Price Decision Analysis for Reusable Product Under Asymmetric Information

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Abstract The reverse supply chain system is studied in this paper between one manufacturer and one retailer. The basic model is developed by using the principle-agent theory. Under asymmetric information, the price decisions of recycled products and the results were further analyzed. Finally a numerical example is also given.

Keywords Asymmetric information • Operational research • Principle-agent theory

1 Introduction

Reusable product is not a new phenomenon. Due to environment and economic incentive, product reusable is receiving increasing more attention (Schrady 1967). Product reusable can decrease the waste as much as possible and make the energy reuse. The main reason for companies to engage in the product reusable business is to regain more virgin materials and reduce the total cost. There are three forms of reusable product which contains recycling, repair, remanufacturing, according to the literatures. Literatures (Teunter 2004; Shie-Gheun Koh et al. 2002) study inventory control problem with recycling products; Literature (Gu Qiushuang 2004) researches on remanufacturing logistics networks. In recent years, in the reverse supply chain areas there has been a trend of research on perspective shift from single optimal model research of game theory. Using Stackelberg game theory, Stackelberg game models are established in Literatures (He Yong et al. 2004; Gu Qiaolun et al. 2005). Product application of principal-agent theory to study the

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problem of recycling-related documents are rare, but in real life, in order to maintain good relations of cooperation among enterprises with mutual understanding of each other's information However, in most cases, even if the mutual cooperation of enterprises, for the benefit of themselves, their cost tends to business secret information as strictly confidential, and other enterprises in order to fully understand this information is not easy. So we will use principal-agent theory, study under the symmetric information of recyclable product pricing strategies.

This article is based on a single manufacturer and a single retail reverse logistics system consisting of a basic model of principal-agent analysis. Under the symmetric information pricing strategies of recycling of waste products are researched.

2 Problem and Assume

2.1 Problem Description

It is assumed that a single manufacturer and a single retailer, manufacturers commissioned retailers responsible for the recall of a product at a certain price from a retailer. Manufacturers reproduce recycling waste products which form the new product. At a certain price from consumers retailers recycle waste products, and then sell it to manufacturers. It is assumed that recovery mode with the same cost structure from different retailers (namely the supply of waste products and retailers operating costs are the same). The structure of the model is showed in Fig. 1. Therefore, we discuss only a single retailer, assuming that the whole recycling products used to manufacture. Study on the model of principal-agent framework, manufacturers as a principal, the retailer as agent, we intend to seek to individuals optimal solutions of rational constraints, make the principal and the agent's profit reaches the maximum.

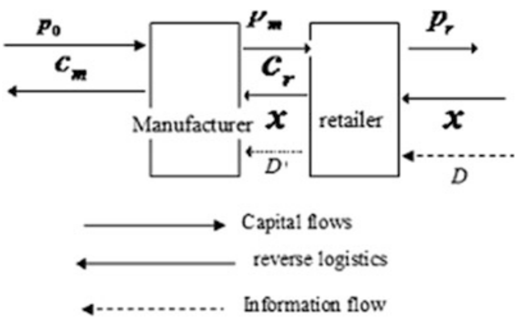

Fig. 1 Reverse logistics structure

2.2 Symbol Description

p_0: Recycled product unit sales price (RMB/piece), it is constant.
c_m: the marginal cost of regeneration processing recycled products for manufacturer (RMB/piece);
p_m: Manufacturer buy unit cost of waste products from the retail price. It is decision variable for manufacturers, and unit sales price for retailer, $p_m \leq p_0 - c_m$, (decision variable);
c_r: the cost of marginal operating outlets (including inventory, transportation);
p_r: unit price of recycle waste products for retailers from consumers, a decision variable for retailers;
D: amount of waste products in the market;
x: amount of recycling products if the unit price is p_r. It is assumed that: $x = d(p_r)^k, (d > 0, k > 1)$ (Gu Qiaolun et al. 2005), d is constant, k is price elasticity. $x \leq D$;
π_m: profit for manufacturer;
π_r: profit for retailer.

2.3 Basic Model

First, we take into account the manufacturer's profit function, which is the principal objective function

$$\pi_m (p_m, p_r) = (p_0 - c_m - p_m)\, x,$$

Manufacturers of personal rational constraints

$$Q_1 \leq x \leq Q_2,$$

Where Q_1, Q_2 are the manufacturer's minimum and maximum production capacity, this constraint indicates that the manufacturer no longer productive rational constraints. In order to benefit from processing recycled products, manufacturers must satisfy the following constraints

$$p_m \leq p_0 - c_m.$$

Profit function for retailers, it is agents of the objective function

$$\pi_r (p_m, p_r) = (p_m - c_r - p_r)\, x,$$

Retailer of personal rational constraints

$$x \leq D.$$

In the principal-agent problem, as agent of the outlets of its operating cost parameter c_r is an observation-related information. If in full under the condition of information, c_r can be observed, c_r is known for principal and agent. But under the condition of asymmetric information, in order to make more profits, retailers are likely lied about cost, so c_r is not observable. c_r is unknown for delegates, c_r is known for agents.

2.4 Recovery Pricing Strategy Under Asymmetric Information

Enterprise tends to keep private information to get the maximum profit. Therefore, in reality pricing strategy in the reverse supply chain problems closes to game theory under asymmetric information. Under the condition of asymmetric information, c_r is unknown for clients but c_r is known for agent. In General, under the condition of incomplete information, principal-agent problem can be turned into an optimal control problem (Huang Xiaoyuan 2004; Blizorukova and Maksimov 2006).

According to the simple method of paper (Huang Xiaoyuan 2004), a Personal rational constraint of manufacturer is turned into a quadratic function; we get the manufacturer's generalized form of profit function

$$\begin{aligned}\pi_1 = (p_0 - c_m - p_m)\, x - \frac{1}{2} a_1 (x - Q_1)^2 \\ - \frac{1}{2} a_2 (Q_2 - x)^2,\end{aligned} \tag{1}$$

Where a_1, a_2 are the minimum and maximum capacity constraints of reproduction capacity rational parameters for the manufacturers $a_1, a_2 > 0$.

Using the similar transformation method of personals rational constraints to the manufacturer, we get the retailer's generalized form of profit function.

$$\pi_2 = (p_m - c_r - p_r)\, x - \frac{1}{2} b (D - x)^2. \tag{2}$$

Where b is rational constraints parameter of quadratic function for the retailer. $b > 0$.

In the case of hiding information objective function for manufacturer is

$$\max \pi_3\,(p_r) = \int_{c_{r1}}^{c_{r2}} \pi_1 f\,(c_r)\, dc_r. \tag{3}$$

Where π_1 is determined by the (1), operating cost parameter for retailers is $c_r \in [c_{r1}, c_{r2}]$, probability density function and distribution function are $f(c_r)$ and $F(c_r)$.

Objective function for Retailer is

$$\arg\max \pi_2 = \arg\max_{\overline{c_r}} \left[p_m x - (\overline{c_r} + p_r\,(\overline{c_r}))\, x - \frac{1}{2} b (D - x)^2 \right], \tag{4}$$

Where $\overline{c_r}$ is retailer's operating cost estimates for manufacturer, $x = d(p_r)^k$, $(d > 0, k > 1)$. Based on the principal-agent theory, let $p_m x = P$, derivative of right side of (4) at $\overline{c_r}$ and let it equal to 0, then

$$\begin{aligned} P' &= (1+u)\,x + (c_r + p_r)\,dkp_r^{k-1}u \\ &\quad - b\,(D-x)\,dkp_r^{k-1}u, \\ p_r{}' &= u. \end{aligned} \tag{5}$$

So, (3) is the objective function and (5) is equation of state control for the principal-agent problems under asymmetric information. According to the maximum principle (Wang and Wu 2009; Zhou Yong-wu and Wang Sheng-dong 2008), the Hamiltonian function for this problem is

$$\begin{aligned} H &= \Big[\,(p_0 - c_m)\,x - P - \frac{1}{2}a_1(x - Q_1)^2 - \frac{1}{2}a_2(Q_2 - x)^2\Big]f\,(c_r) \\ &\quad + \lambda_1\Big[\,(1+u)\,x + (c_r + p_r)\,dkp_r^{k-1}u - b\,(D-x)\,dkp_r^{k-1}u\Big] + \lambda_2 u. \end{aligned} \tag{6}$$

Where λ_1, λ_2 are state variables for the control problem.

Control equation is

$$\begin{aligned} \frac{\partial H}{\partial u} &= \lambda_1\Big[x + (c_r + p_r)\,dkp_r^{k-1} \\ &\quad - b\,(D-x)\,dkp_r^{k-1}\Big] + \lambda_2 = 0. \end{aligned} \tag{7}$$

State equation is

$$\frac{d\lambda_1}{dc_r} = -\frac{\partial H}{\partial P} = f\,(c_r)\,, \tag{8}$$

$$\begin{aligned} \frac{d\lambda_2}{dc_r} &= -\frac{\partial H}{\partial p_r} = -\{[\,(p_0 - c_m) - a_1\,(x - Q_1) \\ &\quad + a_2\,(Q_2 - x)\,]dkp_r^{k-1}f\big(c_r\big) + \lambda_1 dkp_r^{k-2}[\,(1+2u)\,p_r \\ &\quad + (c_r + p_r)\,(k-1)\,u + bdkp_r^2 u - b\,(D-x)\,(k-1)\,u\big]\}. \end{aligned} \tag{9}$$

Solving (8), we have

$$\lambda_1 = F\,(c_r)\,, \tag{10}$$

(7), (9) and (10) together yield

$$p_r = \frac{1}{1+k}\left[Ak - \frac{F\left(c_r\right)}{f\left(c_r\right)}k + b\left(D-x\right)k - c_r k\right]. \tag{11}$$

where

$$A = p_0 - c_m - a_1\left(x - Q_1\right) + a_2\left(Q_2 - x\right),$$
$$x = d\left(p_r\right)^k, \left(d > 0, k > 1\right).$$

Under the condition of asymmetric information optimal recovery prices for retailer satisfy Eq. (11). Using (5) we get the purchase price for manufacturer under asymmetric information

$$p_m = \frac{1 + p_r{}'}{p_r{}'k} + c_r + p_r - b\left(D - dp_r^k\right)$$

3 Numerical Experiments

Assuming this model parameters as shown in Table 1, initial point $p^{(0)} = (5{,}3)$, $Q_1 = 100$, $Q_2 = 2{,}000$, $a_1 = 0.4$, $a_2 = 0.4$, $\varepsilon = 0.1$, $b = 0.6$, $k = 5$. The cost of marginal operating outlets (including inventory, transportation) under the condition of asymmetric information subjects to the uniform distribution [0.1,0.6]. Optimal solution under the condition of asymmetric information and different price elasticity are given in Table 2.

It can be seen from Table 2 that manufacturers can set a price $\{p_m, p_r\}$ to select the right agent in a large number of retailers according to the design of price strategies.

Table 1 Parameters for the model

p_0	c_m	c_r	D	d	k	ω_1	ω_2
100	2	0.5	1,500	10	5	0.5	0.5

Table 2 Optimal solution under the condition of asymmetric information and different price elasticity

k	p_m	p_r	π
1	155.2225	114.8187	1.9985×10^4
1.5	62.4226	25.4241	9.2397×10^4
2	17.3943	11.4017	1.1193×10^5
2.5	8.9691	7.0189	1.1809×10^5
3	6.3246	5.0753	1.2083×10^5
3.5	5.764	4.0252	1.2231×10^5
4.5	4.1896	2.9643	1.2567×10^5
5	4.0313	2.6512	1.2424×10^5

Under the asymmetric information, optimal recovery prices for manufacturers and retailers are reduced, but the total profits are increased as the price elasticity of goods increase.

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