Research on Supply Chain Coordination Strategy under Extended Producer Responsibility System

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Keywords: Extended producer responsibility, Three-stage closed-loop supply chain, Revenue sharing contract, Supply chain coordination

Abstract: For a simple three-stage closed-loop supply chain, each participant has an independent competitive goal, yet each part's being profitable doesn't foretell a optimal result for the whole. This paper aims to reshape the supply-retail-recycle pricing model by taking the extended producer responsibility into consideration. Based on the analysis of EPR and supply chain coordination theory, it is proposed that centralized decisions are better than decentralized ones, and revenue-sharing contracts contribute to achieve supply chain coordination holding the premise of decentralized decision-making. Furthermore, a simulation study run by Matlab is arranged to test these views, of which the results show that the optimal profit of supply chain under centralized decision is higher than under decentralized decision, for in the former case, both the recycling price of recyclers and the utilization rate of waste products are improved, besides, the total profit of the supply chain and every part of it increase. Therefore, by designing reasonably revenue-sharing contracts, supply chain coordination can be effectively achieved, every participant tends to proactively obey contracts and shall expect increasing profits at the same time.

1. Introduction

In the early days, traditional supply chain structure was that the manufacturer produced products and sold products to consumers via retailers or distributors. In December 2016, the General Office of the State Council of China promulgated a plan to propose that producers are not only responsible for the production of new products, but for the influence of new products on the supply chain, environment and society [1]. When the parties make "rational" decisions based on their own interests, the profits of the entire supply chain tend to be lower than the optimal level under ideal conditions. Since the mid-1990s, a large number of studies about supply chain contracts have emerged, which have prompted supply chain entities to maximize the total profit.

The literature research relevant focuses on two aspects: extended producer responsibility and supply chain contract coordination. In terms of extended producer responsibility, Li Jun elaborated on the connotation of EPR and its implementation in various countries, and discussed some problems when EPR was conducted in China [2].

In terms of supply chain contracts, Shi Wenqiang studied the three-level supply chain coordination strategy using quantity flexibility contract in emergencies, and analyzed the impact of elasticity coefficient changes on the entire supply chain [3]. Among them, there are many researches about revenue sharing contracts. Liu Juan analyzed the coordination of revenue sharing contracts to the supply chain with retailers' participation [4]. Chuanyong Xu studied the impact of revenue sharing on the profit of all parties, and considered the optimal strategy of each party [5].

In the context of different decision-making, a three-level closed-loop supply chain is built based on the above literature research, which considers centralized decisions and decentralized ones. Furthermore, the change of the whole profit and relevant information are studied under revenue sharing contract.

  DOI: 10.25236/iwass.2019.046

2. Extended producer responsibility

2.1 The meaning of extended producer responsibility

EPR was first proposed by Thomas Linhurst of Lund University in Sweden. He believed that the responsibility of the producer should be extended to products' entire life cycle, and also pointed out producers should bear environmental damage liability, economic responsibility, ownership responsibility, material responsibility and information disclosure responsibility [6].

2.2 Responsibility scope of extended producer responsibility

(1)Ecological design. When designing products, manufacturers try their best to make products be lightweight, singular, low-invasive, and easy to maintain. Manufacturers also need to take service life and energy saving into consideration.

(2)Use renewable raw materials. Under the guarantee of product quality and safety, producers can consider to use renewable raw materials and continuously develop regeneration technology to implement green management.

(3)Recycling standardization. Manufacturers can standardize recycled waste and its packaging through independent or entrusted recycling methods.

2.3 Responsible parties of extended producer responsibility

(1)Producer's responsibility (main responsibility)

A.Responsible for product recycling and utilization. Producers can use any of the three conditions to recycle waste products: be only responsible for recycling; be entrusted to the third party; producer responsible for recycling, main bodies (such as retailers) recycle the product.

B.Pay for the recycling of the corresponding waste products. The specific commitment cost is determined by various factors such as the type of product and producers undertakes it according to a certain proportion.

(2)Recycling company's responsibility

Recycling companies can simply sort out the waste products (such as stacking neatly), and then transfer recycled waste products to the processing enterprises and sign the entrusted recycling agreement with the processing company.

(3)Consumer's responsibility

Dispose of wasted products to a designated location. The wasted can't be discarded and consumers can't engage in dismantling activities.

(4)Government's responsibility

As the maker and promoter of the EPR system, the government formulates the EPR legal system and related standards, continuously improves the EPR evaluation system, quantifies the implementation effect and highlights the supervision of the EPR.

3. Supply chain coordination

3.1 The meaning of supply chain coordination

Supply chain coordination refers to a stable state achieved by two or more enterprises in order to achieve strategic objectives (usually profit maximization) through a certain agreement or strategy. Meanwhile, through some necessary adjustments and appropriate reconciliation, the competitive advantage of enterprises can be enhanced.

3.2 The method of supply chain coordination

The supply chain is made up of many parties that meet customer needs and maximize the overall profit of the supply chain. The basic methods for achieving supply chain coordination are:

(1)Share market demand data. If demand data are shared between the various parts of the supply chain, all parties can make more reasonable decisions based on the data obtained.

(2)Build a strategic partnership. Long-term cooperation can reduce transaction costs and improve work efficiency. If retailers trust the quality of the product and the delivery time, they

can reduce inventory and acceptance.

(3) Fairness. If one of the parties in the supply chain feels that overall interests are not shared fairly, the supply chain is uncoordinated. Therefore, those high-level managers in the supply chain must pay attention to this and ensure that the benefits are shared fairly.

3.3 Supply chain coordination mechanism

The current supply chain consists of producers, numerous intermediaries and customer groups. The factors in real life will inevitably lead to contradictions and conflicts. An effective supply chain contract can reduce the total cost of the supply chain, enhance the information exchange, achieve the optimal profit and form greater competitive advantages. There are many uncertainties that lead to supply chain imbalances, including market demand, lead time, price, and information availability. Common supply chain contracts include: quantity discount contracts, quantity flexible contracts, buyback contracts and revenue sharing contracts.

4. Research on supply chain coordination strategy

4.1 Problem description

Traditional supply chain only exists normal trading relationships. This paper studies optimal pricing decisions of participants under stochastic demand in a supply-retail-recycle supply chain. In the entire supply chain discussed in this article, the supplier produces new products and re-products. The retailer orders according to the information obtained. The demand is satisfied by the inventory, the unsatisfied part is directly lost and the order delivery has no time interval. Then, the retailer sells the product to consumers. After products are consumed, the supplier transfers the recycled waste from the recycler, then processes and reuses waste products. Under the EPR, the supplier bears the cost of implementing the EPR, but the increase in the cost of the EPR will bring an increase in sales and recycling volume. At the same time, the higher quality waste product, the lower cost of recycling. Figure 1 is a structure of the closed loop supply chain in question.

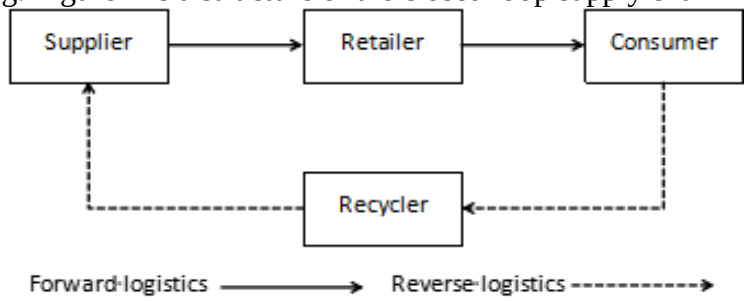

Figure.1 Supply chain structure.

4.2 Problem assumption and parameter identification

The model assumptions constructed in this paper are as follows:

(1)Stochastic market demand meets $D = a - bp$, $a > bp$, $b > 0$.

(2)The unit production cost of the supplier to produce new finished products and re-products is respectively c_n , c_u ($c_n > c_u$)and the supplier wholesales the price w to the retailer.

(3)The positive supply chain and the reverse supply chain are all in an ideal state, and the excess products are consumed internally.

(4)The retailer orders Q from the supplier according to the stochastic market demand of the supply chain. Assuming that the market demand is consistent with the order quantity, the retailer's unit operating cost is c_r and then the product is sold to customers at the price p and $p > w$ is satisfied.

(5)Recyclers recycle waste products from consumers. The unit recycling cost (including

finishing, transportation costs, etc.) is c_x ,the recovery price(including centralized transportation, land occupation cost, etc.) is v , the utilization rate of the discarded products after the supplier recycles is i and $v \geq c_x$ is satisfied.

(6)Assume that the amount of waste product $Q_r = \alpha + \beta c_x$ is recycled($\beta > 0$, $c_x \geq 0$).

(7)Throughout the process, each party appears to be risk-neutral and completely rational with symmetrical information. Pursuing different contract types ensures that chain coordination and the profits of both parties are positive. Other parameters in the model are listed in Table 1.

Table 1 : Other parameters identified in the model.

mark	meaning
π_s, π_r, π_h	Expected profit from suppliers, retailers, recyclers
Π	Expected profit of the supply chain

4.3 Centralized decision analysis

In the case of centralized decision making, each party makes decisions as a holistic system with the same goal-profit maximization. When they make centralized decisions, the entire supply chain's profits are:

$$\Pi = \pi_s + \pi_r + \pi_h \tag{1}$$
$$= (p - c_n - c_r)(a - bp) + [(c_n - c_u)i - c_x](\alpha + \beta c_x)$$

For the equation (1),we can get:

$$\frac{\partial \Pi}{\partial p} = a + bc_n + bc_r - 2bp \,, \frac{\partial \Pi}{\partial c_x} = \beta[(c_n - c_u)i - c_x] - (\alpha + \beta c_x)$$

Since the supply chain profit function is second-order derivative of products' price and discarded products' recycling price, the supply chain profit has the maximum value, and the optimal decision condition under the centralized decision can be obtained according to the first derivative:

$$p^* = \frac{a + bc_n + bc_r}{2b} \,, c_x^* = \frac{\beta(c_n - c_u)i - \alpha}{2\beta}$$

Substituting the optimal decision conditions into (1), the optimal profit of the entire supply chain under centralized decision is:

$$\Pi^* = (p^* - c_n - c_r)(a - bp^*) + [(c_n - c_u)i - c_x^*](\alpha + \beta c_x^*) = \frac{(a - bc_n - bc_r)^2}{4b} + \frac{[\beta(c_n - c_u)i + \alpha]^2}{4\beta} \tag{2}$$

4.4 Decentralized decision analysis

Under decentralized decision-making, each subject in the supply chain is independent of each other and maximizes their own profits as a main goal. In the case of non-cooperation, the retailer pays the supplier and the supplier pays the recycler. According to supply chain conditions, you can get: $T_0 = wQ$, $T_1 = vQ_r$.

$$\pi_s = T_0 - c_n Q + (c_n - c_u) i Q_r - T_1 \tag{3}$$
$$= (w - c_n)(a - bp) + [(c_n - c_u)i - v](\alpha + \beta c_x)$$
$$\pi_r = pQ - T_0 - c_r Q \tag{4}$$
$$= (p - w - c_r)(a - bp)$$
$$\pi_h = T_1 - c_x Q_r \tag{5}$$
$$= (v - c_x)(\alpha + \beta c_x)$$

From the view of analytic decision making, the retailer first determines the optimal price of the product according to its own optimal decision. In order to maximize its own profit, the retailer solves the first derivative according to equation (4) and we can get the most excellent price:

$$p^{**} = \frac{wb + c_r b + a}{2b}$$

The recycler solves the first derivative and the second derivative according to the equation (5), and the optimal recovery price of the recycler at this time can be introduced as $c_x{}^{**} = \frac{\beta v - \alpha}{2\beta}$.

Putting p^{**}, $c_x{}^{**}$ into equation (3),you can get:

$$\pi_s = (w - c_n)(a - bp) + [(c_n - c_u)i - v](\alpha + \beta c_x)$$
$$= \frac{(w - c_n)(a - wb - c_r b) + (\beta v + \alpha)[(c_n - c_u)i - v]}{2}$$

For the above formula, the first-order partial derivative for w and v is obtained and equal to 0:

$$w^{**} = \frac{a - bc_r + bc_n}{2b}, v^{**} = \frac{\beta(c_n - c_u)i - \alpha}{2\beta}$$

Then you will get:

$$p^{**} = \frac{c_n b + c_r b + 3a}{4b}, c_x{}^{**} = \frac{\beta(c_n - c_u)i - 3\alpha}{4\beta}$$

Substituting $p^{**}, c_x{}^{**}, w^{**}$ and v^{**} into the corresponding profit function, you can get each optimal profit under decentralized decision:

$$\pi_s{}^{**} = \frac{(a - bc_n - bc_r)^2}{8b} + \frac{[\beta(c_n - c_u)i + \alpha]^2}{8\beta}$$

$$\pi_r{}^{**} = \frac{(a - bc_n - bc_r)^2}{16b}, \pi_h{}^{**} = \frac{[\beta(c_n - c_u)i + \alpha]^2}{16\beta}$$

So, the optimal profit of the entire supply chain under decentralized decision-making is:

$$\Pi^{**} = \frac{3(a - bc_n - bc_r)^2}{16b} + \frac{3[\beta(c_n - c_u)i + \alpha]^2}{16\beta}$$

It's easy to know that the expected profit level under centralized decision is higher than the decentralized because the double marginal behavior decreases the decentralized' total profit. Under decentralized decision-making, whether the supplier or the retailer occupies the dominant position in the market, the loss is inevitable, so it can be considered to adopt a supply chain contract. Based on a certain proportion, this paper considers revenue-sharing contract to pursue the maximization of the overall profit of the supply chain, and observes whether the coordination among the members of the supply chain can be achieved.

4.5 Coordination strategy analysis

Under revenue sharing contract, the seller cooperates with the buyer by setting the selling price of the product and the buyer lets the seller share part of the proceeds as a reward for obtaining the wholesale price discount. In the entire supply chain, revenue sharing contracts share the benefits of supply chain activities. This article discusses that using a revenue-sharing contract in a forward-supply chain, the retailer buys products from the supplier, and the retailer only retains the sales revenue $\theta_1 \in [0,1]$. In the reverse supply chain, the waste products of iQ_r are recycled again by the supplier in the reverse supply chain. The retailer pays T_0' to the supplier and the supplier pays T_1' to the recycler, then you can get: $T_0' = wQ + (1 - \theta_1)pQ$, $T_1' = vQ_r$.So under the revenue sharing contract, the supplier's expected profit, retailer's and recycler's is:

$$\pi_s = T_0' + (c_n - c_u)iQ_r - T_1' - c_n Q \quad (6)$$
$$= [w + (1 - \theta_1)p - c_n](a - bp) + [(c_n - c_u)i - v](\alpha + \beta c_x)$$

$$\pi_r = pQ - T_0' - c_r Q \quad (7)$$

$$= (\theta_1 p - w - c_r)(a - bp)$$

$$\pi_h = T_1' - c_x Q_r \tag{8}$$

$$= (v - c_x)(\alpha + \beta c_x)$$

For equation (7) and equation (8), the first-order partial derivative of the relation is obtained for p , c_x , so that it is equal to 0, and you can get:

$$p^{***} = \frac{\theta_1 a + bw + bc_r}{2\theta_1 b}, c_x^{***} = \frac{\beta v - \alpha}{2\beta}$$

When the profit of the entire supply chain under the revenue sharing contract is equal to the total profit under the centralized decision, $p^* = p^{***}, c_x^* = c_x^{***}$ are satisfied at the same time. In the coordination model, the recycling cost of the recycler is all borne by the supplier, so the price of the two is equal to the optimal solution of the recovery price:

$w^{***} = \theta_1(c_n + c_r) - c_r, v^{***} = (c_n - c_u)i$

In order to ensure that all parties in the supply chain have the incentive to execute this contract, $\pi_s^{***} \geq \pi_s^{**}, \pi_r^{***} \geq \pi_r^{**}$ must be met. Finishing is available:

$$\frac{1}{4} \leq \theta_1 \leq \frac{1}{2} - \frac{[\beta(c_n - c_u)i + \alpha]^2}{2\beta(a - bc_n - bc_r)}$$

In the case of a revenue-sharing contract, when the equation (9) is satisfied, the supply chain entity can participate in the contract to maintain the supply chain coordination and ensure that the profits of each entity are greater than 0. So they have the incentive to execute the coordination contract. At this time, the total profit of the supply chain is equal to the total profit under the centralized decision.

5. Case analysis

In order to further illustrate the effectiveness of the revenue sharing contract, a simulation study is carried out on the above strategy research. This article assumes that the parameter value is $a = 100, b = 2, \alpha = 10, \beta = 6, c_n = 12, c_u = 4, c_r = 2$ Using *Matlab* software and above parameters, the numerical simulation of the decision under different models is carried out.

5.1 Contrastive analysis of centralized decision and decentralized decision

According to the parameter values and the operation of *Matlab* software, the centralized decision and the opposite one are analyzed and the pricing problem and profitability are studied. It can be seen from Table 2 that the recycling price of the recycler under the centralized decision is higher than the decentralized decision-making level, and the optimal selling price is lower than the decentralized decision-making level, which indicates that the centralized decision-making is more favorable to consumers. The centralized decision-making under the cooperative mode is better than the decentralized under the non-cooperative mode. Under decentralized decision-making, all parties in the supply chain only consider their own profits. The double marginalization of retailers and recyclers leads to low recycling efficiency of waste products and product production is affected to some extent, which decreases the total profit of a three-stage closed-loop supply chain.

Table 2 Comparison of optimal solutions for centralized and decentralized decision making.

	p	c_x	w	v	Π
Centralized decision	32	2.367	-	-	745.61
Decentralized decision	41	0.35	30	2.367	559.21

5.2 Coordination strategy analysis

According to the analysis of θ_1, we can get the profit of each subject in the supply chain (Figure 2). As can be seen from Figure 2, $\theta_1 \in [0.25,0.6]$ must be best. At this time, when the supplier's profit reduces, the retailer's profit will increase, but the overall profit of the supply chain has no much change.

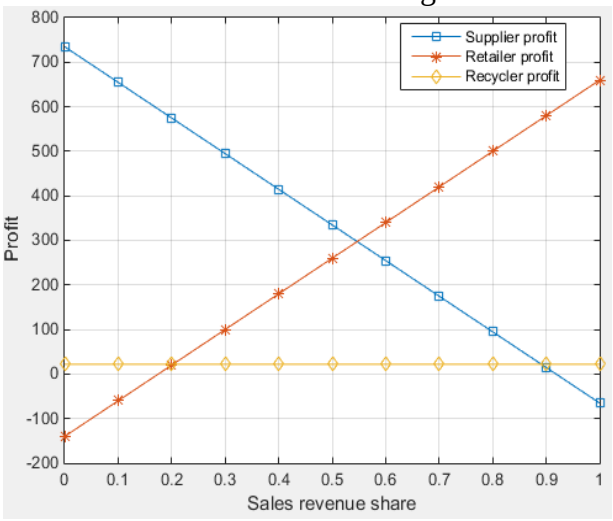

Figure.2 The relationship between the proportion of sales revenue and the profit of all parties.

5.3 Parameter sensitivity analysis (P=40, Cx=2,W=5,V=3, $\theta_1 = 0.5$)

(1)Relationship between recycling rate and recycling price of recycler

Since consumers use the product, the degree of damage to the consumed product is different, resulting in the uneven value of the recycled product. The high value may be profitable through re-manufacturing. Only some parts with low quality may be put into production. It is generally believed that the re-manufactured efficiency of recycled waste products is higher than that obtained by using some parts. As can be seen from Figure 3 that the higher the utilization rate of the waste product by the supplier, the greater the recycling price of the recycler. This is because the utilization of waste products is increased, the value of recycling waste products is greater, and the recycling price of waste products is higher. Compared to disposable products, the recycling of waste products encourages consumers to prefer to sell discarded products to recyclers at high recycling prices. Such two-way incentives will make consumers more inclined to choose such products to promote sales, while collecting more waste products can increase the amount of recycling.

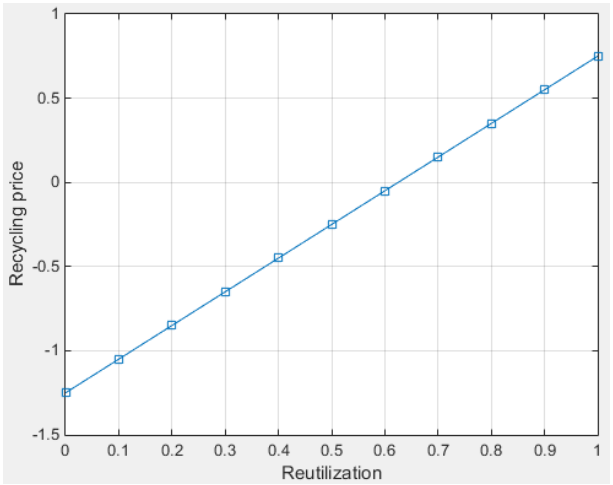

Figure.3 Relationship between Re-Utilization and recycling price.

(2)Relationship between recycling rate and profit of all parties in the supply chain

As can be seen from Figure 4, although retailers in the supply chain are not involved in the recycling of waste products, the higher the utilization rate of suppliers for recycling waste products, the greater the profits of suppliers and recyclers in the closed-loop supply chain. The utilization rate of waste products is increasing, and the value of recycling waste products is even greater. The increased awareness of consumers' recycling will inevitably lead consumers to purchase such products, which will increase the market demand for products, to a certain extent to suppliers and Retailers bring an increase in sales revenue, which increases the overall profit of the supply chain.

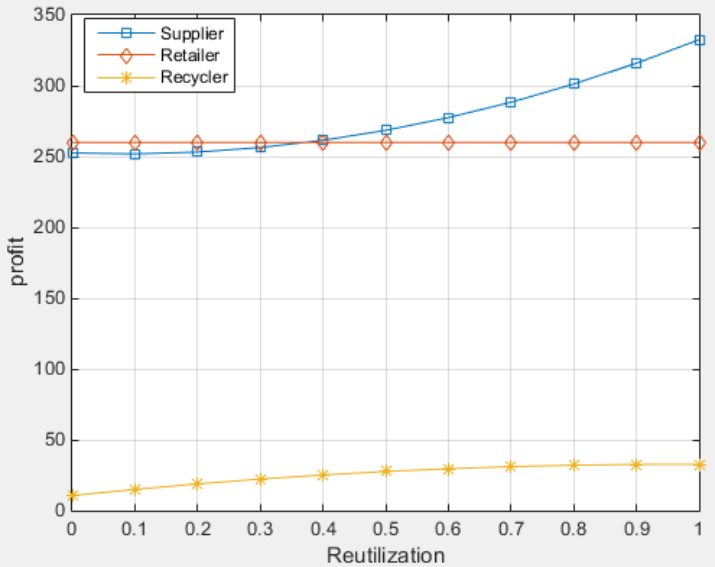

Figure.4 Relationship between Re-Utilization and profit of all parties in the supply chain.

6. Conclusions

In the centralized decision-making under the cooperative mode, the recycler's recycling price is higher than the decentralized one under the non-cooperative mode, but the optimal selling price is lower than the decentralized decision. Compared with decentralized decision-making, the optimal profit is higher under centralized decision-making. The existence of a dual marginalization problem for retailers and recyclers has reduced the total profit of the decentralized decision supply chain. The higher the utilization rate of the waste product by the supplier, the greater the recycling price of the recycler. The higher the supplier's utilization rate of recycled waste products, the greater the profits in the closed-loop supply chain, and the greater the overall profit of the supply chain. The implementation of supply chain coordination is diversified, and the methods and ideas for analysis need to be more diversified.

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