# Research on Revenue-sharing Contract of Closed-loop Supply Chain under Reward-penalty Mechanism

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## Abstract

Considering the reward-penalty mechanism, the impact of different revenue-sharing contracts on the recovery rate and the profit of supply chain members is studied from the perspective of supply chain coordination. There are two revenue-sharing contract models. One is the benefit-sharing model directly determined by the retailer and the manufacturer, and the other is the revenue-sharing model determined by the manufacturer and the retailer through negotiation. The results of the study show that the benefit sharing is beneficial to both supply chain participants and the overall compared to decentralized decisions without revenue-sharing. Besides, comparing the two different revenue-sharing models, it is found that the revenue-sharing model based on Nash negotiation is more beneficial to the manufacturer and the supply chain as a whole but not the retailer.

## Keywords

Reward-penalty mechanism; closed-loop supply chain; revenue-sharing contract; Nash bargaining

## 1. Introduction

With the development of technology, China produces a large amount of waste electrical and electronic equipment (WEEE) every year. WEEE contains a large amount of available resources, and reasonable recycling and disassembly can bring huge economic value. Sichuan Changhong reduced production costs by approximately 40-65% through the repeated use of parts and materials, and saved nearly $200 million in material costs in less than five years. Due to the improvement of people's environmental awareness and the great economic value of WEEE, many countries have put forward and implemented regulations on recycling and remanufacturing. In 2003, the European Union officially issued the *Waste Electrical and* Electronic *Equipment Directive*. China borrowed the successful experience of developed countries and issued the *Regulations on the Management of Waste Electrical and Electronic Products Recycling* in 2009. In 2017, the Ministry of Industry and Information Technology (MIIT) issued the *2018-2020 High-end Intelligent Remanufacturing Action Plan*. Therefore, this paper studies how the revenue-sharing contract affects the manufacturer's recycling and remanufacturing strategy under the incentive and punishment mechanism.

## 2. Model and Hypothesis

### 2.1 Model hypotheses

For the secondary closed-loop supply chain model consisting of a single manufacturer and a single retailer, considering the manufacturer's recycling and remanufacturing, this paper studies the three game models, namely revenue-free-sharing contract (ND), revenue-sharing contract (RSC) and revenue-sharing contract based on Bargaining (RSB). The manufacturer sells the product to the retailer at the wholesale price $w$, and the retailer sells the product to the consumer at the price $p$.

The market demand $q$ is a linear function of the price $p$. Referring to previous studies, the hypotheses in this paper are as follows:

Suppose the unit cost of the manufacturer to produce a new product is $c_m$ ,the unit cost to remanufacture product is $c_r$ . $\Delta$ represents the cost saved by the manufacturer using the waste product for remanufacturing, so $\Delta = c_m - c_r$ . Reference Savaskan, manufacturer's recycling cost can be expressed as a quadratic function of recovery rate, $m$ is the recovery effort degree coefficient, $\tau(0 < \tau < 1)$ is the recovery rate of waste products, $c(\tau) = m\tau^2$ . The more waste products you recycle, the more the manufacturer will pay. $\tau_0$ denotes the government's target recovery, and $m$ is government's reward and punishment. The government rewards the recyclers with $m(\tau - \tau_0)(a - bp)$. To simplify the model, this article does not consider the unit cost of the manufacturer in recycling used products. Assume that there is no difference between the new product and the re-product, and the consumer's acceptance of both products is the same.

**2.2 Basic game models**

2.2.1 Decentralized decision model without profit sharing (ND)

In the manufacturer-led stackelberg game model, retailers are followers. The manufacturer first determines the wholesale price $w$ and the recovery rate $\tau$ of the product according to the principle of profit maximization. Then the retailer determines the retail price $p$ of the product according to the wholesale price $w$ determined by the manufacturer. The manufacturer's profit function is expressed as:

$$\pi_M = (w - C_m + \Delta\tau)(a - bp) - k\tau^2/2 + m(\tau - \tau_0)(a - bp) \quad (1)$$

The profit function of the recycler is:

$$\pi_r = (p - w)(a - bp) \quad (2)$$

2.2.2. Revenue-sharing contract (RSC)

From the perspective of recycling and remanufacturing, this paper studies the issue of revenue-sharing in the cooperation between manufacturers and retailers in the supply chain. In the case of manufacturer recycling and remanufacturing, the manufacturer bears all the recycling costs. The recycling cost is huge and it is too difficult for the manufacturer to bear it alone. The retailer's revenue-sharing contract relieved manufacturers' burden of recycling waste products and coordinates the redistribution of benefits.

Compared with upstream manufacturers, downstream retailers are more aware of market demand and have clear advantages in the game. Based on these two points, we establish a revenue-sharing contract in which retailers determine the revenue-sharing ratio while maximizing their own interests. The order and rules of the game are as follows: The manufacturer first determines the wholesale price $w$ and the recovery rate $\tau$ . On this basis, the retailer determines the sales price $p$ of the product and proposes a profit distribution ratio $\lambda$ $(0 < \lambda < 1)$. Therefore, the profit of the retailer is $\lambda$ times the revenue from the final sale, 1- $\lambda$ is shared with the manufacturer.

Therefore, under the revenue-sharing contract, the profit function of manufacturers and retailers has changed, as follows:

$$\pi_R^{RSC} = (1 - \lambda)(p - w)(a - bp) \quad (3)$$

$$\pi_M^{RSC} = (w - C_m + \Delta\tau)(a - bp) - \frac{k\tau^2}{2} + m(\tau - \tau_0)(a - bp) + \lambda(p - w)(a - bp) \quad (4)$$

2.2.3. Revenue-sharing contract based on Bargaining (RSB)

In order to explore the impact of the bargain, in this section, game participants determine the proportion of revenue-sharing through bargain. The revenue-sharing ratio $\lambda$ is no longer determined

solely by the retailer, but jointly by the manufacturer and the retailer through bargaining. Manufacturers and retailers first negotiate a revenue-sharing factor and derive a revenue-sharing ratio $\lambda$. The manufacturer decides the wholesale price $w$ and the recovery rate $\tau$ based on the revenue-sharing ratio $\lambda$. The retailer determines the market price $p$ based on the revenue-sharing ratio $\lambda$ and the manufacturer's decision. According to the literature, the RSC model $\pi_B(\lambda)=\pi_r\pi_m$ was established. When the maximum $\pi_B$ is reached, the resulting parameter $\lambda$ will give the game model the best return.

All values of the above expressions are listed in Table 1.

Table 1 Results of different supply chain contracts

| | ND | RSC | RSB |
|---|---|---|---|
| $\lambda$ | — | $\frac{b(\Delta+m)^2}{2k}$ | $\frac{2k+b(\Delta+m)^2}{4k}$ |
| $w$ | $\frac{\left[2k-b(\Delta+m)^2\right]a+2kb(c_m+m\tau_0)}{b\left[4k-b(\Delta+m)^2\right]}$ | $\frac{\left[k-b(\Delta+m)^2\right]a+kb(c_m+m\tau_0)}{b\left[2k-b(\Delta+m)^2\right]}$ | $\frac{\left[2k-3b(\Delta+m)^2\right]a+4kb(c_m+m\tau_0)}{3b\left[2k-b(\Delta+m)^2\right]}$ |
| $p$ | $\frac{\left[3k-b(\Delta+m)^2\right]a+kb(c_m+m\tau_0)}{b\left[4k-b(\Delta+m)^2\right]}$ | $\frac{\left[3k-2b(\Delta+m)^2\right]a+kb(c_m+m\tau_0)}{2b\left[2k-b(\Delta+m)^2\right]}$ | $\frac{\left[4k-3b(\Delta+m)^2\right]a+2kb(c_m+m\tau_0)}{3b\left[2k-b(\Delta+m)^2\right]}$ |
| $\tau$ | $\frac{(\Delta+m)(a-bc_m-bm\tau_0)}{4k-b(\Delta+m)^2}$ | $\frac{(\Delta+m)(a-bc_m-bm\tau_0)}{4k-2b(\Delta+m)^2}$ | $\frac{2(\Delta+m)(a-bc_m-bm\tau_0)}{3\left[2k-b(\Delta+m)^2\right]}$ |
| $\pi_M$ | $\frac{k\left[a-bc_m-bm\tau_0\right]^2}{2b\left[4k-b(\Delta+m)^2\right]}$ | $\frac{k\left[a-bc_m-bm\tau_0\right]^2}{4b\left[2k-b(\Delta+m)^2\right]}$ | $\frac{k\left[a-bc_m-bm\tau_0\right]^2}{3b\left[2k-b(\Delta+m)^2\right]}$ |
| $\pi_R$ | $\frac{k^2\left[a-bc_m-bm\tau_0\right]^2}{b\left[4k-b(\Delta+m)^2\right]^2}$ | $\frac{k(a-bc_m-bm\tau_0)^2}{8b\left[2k-b(\Delta+m)^2\right]}$ | $\frac{k\left[a-bc_m-bm\tau_0\right]^2}{9b\left[2k-b(\Delta+m)^2\right]}$ |

## 3. Model comparison

Comparing and analyzing the equilibrium solutions and profits of the above three game models, we can get the following conclusions.

Proposition 1. The revenue-sharing ratio under different profit sharing contracts is satisfied: $\lambda^*_{RSB}>\lambda^*_{RSC}$.

Under the direct revenue-sharing contract, the ratio shared by the retailer and the manufacturer is smaller than that under the profit-sharing contract based on the bargaining. The revenue-sharing ratio is related to the recycling cost, the remanufacturing cost savings, and the intensity of government regulation.

Proposition 2. Comparing the recovery rates of the three models, there are $\tau^*_{ND}<\tau^*_{RSC}<\tau^*_{RSB}$.

From a government perspective, the recycling rate of waste products under the conditions of decentralized decision-making is the lowest. The revenue-sharing contract is conducive to improving the recovery rate of waste products. Therefore, the recovery rate under the two revenue-sharing contracts is higher than that under the non-revenue-sharing contract. The recycling rate of waste products under the revenue-sharing contract based on bargaining is higher than the direct revenue-sharing contract.

Proposition 3. Comparing the optimal wholesale price of the three models,there are $w^*_{ND}>w^*_{RSB}>w^*_{RSC}$.

The wholesale price of the product is the highest in the decentralized decision-making, followed by the direct revenue-sharing contract, and the lowest in the revenue-sharing contract based on bargaining. The revenue-sharing contract mitigates the double marginal effect of decentralized

decision-making, thereby revenue-sharing contract reduces the wholesale price of products, especially the revenue-sharing contract based on bargaining.

Proposition 4. Comparing the optimal retail price of the three models,there are $p_{ND}^{*} > p_{RSB}^{*} > p_{RSC}^{*}$.

From a consumer perspective, the retail price of a product is highest under decentralized decision making. The revenue-sharing contract encourages manufacturers to reduce the wholesale price of the product, so the retailer reduces the retail price of the product. The wholesale price of the product under the revenue-sharing contract based on bargaining is the lowest, so the retail price of the product under it is the lowest.

Proposition 5. Comparing the optimal manufacturer profit of the three models, there are $\pi_M^{ND*} < \pi_M^{RSC*} < \pi_M^{RSB*}$.

From the manufacturer's point of view, the profit of the manufacturer under the revenue-sharing contract is higher than that under the decentralized decision. When manufacturers are stronger, they bargain with retailers and demand redistribution of profits to maximize their profits. Therefore, the profit of the manufacturer will be higher in the case of a revenue-sharing contract based on bargaining.

Proposition 6. Comparing the optimal retailer profits of the three models,there are $\pi_R^{RSB*} < \pi_R^{ND*} < \pi_R^{RSC*}$.

From the retailer's point of view, the retailer's profit under the revenue-sharing contract is higher than that under the decentralized decision. For retailers, the increased sales revenue due to increased product recovery cannot offset the increase in the cost of the manufacturer's revenue sharing, so the revenue-sharing contract based on bargaining leads to lower retailer profit, even lower than that under decentralized decision making. In order to encourage retailers to accept the revenue-sharing contract based on bargaining, new incentives can be added or the retailer's revenue-sharing ratio can be appropriately increased to ensure that the retailer profit is not lower than that under decentralized situation.

Proposition 7. comparing the total profit of the supply chain of the three models, there are $\pi_{SC}^{ND*} < \pi_{SC}^{RSC*} < \pi_{SC}^{RSB*}$.

From the perspective of the overall supply chain, the revenue-sharing contract stimulates the manufacturer's recycling and re-manufacturing activities and increases the total profit of the supply chain compared with the decentralized decision-making condition. The total profit of the supply chain under the revenue-sharing contract based on bargaining is higher than the direct revenue-sharing contract.

## 4. Numerical analysis

This section compares the decision results of the three models through an example. The relevant parameters of the product are: $a=100, b=1, c_m=50, m=50, \Delta=30, k=7000$. The results obtained are shown in Table 2.

Table 2 Numerical analysis of different supply chain contracts

| | $w$ | $p$ | $\tau$ | $\pi_M$ | $\pi_R$ | $\pi_{SC}$ |
|---|---|---|---|---|---|---|
| ND | 83.796 | 91.898 | 0.093 | 101.273 | 65.64 | 166.913 |
| RSC | 76.974 | 88.487 | 0.132 | 143.914 | 71.957 | 215.871 |
| RSB | 69.298 | 84.649 | 0.175 | 191.886 | 63.962 | 255.848 |

As can be seen from Table 2, compared with the decentralized decision, for revenue-sharing contract, the retail price is reduced, the recovery rate is increased, and the profit of the manufacturer, the retailer and the supply chain is increased. It can be seen that the revenue-sharing contract can reduce the double marginal effect in decentralized decision making. The revenue-sharing contract based on Nash bargaining further reduces the retail price of products, increases the recovery rate, and improves the

profit of manufacturers and supply chains. But retailers' profit declines, even lower than that under decentralized decision-making situation.

## 5. Conclusion

Based on the government reward and punishment mechanism, this paper studies the revenue sharing between the upstream and downstream members of the closed-loop supply chain. The results are analyzed and the following conclusions are drawn: (1) The revenue-sharing ratio is related to the recovery cost coefficient, the remanufacturing cost savings and the intensity of government regulation. (2) Compared with the non-revenue-sharing contract, the direct revenue sharing improves the recycling rate of used products, lowers the price of products, and increases the supply chain participants and overall profits. (3) Compared with the direct revenue-sharing contract, in the revenue-sharing contract based on bargaining, the recycling price of waste products is reduced and the recovery rate is increased. The profit of manufacturers and supply chains increases, but retailers' profits are even lower than those under decentralized decisions, thus retailers will reject them. Therefore, in order to successfully establish a revenue-sharing contract based on Nash bargaining, it is necessary to take appropriate measures to compensate the retailer's loss of profits.

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