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Pricing strategy in remanufacturing system of closed-loop supply chain

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ABSTRACT

This paper constructs a closed-loop supply chain model consisting of one manufacturer and one distributor. The distributor recycles wastes, and the manufacturer or the distributor assumes remanufacturing. In this system, we introduce a pricing strategy to maximize the profits of the manufacturer and the distributor. On this basis, the boundary conditions that the manufacturer or the distributor undertakes remanufacturing are given. The pricing strategy can improve total system profits.

KEYWORDS

Closed-loop supply chain; Remanufacturing; Manufacture; Distributor; Price decision.

INTRODUCTION

Along with human productivity improvement, raw material and energy consumption increases enormously, the environmental pollution is towards worsening, and the earth's ecological system is difficult to exit[1]. A lot of countries put in place a series of related policies to require enterprises are responsible for product life cycle, especially recycling wastes. Remanufacturing is an advanced manufacturing engineering facing circular economy. Through remanufacturing, the product can reach the standard of the new one. It can also play a positive role for social sustainable development, circulation resource and environmental protection[2].

Remanufacturing is a new manufacturing philosophy. It is under the guidance of the design and management theory about product life cycle, and aims at fine quality, high efficiency, energy conservation, saving energy and environmental protection[3]. The importance of remanufacturing is: the quality and performance of the remanufactured product reaches or excesses the new one, but cost is about 50%, energy conservation is about 60% and saving energy is over 70%. The contribution of remanufacturing for environmental protection is very marked[4]. Logical framework based on the value recovery of the closed-loop supply chain perspective is summarized as follows:

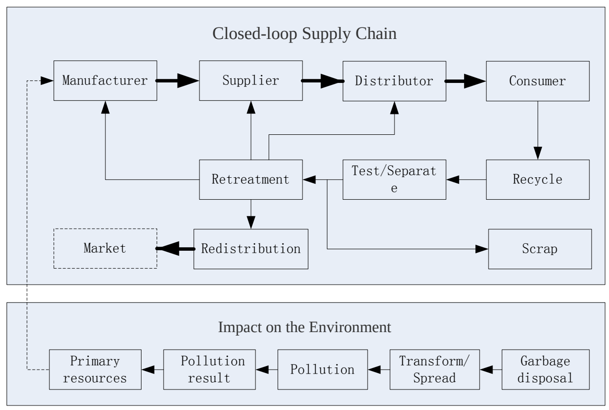

Figure 1: Recycling and value recovery system

There have been various studies on supply chain coordination and a continuous interest has been attracted. Thierry et al is the first group to investigate recovery efficiency systematically[3]. They presented that the profitability of recycling and value recovery system depends on the technical feasibility, the efficiency of the recycling system (fully invested), remanufactured goods market demand. Canan et al. studied the issues including the investment decisions of the recovery system and the recovery mode choice. The investment subject is the manufacturer, and the recovery subject could be main manufacturer, distributor or the third-party logistics provider[5]. Fuminori investigated two discarded electronic material recovery models, such as monopoly and competition modes. He has assessed the advantages of each mode and given the factors affecting the recovery mode selection[6]. Inspired from the modeling idea of the newsboy problem, Kaya has a survey on the modeling and incentive of the recovery amount in order to improve the efficiency of the recycling system[7].

This paper introduces two models of closed-loop supply chain. The manufacturer is the leader, and it produces new products. The distributor recycles wastes and sells products. Then the manufacture recycles wastes from distributor to complete remanufacturing, or the distributor completes remanufacturing directly. The price decision under the two modes and the impact on the profit of supply chain are also studied.

PROMBLEMS AND MODELS

The supply chain consists of a manufacturer and a distributor, and distinguished by superscript. That m is manufacturer, r is distributor, s is supply chain, and the profit of supply chain is π^s.
The wholesale price of manufacturer is P_n^m, the price of recycling wastes from distributor is P_r^m, the cost of the new product is C_n^m, and the manufacturer's cost of remanufacturing product is C_r^m.

The selling price of distributor is P_n^r, the recycling price of distributor is P_r^r, the distributor's unit cost of selling is C_n^r, the recycling cost of distributor is C_r^r, and the distributor's cost of remanufacturing product is C_{rr}^r.

Market demand is d, $d = D - \lambda P_n^r$, D and λ are positive numbers decided by marking, and the demands decrease along with selling price. The supply function of wastes is s, $s = a + \alpha P_r^r$, a is the fixed quantity of recycling wastes, and a doesn't change when recycling price has changed. α is the elastic coefficient of quantity of recycling wastes to recycling, $\alpha > 0$.

To simplify the model, we form hypotheses:

Hypothesis 1: The manufacturer and the distributor are all risk-neutral and pursue optimal interest, and the manufacturer is the leader in supply chain.

Hypothesis 2: The recycling products are all remanufactured to sell, and the quality is the same to the new ones.

Hypothesis 3: For manufacturer's meaning to supply chain, the sum of manufacturer's remanufacture cost and recycling price will not exceed the new product's cost, as $P_r^m + C_r^m < C_n^m$. In the same way, the sum of distributor's remanufacture cost and recycling price will not exceed the new product manufacturer cost, as $P_r^r + C_{rr}^r + C_r^r < C_n^r$.

Hypothesis 4: Let the current production is equal to previous production, market demand is minus function to selling price, the supply of wastes is increasing function, and the quantity of recycling wastes will not exceed the market demand, as $s < d$.

Based on the hypotheses above, we construct reward function of the manufacture remanufacturing and the distributor remanufacturing.

The revenue functions of the manufacturer and the distributor when the manufacturer completes remanufacturing are shown as:

$$\begin{aligned}\pi_m^m &= (P_n^m - C_r^m - P_r^m)s + (P_n^m - C_n^m)(d-s)\\ &= (P_n^m - C_r^m - P_r^m)(a+\alpha P_r^r) + (P_n^m - C_n^m)\\ &\quad [(D-\lambda P_n^r) - (a+\alpha P_r^r)]\\ \pi_m^r &= (P_n^r - P_n^m - C_n^r)d + (P_r^m - P_r^r - C_r^r)s\\ &= (P_n^r - P_n^m - C_n^r)(D-\lambda P_n^r) + (P_r^m - P_r^r - C_r^r)\\ &\quad (a+\alpha P_r^r)\end{aligned}$$

The revenue functions of the manufacturer and the distributor when the distributor completes remanufacturing are shown as:

$$\begin{aligned}\pi_r^m &= (P_n^m - C_n^m)(d-s)\\ &= (P_n^m - C_n^m)[(D-\lambda P_n^r) - (a+\alpha P_r^r)]\end{aligned}$$

$$\begin{aligned}\pi_r^r &= (P_n^r - P_n^m - C_n^r)(d-s) + (P_n^r - P_r^r - C_r^r - C_n^r\\ &\quad - C_{rr}^r)s\\ &= (P_n^r - P_n^m - C_n^r)([(D-\lambda P_n^r) - (a+\alpha P_r^r)]) +\\ &\quad (P_n^r - P_r^r - C_r^r - C_n^r - C_{rr}^r)(a+\alpha P_r^r)\end{aligned}$$

We form hypotheses:

$$\begin{aligned}F_1 = \{&(P_n^m, P_r^m, P_n^r, P_r^r) \mid \max(C_r^m + P_r^m, C_n^m) \le P_n^m\\ &\le P_n^r - C_n^r, P_r^r + C_r^r \le P_r^m,\\ P_r^r &\le \frac{D-a-\lambda P_n^r}{\alpha}\}\end{aligned}$$

$$\begin{aligned}F_2 = \{&(P_n^m, P_n^r, P_r^r) \mid \max(P_r^r + C_{rr}^r + C_r^r, C_n^r) \le P_n^m\\ &\le P_n^r - C_n^r,\\ P_r^r &+ C_r^r \le P_r^m, P_r^r \le \frac{D-a-\lambda P_n^r}{\alpha}\}\end{aligned}$$

When the manufacturer completes remanufacturing, $P_n^m, P_r^m, P_n^r, P_r^r$ are must be decided above F_1. When the distributor completes remanufacturing, P_n^m, P_n^r, P_r^r are must be decided above F_2.

REMANUFACTURING MODEL OF THE MANUFACTUER

When the manufacturer gives P_n^m and P_r^m to maximize its profit, the distributor decides P_n^r and P_r^r to maximize its profit. The decision model is:

$$\begin{aligned}&\max \quad \pi_m^m(P_n^m, P_r^m, P_n^r, P_r^r)\\ &s.t. \quad \max \quad \pi_m^r\\ &\qquad [P_n^m, P_r^m, P_n^r, P_r^r] \in F_1\end{aligned}$$

According to the retrograde induction, the optimal solution is:

$$P_n^r = \frac{3D + \lambda(C_n^m + C_n^r)}{4\lambda}, \quad P_r^r = \frac{\alpha(C_n^m - C_r^m - C_r^r) - 3a}{4\lambda}$$

$$P_n^m = \frac{D - \lambda(C_n^r - C_n^m)}{2\lambda}, \quad P_r^m = \frac{\alpha(C_n^m - C_r^m + C_r^r) - a}{2\alpha}$$

$$s = \frac{a - \alpha(C_r^m + C_r^r - C_n^m)}{4}, \quad d = \frac{D - \lambda(C_n^r + C_n^m)}{4}$$

$$\pi_m^m = \frac{[D - \lambda(C_n^r + C_n^m)]^2}{8\lambda} + \frac{[a - \alpha(C_r^m + C_r^r - C_n^m)]^2}{8\alpha}$$

$$\pi_m^r = \frac{[D - \lambda(C_n^r + C_n^m)]^2}{16\lambda} + \frac{[a - \alpha(C_r^m + C_r^r - C_n^m)]^2}{16\alpha}$$

$$\pi_m^s = \frac{3[D - \lambda(C_n^r + C_n^m)]^2}{16\lambda} + \frac{3[a - \alpha(C_r^m + C_r^r - C_n^m)]^2}{16\alpha}$$

Based on the above results, in the remanufacturing mode of manufacturer, the manufacturer’s wholesale price is related to the distributor’s cost of selling and the new product cost. The lower distributor’s cost of selling higher new product cost as well as manufacturer’s wholesale price. So the manufacturer’s wholesale price is not influenced by reverse logistics. The manufacturer’s price of recycling wastes is related to the new product’s cost, remanufacturing product’s cost and the distributor’s recycling cost, so it is influenced by positive and reverse logistics. The distributor’s selling price is related to the new product’s cost and the distributor’s cost of selling, and it is not influenced by reverse logistics. The distributor’s recycling price is related to the new product’s cost, remanufacturing product’s cost, and it is influenced by positive and reverse logistics.

REMANUFACTURING MODEL OF THE DISTRIBUTOR

When the manufacturer gives P_n^m to maximize its profit, the distributor decides P_n^r and P_r^r to maximize its profit. It is diffident from the front part, that the manufacturer doesn’t need to decide P_r^m. So the decision model is:

$$\begin{aligned} &\max \quad \pi_r^m(P_n^m, P_r^m, P_n^r, P_r^r) \\ &s.t. \quad \max \quad \pi_r^r \\ &\qquad [P_n^m, P_n^r, P_r^r] \in F_2 \end{aligned}$$

According to the retrograde induction, the optimal solution is:

$$P_n^r = \frac{(\lambda + 2\alpha)C_n^r + (\lambda + \alpha)C_n^m + \alpha(C_r^r + C_{rr}^r) + D - a}{4(\lambda + \alpha)} + \frac{D}{2\lambda}$$

$$P_r^r = \frac{(\lambda + \alpha)C_n^m - \lambda C_n^r - (2\lambda + \alpha)(C_r^r + C_{rr}^r) + D - a}{4(\lambda + \alpha)} - \frac{a}{2\alpha}$$

$$P_n^m = \frac{(\lambda + \alpha)C_n^m - \lambda C_n^r + \alpha(C_r^r + C_{rr}^r) + D - a}{2(\lambda + \alpha)}$$

$$d = -\frac{\lambda(\lambda + 2\alpha)C_n^r + \lambda(\lambda + \alpha)C_n^m + \alpha\lambda(C_r^r + C_{rr}^r) + \lambda(D - a)}{4(\lambda + \alpha)} + \frac{D}{2}$$

$$s = \frac{\alpha(\lambda + \alpha)C_n^m - \lambda\alpha C_n^r - \alpha(2\lambda + \alpha)(C_r^r + C_{rr}^r) + \alpha(D - a)}{4(\lambda + \alpha)} + \frac{a}{2}$$

$$\pi_r^r = \frac{[-(\lambda+\alpha)C_n^m - \lambda C_n^r + \alpha(C_r^r + C_{rr}^r) + \alpha(D-a)]^2}{8(\lambda+\alpha)}$$

$$\pi_r^m = [\frac{(\lambda+\alpha)C_n^m - \lambda C_n^r - (4\lambda+3\alpha)(C_r^r + C_{rr}^r) + (D-a)}{4(\lambda+\alpha)} + \frac{a}{2\alpha}]s + [\frac{-(\lambda+\alpha)C_n^m - (\lambda+2\alpha)C_n^r - \alpha(C_r^r + C_{rr}^r) + (D-a)}{4(\lambda+\alpha)} + \frac{D}{2\lambda}]d$$

$$\pi_r^s = \pi_r^r + \pi_r^m$$

Based the above results, we can find that the distributor's remanufacturing is more complicated than the manufacturer's remanufacturing, because the distributor is not only selling but also remanufacturing products. The manufacturer's wholesale price, the distributor's selling price and recycling price is influenced by positive and reverse logistics, and it is related to the new product cost, the selling cost, the distributor's recycling cost and the remanufacturing cost.

COMPARISON OF TWO REMANUFACTURING MODELS

In the formal two parts, the price decisions of the manufacturer and the distributor which participant remanufacturing are studied. We can find from quantitative results that:

In the remanufacturing mode of manufacturer, the manufacturer's wholesale price and the distributor's selling price is not influenced by reverse logistics, and is means that the behavior of recycling wastes doesn't influence the optimal price and market demands. The recycling prices of manufacturer and distributor are related to reverse logistics, and the quantity of recycling wastes is also influenced by these factors.

In the remanufacturing mode of distributor, the distributor is not only selling products but also remanufacturing products and recycling wastes. Based the above results, we can find that the distributor's remanufacturing is more complicated than the manufacturer's remanufacturing, because the distributor is not only selling but also remanufacturing products. The manufacturer's wholesale price, the distributor's selling price and recycling price is influenced by positive and reverse logistics, and it is related to the new product cost, the selling cost, the distributor's recycling cost and the remanufacturing cost. The manufacturer's wholesale price, the distributor's selling price and recycling price is influenced by positive and reverse logistics, and they are related to the new product cost, the selling cost, the distributor's recycling cost and the remanufacturing cost. The demands of positive logistics and the quantity of recycling wastes are also influenced by these factors.

NUMERICAL ANALYSIS

In this section, we would like to investigate the profits of the supply chain that manufacturer assumes recycling and the distributor assumes recycling. The parameters in the numerical analysis are follows: $D=1$, $\lambda=0.01$, $a=0.5$, $\alpha=0.1$. ($C_n^r, C_n^m, C_r^m, C_r^r, C_{rr}^r$) come from random numbers. The above values of parameters satisfy the basic assumptions of this paper.

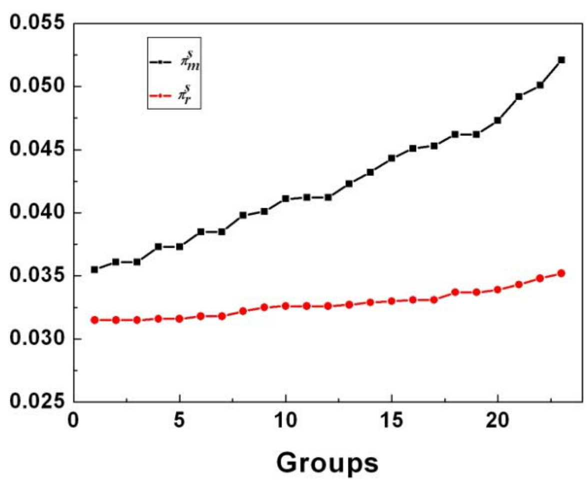

Figure 2 : Profits of supply chain

As it is shown in Figure 2, we can find that the manufacture's recycling is superior to the distributor's recycling.

CONCLUSIONS

This paper constructs a closed-loop supply chain of a manufacturer and a distributor.. The price decision and the decision boundary on when to enter the remanufacturing field about manufacturer and distributor are analyzed. Then the decision features of the above two models are compared. The research on the state of the manufacturer and the distributor, in which they participant remanufacturing at the same time, is not referred to. The research on optimization model and price decision with more information can be introduced in the future.

CONFLICT OF INTEREST

The authors have not declared any conflict of interests.

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