses the optimal decisions for all companies in the supply chain and the influence of premium & penalty mechanism on the efficiency and coordination of CLSC. Considering the real decision-making situation, we establish a decentralized decision-making model for CLSC based on game theory. The differences between this paper and other related researches are listed as follows: (1) As to research objective, concerning reverse logistics enterprise as a third-party during the operation in CLSC, the influence of the government's premium & penalty mechanism acting on a third-party recycler is discussed; (2) As to research methods, mathematical modeling method of non-cooperative game is employed to establish a closed-loop supply chain model; (3) As to research content, under the background of recovery and remanufacturing as well as a premium & penalty mechanism on the reverse logistics enterprise, the optimal decision strategy of all subjects is analyzed. And we are devoted to discuss the influence of premium & penalty mechanism of government for the closed-loop supply chain. The results of this paper not only have a practical effect on promoting the efficiency of CLSC with remanufacturing, but also provide a decision-making reference for the government to make recycling and reusing policy of renewable resources.

This paper is organized as follows: Section 2 is devoted to the problem description, research assumptions, parameter setting and decision-making model formulation. And in section 3, the model is further analyzed and discussed. Meanwhile, 4 conclusions are obtained. Section 4 is an example to test the above conclusions. Finally, the conclusion and prospect are made in section 5.

2 Model Formulation of CLSC with Remanufacturing

2.1 Problem Description

Considering a closed-loop supply chain consisting of one manufacturer, one retailer and one reverse logistics enterprise, the government leads the recycling behavior of reverse logistics enterprise by using premium & penalty method, as shown in figure 1 (parameter setting see 2.3). Manufacturer, retailer and reverse logistics enterprise are all independent decision makers, who make decisions to realize their own profit maximization .In order to encourage the recycling and remanufacturing of waste products, similar to [18], we assume that government needs to take appropriate premium & penalty measures according to the recycling condition of reverse logistics enterprise: the government sets the minimum of waste products recycling rate, and the reverse logistics enterprise will be punished if it fails to meet that level; conversely, the reverse logistics enterprise will get corresponding reward from the government if its recycling rate is above it.

This decision-making model aims to determine the following issues: (1) under the premium & penalty mechanism of government, what are the optimal decisions for manufacturer, retailer and reverse logistics enterprise; (2) under the premium & penalty mechanism of government, how is the profitability of manufacturer, retailer and reverse logistics enterprise; (3) how are the government incentive efforts influence the optimal decision and the profitability of all subjects.

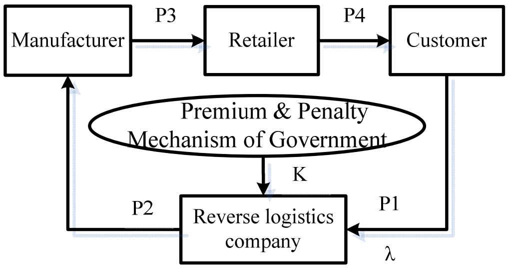

Fig.1 CLSC with Premium & Penalty Mechanism of Government

2.2 Research Assumptions

In order to establish the CLSC decision-making model, it is necessary to limit the scope of this paper by making the following four assumptions:

Assumption 1 (H1): Manufacturer manufactures only one kind of product. It can produce and remanufacture with raw materials as well as recycling product with the same production cost.

Assumption 2 (H2): Remanufactured products and new products have no functional differences, thus sharing the same market demand.

Assumption 3 (H3): As a third-party recycler, reverse logistics enterprise is responsible only for recycling waste products. All products recycled by reverse logistics enterprise can be used in remanufacturing activities.

Hypothesis 4 (H4): Manufacturer is the leader of the market and in a dominant position of supply chain. In the first stage, the manufacturer makes its decision which will influence the decision of both retailer and reverse logistics enterprise.

2.3 Notation

To develop the decentralized decision-making model, the following notations are used throughout the paper. Additional notations will be given out when required:

P_1: Unit price of waste product paid to customers when reverse logistics enterprise recycling;

P_2: Unit price of waste product which the reverse logistics enterprise selling to the manufacturer;

P_3: Wholesale price of unit product set by the manufacturer which is a decision variable;

P_4: Retail price of unit product set by the retailer which is a decision variable;

C_1: Unit cost of new material when manufacturer remanufactures product;

C_2: Unit cost for reverse logistics enterprise to recycle waste product;

C_3: Manufacturing cost of making unit product;

λ: Waste products recycling rate of the reverse logistics enterprise, which can be regarded as recycling effort coefficient and it is a decision variable;

C_0: Cost coefficient of the reverse logistics enterprise recycling waste product, see reference

[1], assuming it costs $C_0 \lambda^2$ for reverse logistics enterprise to recycle waste product and $C_0 > 0$;

λ_0: Minimum recycling rate set by the government;

k: Level of premium and penalty the government implements to reverse logistics enterprise, where k>0 means having premium and penalty measures, otherwise, k=0;

Q: Market demand, $Q=a-bP_4$. a>0, b>0, a represents market capacity, b represents consumers' sensitive coefficient to price;

W:Recycling quantity of waste products, $W=\lambda*Q=\lambda(a-bP_4)$;

Δ: Cost savings when remanufacturing by recycled products instead of totally new materials, $\Delta=C_1-P_2>0$.

2.4 Decision-making Model Considering Premium & Penalty Mechanism of Government

In decentralized decision-making model of closed-loop supply chain with premium & penalty mechanism, as independent decision makers, manufacturer, retailer and reverse logistics enterprise aim at maximizing their own profit. They conduct a two-stage dynamic game of complete information. As the leading party, manufacturer has first-mover advantage. Therefore, in the first stage, manufacturer provides wholesale price P_3 for retailer, realizing its own profit maximization, namely manufacturer equilibrium; in the second stage, according to H4, retailer determines its own retail price P_4 according to the manufacturer's wholesale price P_3; At the same time, reverse logistics enterprise determines recycling rate λ according to manufacturer's decision in order to realize profit maximization of retailer and reverse logistics enterprise, namely retailer equilibrium and reverse logistics enterprise equilibrium.

The purpose of premium & penalty mechanism of government is to improve the efficiency of closed-loop supply chain by encouraging reverse logistics enterprises to improve recycling rate of waste products, so as to promote the development of recycle remanufacture industry. k (k > 0) is the premium & penalty level setting by government. According to the assumptions above, government takes corresponding punishment or incentive measures on reverse logistics enterprise for not achieving or exceeding the lowest recycling rate λ_0 by k. In this case, the profit functions of retailer, reverse logistics enterprise and manufacturer are shown in the formula (1) (2) (3), where $k \geq 0$.

Based on the problem description and parametric hypothesis above, profit functions of each supply chain subject are given as follows:

Profit function of retailer:

$$\pi_r = (p_4 - p_3)Q = (p_4 - p_3)(a - bp_4) \tag{1}$$

Profit function of reverse logistics enterprise:

$$\pi_{re} = (p_2 - p_1 - c_2)(a - bp_4)\lambda - C_0\lambda^2 + k(\lambda - \lambda_0) \tag{2}$$

Profit function of manufacturer:

$$\pi_m = (p_3 - c_1 - c_3)Q + \Delta w = (a - bp_4)(p_3 - c_1 - c_3 + \Delta\lambda) \tag{3}$$

The optimal wholesale price p_3^*, retail price p_4^* and recycling rate λ^* can be obtained through reverse induction:

Take first partial derivative of λ and P_4 in the formula (1)、(2):

$$\begin{cases} \dfrac{d\pi_r}{dp_4}=0 \\ \dfrac{d\pi_{re}}{d\lambda}=0 \end{cases}$$, we can get:

$$\begin{cases} p_4=\dfrac{a+bp_3}{2b} \\ \lambda=\dfrac{(p_2-p_1-C_2)(a-bp_3)+2k}{4C_0} \end{cases} \tag{4}$$

Put formula (4) into (3), we can get:

$$\pi_m=\frac{a-bp_3}{2}\cdot[p_3-c_1-c_3+\Delta\cdot\frac{(p_2-p_1-c_2)(a-bp_3)+2k}{4C_0}] \tag{5}$$

Take first partial derivative of P_3 in the formula (5), we can get p_3^*:

$$p_3^*=\frac{2C_0(a+bc_1+bc_3)-ab\Delta(p_2-p_1-c_2)-kb\Delta}{b[4C_0-b(p_2-p_1-c_2)\Delta]} \tag{6}$$

Put formula (6) into (4), p_4^* and λ^* can be calculated:

$$p_4^*=\frac{2C_0(3a+bc_1+bc_3)-2ab\Delta(p_2-p_1-c_2)-kb\Delta}{2b[4C_0-b(p_2-p_1-c_2)\Delta]} \tag{7}$$

$$\lambda^*=\frac{(p_2-p_1-c_2)[2C_0(a-bc_1-bc_3)+kb\Delta]}{4C_0[4C_0-b(p_2-p_1-c_2)\Delta]}+\frac{k}{2C_0} \tag{8}$$

Put formula (6)、(7)、(8)into (1)、(2)、(3) ,we can get the optimal profit of retailer π_r^*, reverse logistics enterprise π_{re}^* and manufacturer π_m^* with premium & penalty mechanism.

$$\pi_r^*=\frac{[2C_0(a-bc_1-bc_3)+kb\Delta]^2}{4b[4C_0-b(p_2-p_1-c_2)\Delta]^2} \tag{9}$$

$$\pi_{re}^*=(p_2-p_1-c_2)\frac{2C_0(a-bc_1-bc_3)+kb\Delta}{2[4C_0-b(p_2-p_1-c_2)\Delta]}\left\{\frac{(p_2-p_1-c_2)[2C_0(a-bc_1-bc_3)+kb\Delta]}{4C_0[4C_0-b(p_2-p_1-c_2)\Delta]}+\frac{k}{2C_0}\right\}-$$
$$C_0\left\{\frac{(p_2-p_1-c_2)[2C_0(a-bc_1-bc_3)+kb\Delta]}{4C_0[4C_0-b(p_2-p_1-c_2)\Delta]}+\frac{k}{2C_0}\right\}^2+k\left\{\frac{(p_2-p_1-c_2)[2C_0(a-bc_1-bc_3)+kb\Delta]}{4C_0[4C_0-b(p_2-p_1-c_2)\Delta]}+\frac{k}{2C_0}-\lambda_0\right\} \tag{10}$$

$$\pi_m^*=\left\{\frac{(a-bc_1-bc_3)[2C_0-b\Delta(p_2-p_1-c_2)]-kb\Delta}{b[4C_0-b(p_2-p_1-c_2)\Delta]}+\Delta\left[\frac{(p_2-p_1-c_2)[2C_0(a-bc_1-bc_3)+kb\Delta]}{4C_0[4C_0-b(p_2-p_1-c_2)\Delta]}+\frac{k}{2C_0}\right]\right\}\bullet$$
$$\frac{kb\Delta+2C_0(a-bc_1-bc_3)}{2[4C_0-b(p_2-p_1-c_2)\Delta]} \tag{11}$$

To make the solution more practically significant, let $0\le\lambda^*\le1$, that is,

$$0 \le \frac{(p_2 - p_1 - c_2)[2C_0(a - bc_1 - bc_3) + kb\Delta]}{4C_0[4C_0 - b(p_2 - p_1 - c_2)\Delta]} + \frac{k}{2C_0} \le 1 \cdot \tag{12}$$

3 Discussion

Let $A = C_0(a - bc_1 - bc_3)$, $B = 4C_0 - b(p_2 - p_1 - c_2)\Delta$,

So the profit function of retailer is $\pi_r^* = \frac{[2A + kb\Delta]^2}{4bB^2}$ (13)

And the recycling rate of reverse logistics enterprise is

$$\lambda^* = \frac{2A(p_2 - p_1 - c_2)}{4C_0B} + k\left[\frac{b(p_2 - p_1 - c_2)\Delta}{4C_0B} + \frac{1}{2C_0}\right] \tag{14}$$

Take derivative of k in formula (13) and we can get:

Result 1: $\frac{d\pi_r^*}{dk} > 0$.

Take derivative of k in formula (14): $\frac{d\lambda^*}{dk} = \frac{1}{B} + \frac{1}{4C_0}$ (15)

From formula (15), we can obtain the result as follows:

Result2: when $0 < C_0 < \frac{b\Delta(p_2 - p_1 - c_2)}{8}$ or $C_0 > \frac{b\Delta(p_2 - p_1 - c_2)}{4}$, $\frac{d\lambda^*}{dk} > 0$;and when $\frac{b\Delta(p_2 - p_1 - c_2)}{8} \le C_0 \le \frac{b\Delta(p_2 - p_1 - c_2)}{4}$, $\frac{d\lambda^*}{dk} < 0$.

Likewise, Take derivative of k in formula (6) 、(7): we can also get the result as follows:

Result3: when $0 < C_0 \le \frac{b\Delta(p_2 - p_1 - c_2)}{4}$, $\frac{dp_3^*}{dk} > 0$, $\frac{dp_4^*}{dk} > 0$,and when $C_0 > \frac{b\Delta(p_2 - p_1 - c_2)}{4}$, $\frac{dp_3^*}{dk} < 0$, $\frac{dp_4^*}{dk} < 0$.

Integrate Result 2 and Result 3, Result 4 can be obtained:

Result4: when $C_0 > \frac{b\Delta(p_2 - p_1 - c_2)}{4}$, $\frac{d\lambda^*}{dk} > 0$, $\frac{dp_3^*}{dk} < 0$, $\frac{dp_4^*}{dk} < 0$, and when $\frac{b\Delta(p_2 - p_1 - c_2)}{8} \le C_0 \le \frac{b\Delta(p_2 - p_1 - c_2)}{4}$, $\frac{d\lambda^*}{dk} < 0$, $\frac{dp_3^*}{dk} > 0$, $\frac{dp_4^*}{dk} > 0$.

According to the above Result 1-4, conclusion1-4 can be drawn as follows correspondingly.

Conclusion 1: Manufacturer's optimal profit π_r^* increases with k.

Conclusion 1 shows that: in the decentralized decision-making model of closed-loop supply chain under premium & penalty mechanism, it will bring about greater profits to the retailer if the government increases k, which will encourage the retailer to participate in the manufacturing supply chain actively.

Conclusion 2: when $0 < C_0 < \frac{b\Delta(p_2 - p_1 - c_2)}{8}$ or $C_0 > \frac{b\Delta(p_2 - p_1 - c_2)}{4}$, λ^* increases with k; conversely, when $\frac{b\Delta(p_2 - p_1 - c_2)}{8} \le C_0 \le \frac{b\Delta(p_2 - p_1 - c_2)}{4}$, λ^* decreases with k.

Conclusion 2 shows that: the recycling rate λ^* does not increase with government premium & penalty coefficient k strictly; it also relates to recycling cost coefficient C_0. So, although the government tries to encourage reverse logistics enterprises to improve their recycling rate by using premium &penalty mechanics, at the same time, for the influence of C_o, reverse logistics enterprises need to integrate the government premium &penalty power and their own fixed cost value to determine the recycling rate λ^* , in order to realize their profit maximization.

Conclusion 3: when $0 < C_0 \le \frac{b\Delta(p_2 - p_1 - c_2)}{4}$, wholesale price p_3^* and retail price p_4^* increase with k; when $C_0 > \frac{b\Delta(p_2 - p_1 - c_2)}{4}$, wholesale price p_3^* and retail price p_4^* decrease with k.

From conclusion 3, we can see wholesale price p_3^* and retail price p_4^* do not have a strict increasing or decreasing relationship with k. C_0 and k make a joint decision of p_3^* and p_4^*.

Conclusion 4: when $C_0 > \frac{b\Delta(p_2 - p_1 - c_2)}{4}$, the recycling rate λ^* increases with k, and wholesale price p_3^* and retail price p_4^* decrease with k. It shows that in order to realize their own profit maximization, reverse logistics enterprise sets higher recycling rate with the increase of k; manufacturer saves the cost of new material cost, which reduces the wholesale price; and retailer reduces the retail price to expand sales in the meantime. Thus, the efficiency of the whole supply chain is improved.

Likewise, when $\frac{b\Delta(p_2 - p_1 - c_2)}{8} \le C_0 \le \frac{b\Delta(p_2 - p_1 - c_2)}{4}$, the recycling rate λ^* decreases with k, and wholesale price p_3^* and retail price p_4^* increases with k. So, with the increase of k, the way of all parties to make profit is: the reverse logistics enterprise reduces its recycling rate and the manufacturer and retailer improves their wholesale price and retail price.

4 Example

In this section, we use a numerical example to demonstrate the conclusions mentioned above and further analyze the influence of the level of premium and penalty that government implements to reverse logistics enterprise (k) as well as the cost coefficient of recycling (C_0) on wholesale price, retail price and profits. To make the example practically meaningful, let a=300, b=5, P_1=10, P_2=20, C_1=25, C_2=5, C_3=5, C_0=400, λ_0=0.1, Δ= C_1-P_2=5. In order to meet the requirement of equation (12), k has the following range: 0<k<975.4. By using Matlab, we manage to draw three-dimensional function images (see figure 2-7) in which k and C_0 are supposed to be the independent variables as p_3^* , p_4^* , π_r^* , π_{re}^* , π_m^* , λ^* to the dependent variables. In figure 7,the range of λ^* should be [0,1].

(1) From figure2 and 3, it is obvious that when C_0 is fixed, p_3^* and p_4^* will decrease as k increases. This result shows that premium & penalty policies for government acting on reverse logistics enterprise have a positive effect on wholesale price and retail price. When government put more efforts to reward and punish reverse logistics enterprise, the wholesale price and retail price will become lower.

(2) From figure 4, 5 and 6, we can summarize the following conclusions: ①when C_0 is fixed, π_r^*, π_{re}^* and π_m^* will increase as k increases. This result shows that every party in the CLSC gains profit increases from a high level of premium and penalty. ②The profit of reverse logistics enterprise is the most sensitive to changes of k, followed by the manufacturer and eventually the retailer. This result shows that the premium and penalty mechanism acting on reverse logistics enterprise can greatly stimulate its profit growth.

(3) From figure 7, we can find that when C_0 is fixed, λ^* will increase as k increases. This result shows that higher recycling rate has a positive effect on the willingness of reverse logistics enterprise to recycle more used products, which played an important role in coordinating the whole supply chain.

(4) Integrate figure 2-7, we can find a common feature: the sensitivity of p_3^* , p_4^* , π_r^* , π_{re}^* , π_m^* , λ^* for k began to decrease with the increase of the recovery cost coefficient C_0 . Because over-high recovery cost coefficient means high cost the reverse logistics enterprise should pay in order to increase the recovery rate λ^*. Consequently, the premium & penalty mechanism of government k cannot compensate for its loss which causes the decrease of λ^*, thus affect the decision of every party in the supply chain and their realization of profit.

In summary, the premium & penalty mechanism of government k will play a positive role in p_3^* , p_4^* , π_r^* , π_{re}^* , π_m^* , λ^* when the recovery cost coefficient is in a certain scope. And increasing k will benefit to the profit increase of every party in the supply chain as well as the efficient of the supply chain. Meanwhile, over-high recovery cost coefficient will make the role of k less and less, even do harm to the efficient of the supply chain. So reducing the recovery cost is essential to promote the efficient of closed-loop supply chain.

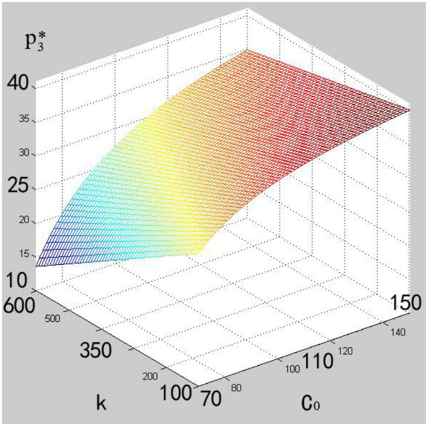

Fig.2 Function Image for p_3^*

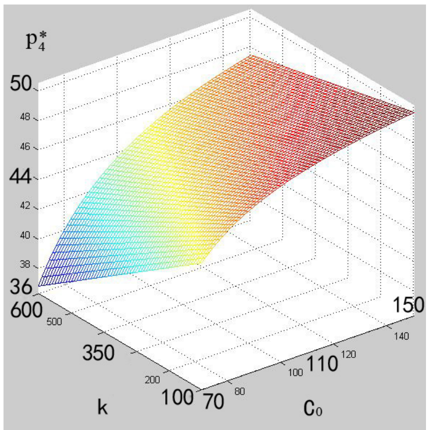

Fig.3 Function Image for p_4^*

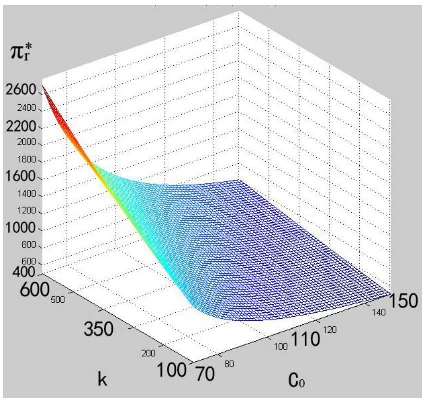

Fig.4 Function Image for π_r^*

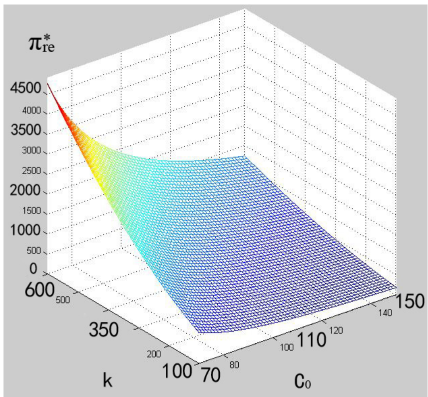

Fig.5 Function Image for π_{re}^*

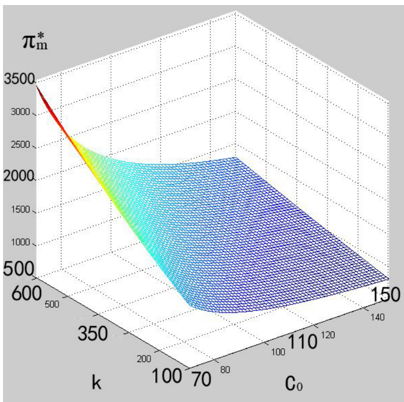

Fig.6 Function Image for π_m^*

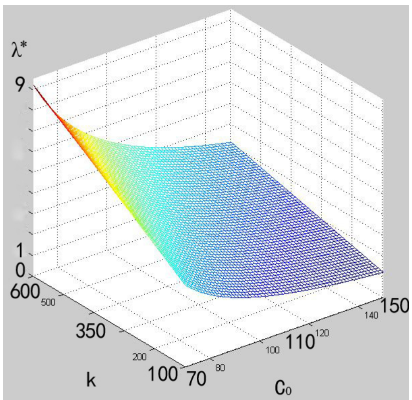

Fig.7 Function Image for λ^*

5 Research Conclusion and Prospect

Considering the premium & penalty mechanism that acts on the third party recovery enterprise, this paper establishes closed-loop supply chain with remanufacturing model based on game theory .Then the profits and optimal decisions of supply chain system and each party in the decentralized decision making condition are obtained. On this basis, we devote to analyzing the influence of premium & penalty mechanism of government for the closed-loop supply chain. Then, we draw these conclusions: (1) The premium & penalty mechanism of government contributes to increasing retailers' profit; (2) Whether the premium & penalty mechanism of government positively influence the recycling rate of reverse logistics enterprise or not depends on the interaction of premium & penalty coefficient k and recycling fixed cost coefficient C_0. (3)As the example in section 4 shows:① if fixed cost recovery coefficient meets certain conditions, higher premium & penalty mechanism of government will increase the recycling rate of reverse logistics enterprise and the profit of each part in the supply chain, and at the same time, it will reduce the wholesale price of manufacturer and the retail price of retailer, thus the efficiency of the closed-loop supply chain will be improved.② Reducing the recovery cost is essential to promote the efficient of closed-loop supply chain.

The result in this paper reveals the operation mechanism of closed-loop supply chain with premium & penalty of the government, which have certain instructive significance for enhancing efficiency of closed-loop supply chain with remanufacturing, as well as providing decision-making references for the government to make policy about the recycle of renewable resources.

In afterward research ,we will further discuss some factors not mentioned in this paper and some deficiencies: for example， the demand function in this paper is based on the assumption that market demand conforms to the linearity ; the closed-loop supply chain model includes only one single manufacturer, one single retailer and one reverse logistic s enterprise; the government doesn't take its own cost and profit target into consideration when it promotes supply chain efficiency by boosting the recycling rate of used products through premium & penalty mechanism. So, the introduction of demand function which is more in line with the actual distribution, the consideration of more participants in supply chain and profit function involving the benefit of government will be served as further research directions.

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