Price Decision Analysis of Closed-Loop Supply Chain under third-party Recyclers’ Competition

Kai Cao, Jie Lin

1, Kai Cao  School of Economics and Management, TongJi University, Shanghai, 200092, China, s1120040443@126.com
2, Jie Lin School of Economics and Management, TongJi University, Shanghai, 200092, China, jielinfd@163.com

Abstract

A closed-loop supply chain recovery model with single manufacturer, single retailer and two competitive third-party recyclers is established with the application of game theory. This paper focuses on analyzing the optimal pricing decisions and profits of all the enterprises members in the decentralized structure. Through the analysis of model, the result shows that the manufacturer’s transfer price and profits, returned products quantity, third-party recyclers’ collect price and profits and the whole profits increase greatly when there exist two third-party recyclers’ market competition. Finally, we cite a special numerical example to verify the results and provide some useful suggestions for manufacturer, retailer and third-party recyclers in order to improve their profits and performance.

Keywords: Closed-Loop Supply Chain, Price Decision, Game Theory

1. Introduction

As a new style of management, closed-loop supply chain management has caused more attention both in industry and academia with the trend of sustainable development. The definition of closed-loop supply chain varies from person to person. Guide defined it as the design, control and operation of a system to maximize value creation over the entire life cycle of a product with dynamic recovery of value from different types and volumes of returns over time [1]. Krikke considered that the main goal of closed-loop supply chain management is to collect used products from consumers and recover the remaining values of returned products by recycling, reusing or remanufacturing activities [2]. He Chao claimed that closed-loop supply chain is from an open-loop structure to a closed-loop structure [3]. Xu Bing defined closed-loop supply chain was a complete cycle supply chain system while adding negative feedback process on the tradition forward supply chain and it formed the closed-loop feedback cycle including “resources, production, consumption, renewable resources”. The forward supply chain was the traditional process which contained raw material supply, production, distribution and consumption [4]. However, Fleischmann pointed out the reverse supply chain included the collection, inspecting, separation, reprocessing, disposal and distribution [5]. That’s why closed-loop supply chain management is so important on the practical aspects for manufacturers, retailers, consumers and recyclers.

Recently more and more scholars have done some researches on the channels selection for the enterprises members and pricing decisions in the closed-loop supply chain. Savaskan focused on the issue on choosing the best reverse channel for collecting the used products from consumers, They summarized three options for collecting used products from consumers while manufacturer is game leader. For manufacturer, one option is to collect used products directly from consumers; second one is to provide suitable incentives to retailer who is responsible for the collection; third one is to subcontracted third party for the collection activity. They developed a detailed comprehension on the implications of manufacturer’s reverse channel choice on forward channel decisions and the used-product return rate from consumers. Then they established a two-echelon supply chain model including single manufacturer and single retailer in order to investigate how reverse channel choice affected the forward channel decisions and the used-product return rates. They provided a good understanding on the implications of different closed-loop supply chain structures on incentives to invest in used-product collection and on supply chain profits. They presented three decentralized supply chain models with remanufacturing, Model M figure 1b. Model R figure 1c and Model 3P figure 1d and compared the
models with respect to the wholesale price, the retail price, the product return rate and the total supply chain profits.

Finally, they got the optimal price decisions for enterprises members in such three closed-loop supply chain models and compared decentralized supply chain models with remanufacturing. They concluded that the most effective undertaker of product collection activity is the agent who is closer to consumers (i.e., retailer) [6]. Kenne, J.P etc dealt with the production planning and control of a single product involving combined manufacturing and remanufacturing operations within a closed-loop reverse logistics network with machines subject to random failures and repairs [7]. Basiri etc extended and enhanced previous models that were proposed for closed loop supply chains using linear programming and minimized the leakage of a closed loop supply chain to avoid waste and reduce SCM costs[8].Vlachos etc tackled the development of efficient capacity planning policies for remanufacturing facilities in reverse supply chains, taking into account not only economic but also environmental issues, such as the take-back obligation imposed by legislation and the "green image" effect on customer demand. The behavior of the generic system under study is analyzed through a simulation model based on the principles of the system dynamics methodology [9]. However, there is shortage in the research assumptions. Most of above model hypothesizes of closed-loop supply chain are based on the assumption that either manufacturer or retailer collects the used products without considering possibility that third party takes the collecting activity.

There is a growing number of academic papers on the pricing decisions and coordination mechanism of three-stage closed-loop supply chain based on the game theory. Zhao Xiao-fang studied issues on the optimal pricing decisions and profits of the enterprises members under decentralized structure. They developed the models of a closed-loop supply chain including single manufacturer, single retailer and single third party by game theory when third party is responsible for collecting the used products. Zhao Xiao-fang developed the decentralized model of closed-loop supply chain in figure 2.

**Figure 1.** Supply Chain Models with Remanufacturing [6]

**Figure 2.** Decentralized model of closed-loop supply chain [10]
In such model, manufacturer is game leader and sells products to retailer with the wholesale price $w$. Then retailer determines the retail price $p$ and sells products to consumers with $p$. After products go to end, third party collects the used products from consumers with the collect price $r$. Finally, manufacturer paid third party the transfer price $b$ to buy the returned products for remanufacturing. They got the optimal prices and profits of manufacturer, retailer and third party with the application of game theory. Comparing with the traditional supply chain system they made the following conclusions: (1) the retail price and wholesale price in closed-loop supply chain are lower than in traditional supply chain. (2) The profits of manufacturer, retailer, third party and the whole system grow rapidly. (3) The decrease of the remanufacturing cost causes low retail price and wholesale price, high profits of members in closed-loop supply chain. Finally, they cited a specific example to verify the results [10]. Gong Yande discussed the pricing strategies both in the centralization structure and decentralization structure by game theory in the three-stage closed-loop supply chain with one manufacture, one retailer and third-party logistics service provider [11]. Yi Yu-yin etc supposed that the closed-loop supply chain consisted of two manufacturers and one common retailer with product remanufacturing were modeled by using game theory [12]. Ferguson analyzed the coordination mechanism of the error recycling of returned products in the closed-loop supply chain. The above literatures show that the three-stage closed-loop supply chain by introducing third-party recyclers was formed and got the pricing decisions and coordination mechanism [13]. But they regarded the closed-loop supply chain with only one member in each layer and did not consider the competition in the same layer.

Recent researches lay emphasis on the competition between members of the same layer in the closed-loop supply chain. He Chao addressed the problem of recycling business competition between two retailers in the closed-loop supply chain recovery model which is based on competitive recovery business. They introduced the competition in the same level of closed-loop supply chain and thought that many factors may influence returned products quantities which cannot be a fixed proportion of new product sales volume. In such recovery model, they supposed a closed-loop supply chain contains a producer and two retailers. Retailers are responsible for collecting EOL products from customers. They got the optimal return prices and retail price both in scattered and centralized decision-making structure and found that the return price and quantity in centralized structure is higher than in scattered structure, but total profit is lower. By analyzing the model, they raised some measures to promote the enterprises’ enthusiasm to recycle EOL products. (1) Government supports return enterprises for their technical improvement and investment of reducing return cost. (2) Set up a contract to encourage return joint to increase social welfare and decrease return cost. (3) The leader of closed-loop supply chain could give some subsidies to return enterprises in order to reduce return cost and increase return price. (4) Increase consumer environmental consciousness and return quantity [3]. Xu Bing analyzed multiple Stackelberg game and joint decision making for the supply chain with single manufacturer and multiple competing retailers when manufacturer is responsible for recycling the discarded products [4]. Gao Wenjun studied the problem of pricing decision and coordination in the supply chain by one manufacture and two competing retailers [14]. Chang Xiang-yun considered a closed-loop supply chain in which a manufacturer sells to a retailer, the retailer sells the products to customers and recollects the used products from customers. Based on the model, the price decisions such as optimal wholesale price, optimal retail price and optimal recollected price between manufacturer and retailer are studied by game theory, a decentralized system and a centralized system are studied. [15]. Although they considered the competition between parties, but only for the two-stage closed-loop supply chain and did not consider the competition between multiple third-party recyclers in the three-stage closed-loop supply chain. Songtao Zhang and Xiaowei Zhao investigated the control problem for a class of dynamic fuzzy discrete switched closed-loop supply chain model with dual-channel, a time-delay and uncertainties of cost parameters, remanufacturing rate, preference rate of the customers to the Internet channel and customers’ demand based on switched cost [16][17]. Xiaoli Li studied the incentive mechanism of the processor and the manufacturer with the Principal-Agent Theory [18].

From the above literatures, we can see that existing researches have not involved the pricing strategies for the three-stage closed-loop supply chain with the competition between two third-party recyclers. Therefore, this paper sets up the competing three-stage closed-loop supply chain including two third-party recyclers on the basis of the above researches and finally presents the optimal pricing strategies of enterprises members under the non-corporation situation. Then manufacturer re-processes the used products and sells to retail by the same wholesale price.
2. Model descriptions

Savaskan raised three forms for the recycling used products in closed-loop supply chain: Manufacture Take-Back; Retailer Take-Back and Third-Party Take-Back [6]. However, whatever recycling form is chosen, the pricing decisions for the used products will still be involved. This paper studies on the pricing strategies for manufacture, retailer and third-party recyclers when two third-party recyclers compete to recycle the returned products.

![Diagram of a three-stage closed-loop supply chain model with a manufacturer, two third-party recyclers, and a retailer interconnected with market consumers.](image)

**Figure 3.** Two third-party competing three-stage closed-loop supply chain model

Fig. 3 describes the supply chain models including single manufacturer, single retailer and two competitive third-party recyclers. In this supply chain system, manufacturer is game leader and sells products to retailer with wholesale price $P_{RM}$. Then retailer determines the retail price $P_{RC}$ and sells to final consumers. At the same time, manufacturer entrusts two recyclers to recycle the old products from consumers by two competitive marketing recycling prices $P_{TC1}$, $P_{TC2}$ and buys all the old ones by $P_{RM}$ from recyclers and remanufacturing into new products which is same as the original products with same market price.

In order to make our research more targeted and scientific, we postulate the following basic assumptions and notations.

**Assumption 1:** manufacture, retailer and recycler are all in complete information roles. That means they are fully aware of costs, pricing strategies etc. However, the two third-party recyclers do not know the market recycling price from each other until the market recycling price is determined.

**Assumption 2:** manufacturer is responsible for manufacturing and remanufacturing products in the closed-loop supply chain. The unit cost for manufacturing new products is $C_{MN}$ and unit cost for remanufacturing products is $C_{MN}$. In order to guarantee manufacturer can earn profits and positively participate in remanufacturing activities we assume $C_{RM} < C_{MN}$ and $\Delta = C_{MN} - C_{RM} > 0$. $\Delta$ is the unit manufacturing cost savings of remanufacturing for manufacturer. At the same time, the two third-party recyclers must determine the market recycling price at the same time. Once the market recycling price is determined, it cannot be modified any more. If the prices given by the two recyclers are same, they will share the market evenly. This paper only discusses the single cycle in closed-loop supply chain. There already exist old products in the market before manufacturer begins remanufacturing activities and the old ones can be recycled and used for manufacturing products. The process is continuous.

**Assumption 3:** the two third-party recyclers just compete by giving the market recycling price and there is no formal or informal collusive behavior between the two third-party recyclers.

**Assumption 4:** demands of product in market are $Q_{md} = D - k P_{Cl}$ under the price $P_{Cl}$, $D$ means the max product demand. At the same time, the quantity of old products for third-party recycler1 is $Q_{T1} = a_0 + a_1 (P_{TC1} - P_{Cl}) + a_2 (P_{TC2} - P_{Cl})$. The quantity of old products for third-party recycler2 is $Q_{T2} = \begin{cases} a_1 (P_{TC1} - P_{Cl}), & P_{TC1} > P_{TC2} \\ 0, & P_{TC1} \leq P_{TC2} \end{cases}$.
describes the awareness of environment protection and that means consumers are willing to give the old products to recyclers with no pay; \( \alpha_2 \) is the sensitivity coefficient for consumer on the two different market recycling price and it can describe the competition between two third-party recyclers.

When there is only one third-party recycler, the quantity of returned products is \( Q_r = \alpha_4 + \alpha_1 P_r^m \).

Assumption 5: Manufacturer is game leader in the market and it has absolute power to control the market. Retailer and third party are followers.

Here are some other symbols in this paper. \( \pi' \) Means the profits of number \( i \) in the supply chain, \( i \in \{M, R, T_1, T_2\} \) M means manufacturer, R means retailer, \( T_1 \) means third-party1 and \( T_2 \) means third-party2. \( C_i \) is the unit operating cost for retailer, \( C_{i1} \) is the unit operating cost for recycler1 and \( C_{i2} \) is the unit operating cost for recycler2.

### 3. Model solutions

In this session, the paper mainly adapts the decentralized strategies to make decisions and get the optimal pricing decisions and profits in the supply chain.

The revenues of manufacturer come from two parts: (1) revenues from selling product to retailer; (2) savings from remanufacturing activities. The costs of manufacturer come from the payment for recycling recyclers.

Therefore, the profits of manufacturer are

\[
\pi_{M} = (P_r^M - C_{i1}^M)Q_d + (\Delta - P_r^M)(Q_{T_1} + Q_{T_2}) \tag{1}
\]

The revenues of retailer come from revenues selling products to consumers. The costs come from costs paying to manufacturer, operating and payment for consumers.

Therefore, the profits of retailer are

\[
\pi_{R} = (P_r^R - P_r^M\alpha_1 - C_r^R)Q_d \tag{2}
\]

The revenues of third-party recyclers come from recycling old products from consumers. The costs come from payment for consumers.

The profits of third party1 are

\[
\pi_{T_1} = (P_r^{T_1} - P_r^{T_2} - C_{T_1})Q_{T_1} \tag{3}
\]

The profits of third party2 are

\[
\pi_{T_2} = (P_r^{T_2} - P_r^{T_1} - C_{T_2})Q_{T_2} \tag{4}
\]

Since such game is a complete information dynamic game, the equilibrium is sub-game refining Nash equilibrium. Therefore, we can adapt the reverse induction method to establish price decision model.

\[
\max_{P_r^M, P_r^R} \pi_{M} = (P_r^M - C_{i1}^M)Q_d + (\Delta - P_r^M)(Q_{T_1} + Q_{T_2})
\]

\[
st\begin{align*}
P_r^M, P_r^R &\in \max \pi_{M} = (P_r^M - P_r^M\alpha_1 - C_r^R)Q_d \\
P_r^{T_1} &\in \max \pi_{T_1} = (P_r^{T_1} - P_r^{T_2} - C_{T_1})Q_{T_1} \\
P_r^{T_2} &\in \max \pi_{T_2} = (P_r^{T_2} - P_r^{T_1} - C_{T_2})Q_{T_2}
\end{align*}
\]

Proposition 1: in this model, the optimal equilibrium price decisions of manufacturer, retailer and third party under decentralized decision strategy are

\[
P_r^{M^*} &= \frac{D - kC_r + kC_{i1}^R}{2k}, \quad P_r^{R^*} = \frac{3D + kC_r + kC_{i1}^R}{4k} \\
P_r^{T_1^*} &= \frac{\Delta}{2} \left( \frac{4\alpha_1 + 4\alpha_2 - 1}{2\alpha_1(2\alpha_1 + 3\alpha_2)} - \frac{(2\alpha_1 + 2\alpha_2)C_{T_1} - 2\alpha_0 - C_{T_2}}{4\alpha_1 + 6\alpha_2} \right) \\
P_r^{T_2^*} &= \frac{\Delta}{2} \left( \frac{4\alpha_1 + 4\alpha_2 - 1}{2\alpha_1(2\alpha_1 + 3\alpha_2)} - \frac{(2\alpha_1 + 2\alpha_2)C_{T_1} - 2\alpha_0 - C_{T_2}}{4\alpha_1 + 6\alpha_2} \right)
\]
Proposition 2: the higher the marginal operating costs of retailer \( C_r \) will cause the wholesale price \( P_{C_r}^{M^*} \) reduction of manufacture and market price \( P_{C_r}^{S^*} \) increase of retailer.

The reason for proposition 2 is that manufacture takes costs of retailer into consideration to ensure retailer ordered more products when determining the product wholesale price. As the operation costs of retailer increase, manufacture will give a lower product wholesale price. At the same time, the increase of product market price will bring retailer more profits. The increase of raw materials also causes the increase of product wholesale price and product market price. When manufacture’s operating costs increase, it will certainly enhance its wholesale price to ensure its profits. While retailer raises its product market price in order to ensure its own profits. But it is disadvantageous for consumers to offer the increase of costs.

The best pricing strategies for manufacture, retailer and third-party recyclers in the three-stage closed-loop supply chain including one recycler are as follows:

\[
P_{C_r}^{M^*} = \frac{2\Delta \alpha_v + 3\Delta \alpha_1 - \alpha_0}{8\alpha_1 + 8\alpha_2 - 2} \frac{2\alpha_1}{\alpha_0} \quad ; \quad P_{C_r}^{S^*} = \frac{P_{C_r}^{M^*} + P_{C_r}^{S^*} - C_{r_1}}{2}
\]

When comparing the two above best pricing strategies, the conclusion could be easily made that \( P_{C_r}^{M^*} \leq P_{C_r}^{S^*} \).

Because there are two third-party recyclers in the three-stage closed-loop supply chain and they make decisions independently without communication. Therefore, they have to increase the recycling price in order to gain more discarded products.

(1) In order to reduce the recycling price, manufacture can take the following measures.

(2) Improve the process and technology of remanufacturing discarded products and reduce the costs of product remanufacturing.

(3) Establish the modern information system which supports sharing by using the same third-party logistics as the third-party recyclers.

4. Model analysis

4.1 Pricing strategies analysis for manufacture

The best pricing strategies of manufacture without cooperation by solving the above models are as follows:

\[
P_{C_r}^{M^*} = \frac{D - kC_r + kC_{M^*}}{2k} \quad ; \quad P_{C_r}^{S^*} = \frac{3D + kC_r + kC_{S^*}}{4k}
\]

\[
P_{C_r}^{M^*} = \frac{\Delta \alpha_v - \alpha_0 (4\alpha_1 + 4\alpha_2 - 1)}{2\alpha_1 (2\alpha_1 + 3\alpha_2)} \quad ; \quad P_{C_r}^{S^*} = \frac{\Delta \alpha_v + \alpha_0 C_r - \alpha_4}{2\alpha_1}
\]

The best product wholesale price of manufacture \( P_{C_r}^{M^*} \) is positively correlated with product capacity \( D \) and also positively correlated with the difference of the operating costs of the two third-party recyclers. It is negatively correlated with the marginal cost of remanufacturing activities for manufacture \( C_{M^*} \).

4.2 Pricing strategies analysis for retailer

The best pricing strategies for retailer without cooperation by solving the above models are as follows:
The product market price of retailer $R^C_P$ is positively correlated with product capacity $D$ and the marginal cost of production for manufacture $C_{r^n}^M$. It is negatively correlated with the operation costs of retailer $C_{r^n}$. Retailer need take the costs of manufacture into consideration when determining the product market price. The higher production costs increase the product market price. The market demand also need be considered and the increase of market demand increases the product market price. Therefore, retailer can take the following measures in order to gain higher product market price.

1. Establish a unified information platform with manufacture in order to reduce operation costs.
2. Enhance product marketing with manufacture in order to increase the market demand greatly.

4.3 Pricing strategies analysis for third-party recycler

The best pricing strategies of the two third-party recyclers without cooperation by solving the above models are as follows:

\[ P_{C^T}^R = \frac{2\Delta \alpha_1 + 3\Delta \alpha_2 - \alpha_5}{8\alpha_1 + 8\alpha_2 - 2} - \frac{\alpha_5}{2\alpha_1} \]

\[ P_{C^T}^C = \frac{P_{r^n}^M + P_{r^n}^I - C_{r^n}}{2} \]

The market recycling price of third-party recyclers $P_{C^T}^R$, $P_{C^T}^C$ are positively correlated with $P_{r^n}^M$ and its own operating costs. It is negatively correlated with the other recycler’s operating costs. The market recycling price increases of recycler as the recycling price of manufacture increases. The market recycling price increases with the reducing of its own costs and other’s costs. Therefore, the third-party recyclers should take their own recycling costs, the recycling price of manufacture and the consumer sensitive on the product market price into consideration when determining the recycling price. Recyclers can take the following measures to determine the best recycling price.

1. Enhance their environmental awareness campaigns in order to increase environmental awareness of consumers.
2. Establish the information platform in order to the operating costs.
3. Establish more recycling products sites in order to improve the recycling service.

5. Example

As some related statistics show, China’s annual output of recycled aluminum is at least more than one million tons. The recycling for waste cans in China is still in the initial stage. 8 million tons of cans are produced in china annually. Since the materials used in cans are a high-grade aluminum alloy, it has a huge market prospects. The discarded cans can be reprocessed into new cans by adapting advanced technology and equipment and the new reprocessed cans can be sold with wholesale price. The whole process is a closed-loop supply chain. We assume there are one manufacture, one retailer and two third-party recyclers in the cans recycling market for easy simulation. The following assumptions are given according to the definition of model parameters and their relationship.

\[ D = 2000, \quad k = 2, \quad \alpha_0 = 60, \quad \alpha_1 = 10, \quad \alpha_2 = 3, \quad \alpha_3 = 5, \quad \alpha_4 = 100, \quad C_{r^n}^M = 115, \quad C_{r^n}^M = 15, \quad \Delta = 100, \quad C_{r^n} = 5, \quad C_{r^n} = 7, \quad C_{r^n} = 30, \quad C_{r^n} = 6 \]

Comparing three-stage closed-loop supply chain including single third-party recycler [5] with the three-stage closed-loop supply chain including two third-party recyclers, we can get the following conclusions:

\[ P_{r^n}^M = 542.25; \quad P_{C^T}^R = 786.25 \]

\[ P_{r^n}^M = 43, \quad P_{r^n}^T < P_{r^n}^M \]

\[ P_{C^T}^R = 8.5, \quad P_{C^T}^C = 28.05, \quad P_{C^T}^C < P_{r^n}^C, \quad P_{C^T}^C < P_{C^T}^C \]

\[ Q_{r^n} = 427, \quad Q_{C^T} = 142, \quad Q_{r^n} = 244, \quad Q_{r^n} < Q_{r^n} \]
It can be concluded by the example that the product market price of three-stage closed-loop supply chain including two third-party recyclers is higher than in three-stage closed-loop supply chain including single recycler. Actually, that is beneficial for consumers and the game between two third-party recyclers can increase the product market price. Also the recycling of manufacture is higher. Because the increase of product recycling price increases the product market price and third-party recyclers provide higher product recycling market price. Therefore, manufacture has to raise the recycling price in order to ensure that recyclers are profitable. The total expected profits of third-party recyclers and total supply chain system profits are much higher than three-stage closed-loop supply chain for a single third-party recycler. This is because the increase of discarded products recycling market price leads to the large growth of recycling number that means consumers are willing to sell more discarded products to third-party recyclers and it leads to the increase of its profits. However, though the recycling price provided by manufacture is higher, the growth of recycling number increased its profits. The increase profits of third-party recyclers leads to the increase of total system profits. Therefore, it is necessary to introduce the market competition between recyclers in order to improve system overall decision-making efficiency and profits.
6. Conclusions

This paper presents a competitive three-stage closed-loop supply chain model including two third-party recyclers and the model introduced a market game competition between the two third-party recyclers. The optimal pricing decisions expression of retailer, manufacture and third-party recycler was given by the use of game theory. This paper analyzed and compared the competitive three-stage closed-loop supply chain model which contains two third-party recyclers with the three-stage closed-loop supply chain model which contains single third-party recycler and presented the optimal pricing strategies, every party’s profit and the overall system profits. The results show that manufacture’s recycling prices, third-party recycler’s market recycling price, the recycling number, manufacture’s profits, third-party recycler’s profits and the total system profits in the competitive three-stage closed-loop supply chain including two third-party recyclers were increasingly higher than in the three-stage supply chain including one third-party recycler.

7. Acknowledgment

This work was supported by National Natural Science Foundation, China (No. 71071114); National Science and Technology Support Program (No.2011BAC10B08).
References


