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Price Decision of Two Period Closed-loop Supply Chain with the Manufacturer's Green Activities Program

Han Xiu-ping[1], Chen Dong-yan[2]*, Chen De-hui[3]
[1]School of Management, Harbin University of Science and Technology, 150080, (CHINA)
[2]School of Applied Science, Harbin University of Science and Technology,150080, (CHINA)
[3]School of Computer and Information Engineering, Harbin University of Commerce, Heilongjiang, Harbin 150028, (CHINA)
E-mail: xiupinghan@163.com

ABSTRACT

In this paper, price strategy of two period remanufacturing closed-loop supply chain is studied. Considering that manufacturers invest green activities program in the end of the first period, the optimal pricing and the optimal level of green activities of centralized and decentralized decision-making are obtained, and the revenue sharing contract of the coordination supply chain is given. The results show that, in order to sell more new products in the first period and ensure more remanufacturing products to increase their profits in the second period, manufacturers should reduce the price of new product. Under the cases of centralized and decentralized decision-making, the price of the new product in the first period will be decrease with the increase of the scale parameter, and the optimal level of green activities will increase with the increase of the scale parameter. But under decentralized decision-making, the member's profit of the supply chain increases with the increase of the scale parameter. Finally, a numerical example given demonstrates the above conclusion.

KEYWORDS

Two period closed-loop supply chain; Level of green activities; Differential price strategy; Collection rate; revenue sharing contract.

INTRODUCTION

With lack of the resources and energy, promulgation of a series of environmental protection regulations and the demand of sustainable development, many manufacturers contain the reverse recovery and re-manufacturing into the general strategy of enterprises and carry out the supply chain management[1,2]. The international financial crisis proved that only the companies focusing on environmental protection and carrying out the green management strategies can get the underlying and long-term competition strengths in 2008. To get waste products required for remanufacturing and enhance the sustainable development capabilities, now many manufacturers in the closed-loop supply chain such as HP, Ford and Kodak consecutively invest the green activities programs, including ad promotion and exchange activities of recycling strategy, logistics service, money and symbolic incentive and employee training, in order to implement new closed-loop supply chain management.

The "extended producer responsibility (called as EPR)" makes manufacturers forced to invest the green activities program in the closed-loop supply chain management. This regulation regulates that the original product manufacturers are responsible for the whole product period, especially recycling and remanufacturing after products are consumed. The EPR regulation regulates to construct the reverse recycling channel of the product recycling and remanufacturing. Manufacturers, retailers or third-parties are responsible for reverse recycling. Savaskan models and analyzes three recycling modes of the waste products in the closed-loop supply chain system and concludes that the retailer-dominated recycling mode is better than the manufacturer-dominated and third-party-dominated recycling mode[3]. He further studies choice of the manufacturer's recycling mode when retailers compete with each other and thinks that choice of the recycling mode is affected by competition degree between retailers to some extent[4]. Hong studies the optimal sale price in three hybrid recycling mode, namely simultaneous recycling of manufacturer and retailer, simultaneous recycling of retailer and third party, and simultaneous recycling of manufacturer and third-party, analyzes and compares profits of members, and gives the contract to coordinate the supply chain[5]. Ni Ming constructs the model of the retailer and repair center recycling mode for the electronic waste products and finds that the recycling price of the repair center recycling mode is higher than it of the retailer recycling mode and the repair center recycling mode can be selected when the repair cost of the repair center is higher than the saved unit cost of remanufacturing[6]. Yi Yuyin and Liang Jiami construct the remanufacturing closed-loop supply chain mode with hybrid recycling in three punishment and reward mechanisms by using the game theory, compare and analyze the collection rate, retailing price, node companies and supply chain profits under different hybrid recycling modes, and study choice of the optimal hybrid recycling mode from the view of environmental protection, consumer, node companies and supply chain[7].

The product period is not considered in the above research. Ferrer studies pricing strategy of the closed-loop chain of remanufacturing products and new products without differences in two, multiple and limitless product periods under monopoly environment of single oligarch and double oligarchs[8], and further studies pricing strategy of remanufacturing products and new products with significant differences in two periods and multiple periods[9]. Mitra considers governmental allowance in two-period model and gives the influences of the governmental allowance on the decision variants[10]. Chen and Chang study dynamic pricing in two periods and multiple periods when new products and remanufacturing products are competing on one market and compare the optimal pricing [11]. Giovanni studies the model of green activities investment programs of manufacturers, retailers or third parties in two-period closed-loop supply chain and concludes that the manufacturers will invest the green activities programs to recycle the waste products when the green activities investment cost is lower or the outsourcing cost is higher. On the contrary, the manufacturers will select outsourcing mode[12].

For contract coordination of the closed-loop supply chain, Giovanni compares the optimal pricing and recycling strategy in cost and benefit contract and non-contract scheme in the closed-loop supply chain of the green activities program invested by manufacturers and concludes that the retailers are willing to perform the cost and revenue sharing contract when the recycling and remanufacturing rate of waste products is enough high and the sharing parameters are not high[13]. Gao Juhong studies the influence of the undertaken social responsibilities on the decision and profiting of closed-loop supply chain and concludes that the pricing contract and revenue sharing contract can realize coordination of closed-loop supply chain and the sharing contract is more flexible[14].

Existing research on the remanufacturing closed-loop supply chain is mainly based on the static game method. Even if the dynamic environment of the product period is considered, only the collection rate is regarded as the external variant and the green investment of the reverse recycling channel is not established. Provided that the manufacturers invest the green activities program and recycle waste products, this paper constructs two-period closed-loop supply chain, studies the optimal price of retailers, optimal green activities level of manufacturers, and coordination of supply chain, and concludes the following conclusions:

Give the optimal price of the retailer in each period and optimal green activities level of manufacturer at the end of first period under the centralized decision and decentralized decision;

The profits of the supply chain in centralized decision are higher than total profit in decentralized decision.

(3) The profit sharing contract is used to coordinate the supply chain and the influence of the scale parameter change is given.

RELATED ASSUMPTIONS AND VARIANT DEFINITION

During two product periods, the manufacturers produce new products by using raw materials and wholesale them to the monopolized retailers for sale at the price ω_1 at the end of the first period. The retailer sells it the products at the price p_1 on the market. For timely management and recycling, the manufacturers should invest the green activities programs to recycle the waste products. The manufacturers will produce new products and remanufacture products in the second period. Two products are of same quality. The manufacturers wholesale them to the retailers at the same price ω_2 and the retailer sells two products at the price p_2 .

Related assumptions

Assumption 1: the manufacturer is the leader of Stackelberg and the retailer is the follower. The manufacturers and retailers maximize self profits. The market is open and the information between manufacturers and retailers are shared. The stock cost and stock lack cost are not considered.

Assumption 2: the manufacturers first meet the market demand by using the products manufactured with the recycled waste products.

Assumption 3: The time value of the profits is considered. δ indicates the time discount rate of the profits in the second period, $\delta \in [0,1]$

Assumption 4[12]: the manufacturers increase recycled pre-sold products by investing the green activities program. given that A is the level of the green activities, the relation between the collection rate τ of the waste product and A is:

$\tau = hA$

Here $h > 0$ is the scale parameter and indicates the response of the consumers to these activities (environmental benefits).

Assuming that cost $c(A)$ required by A for reaching this green activities level is expressed with A increasing concave function, given $c(A) = \frac{\eta A^2}{2}$, $c(0) = 0$

Here $\eta > 0$ is a parameter. To simplify symbols, we take $\eta = 1$.

Symbol representation

$p_1(\omega_1)$: Sale price of new products in the first period (wholesale price);

$c(c_r)$: Unit production cost of new products (remanufacturing products)

$D(p_i) = Q - p_i$: Requirement function of products in i th period, $i = 1, 2$

τ : Collection rate of waste products, $0 \le \tau \le 1$

$\tau D(p_1) = \tau(Q - p_1)$: it indicates the remanufacturing product quantity in the second period.

$s = c - c_r$: Unit production cost saved in remanufacturing;

g : Unit recycling price paid by the manufacturers to the terminal consumers for the recycled waste products, $0 < g < s$

π_j^d : Profits of member j in decentralized decision, $j = r$ indicates the retailer. $j = m$ indicates the manufacturer.

π^c : Profits of supply chain in centralized decision.

OPTIMAL PRICING AND GREEN ACTIVITIES LEVEL IN CENTRALIZED DECISION

The manufacturers and retailers manufacturer and sell products as a whole in the centralized decision, all decisions are made by one centralized decider according to the maximization rule of the whole profits in the supply chain system. At this time, the system decision can be expressed as the optimization problem.

$$\max_{p_1 p_2 A} \pi^c = (p_1 - c)D(p_1) - \frac{A^2}{2} + \delta[(p_2 - c)D(p_2) + (s - g)\tau D(p_1)] \quad \textbf{(1)}$$

Statement 1: for $\delta h(s-g) < \sqrt{2}$ in centralized decision, the optimal sale price, optimal green activities level and system optimal profits of the supply chain are:

$$p_1^* = \frac{Q + c - Q\delta^2 h^2 (s-g)^2}{2 - \delta^2 h^2 (s-g)^2},\ p_2^* = \frac{Q+c}{2},\ A^* = \frac{\delta h (Q-c)(s-g)}{2 - \delta^2 h^2 (s-g)^2} \quad \textbf{(2)}$$

and

$$\pi^{c*} = \frac{(Q-c)^2}{2[2-\delta^2 h^2 (s-g)^2]} + \frac{\delta(Q-c)^2}{4} \quad (3)$$

Proof: supply chain profit function π^c is the Hessian matrix of p_1, p_2, A in the equation (1), $\delta h(s-g) < \sqrt{2}$, H is the negative definite, so π^c is the joint concave function of p_1, p_2, A, so the unique maximum point (p_1^*, p_2^*, A^*) exists. The optimal solution p_1^*, p_2^* and A^* of the equation (1) can be solved by using the first order optimal conditions, shown as the equation (2). The equation (2) is substituted into the target function π^c to get the optimal profit π^{c*}, shown as the equation (3)

To compare p_1^* and p_2^*, we can know $p_1^* < p_2^*$. it indicates that the manufacturers should sell more products at lower sale price in the first period, so it can ensure that more remanufacturing products are used to improve self total profits in the second period.

OPTIMAL PRICING AND GREEN ACTIVITIES LEVEL IN DECENTRALIZED DECISION

The manufacturer acts as the leader of the supply chain in the decentralized decision. First, decide the wholesale price and green activities level in the first period. The retailer decides the sale price of the products in the first period as the follower. The manufacturers invest on recycling and decide the wholesale price of the products in the second period. The retailers decide the sale price of the products in the second period. The system decision problem can be expressed as the following two optimization problems:
Manufacturer optimization problem:

$$\max_{\omega_1,\omega_2,A} \pi_m^d = (\omega_1 - c)D(p_1) - \frac{A^2}{2} + \delta[(\omega_2 - c)D(p_2) + (s-g)\tau D(p_1)] \quad (4)$$

Retailer optimization problem:

$$\max_{p_1, p_2} \pi_r^d = (p_1 - \omega_1)D(p_1) + \delta[(p_2 - \omega_2)D(p_2)] \quad (5)$$

Statement 2: when $\delta(s-g)h < 2$ in the decentralized decision, the optimal wholesale price, optimal green activities level and optimal profit of the manufacturers are:

$$\omega_1^{**} = \frac{2(Q+c) - Q\delta^2 h^2 (s-g)^2}{4-\delta^2 h^2 (s-g)^2}, \ \omega_2^{**} = \frac{Q+c}{2}, \ A^{**} = \frac{h\delta(Q-c)(s-g)}{4-\delta^2 h^2 (s-g)^2} \quad (6)$$

And

$$\pi_m^{d**} = \frac{(Q-c)^2}{2[4-\delta^2 h^2 (s-g)^2]} + \frac{\delta(Q-c)^2}{8} \quad (7)$$

The optimal sale price and optimal profits of the retailer are:

$$p_1^{**} = \frac{3Q + c - Q\delta^2 h^2 (s-g)^2}{4-\delta^2 h^2 (s-g)^2}, \ p_2^{**} = \frac{3Q+c}{4}, \quad (8)$$

and

$$\pi_r^{d**} = \frac{(Q-c)^2}{[4-\delta^2 h^2 (s-g)^2]^2} + \frac{\delta(Q-c)^2}{16} \quad (9)$$

Proof: the backward induction method is used. First, the decision problem of the second period is considered.

The optimal sale price of the retailer meets the optimization problem: $\max\limits_{p_2,} \pi_{r2}^d = (p_2 - \omega_2)D(p_2)$

From concave solute of π_{r2}^d for p_2, we can get $p_2(\omega_2) = \dfrac{Q+\omega_2}{2}$ **(10)**

At this time, the optimal wholesale price of the manufacturer meets the optimization problem:

$$\max_{\omega_2} \pi_{m2}^d = (\omega_2 - c)D(p_2) + (s-g)\tau D(p_1)$$

From the validation, π_{m2}^d is the concave function on ω_2, based on the first order optimal conditions, we can get: $\omega_2 = \dfrac{Q+c}{2}$ **(11)**

By combining the equation (10), we can get $p_2^{**} = \dfrac{3Q+c}{4}$ **(12)**

Next, the decision of the first period is considered. p_2^{**} is substituted to the retailer optimization problem (5), we can get: $\max\limits_{p_1} \pi_{r1}^d = (p_1 - \omega_1)(Q - p_1) + \delta \dfrac{(Q-c)^2}{16}$

From the first order optimal condition of π_{r1}^d on p_1, we can get: $p_1(\omega_1) = \dfrac{Q+\omega_1}{2}$ **(13)**

The equation (13), (12) and (11) are substituted to the optimization problem (4) of the manufacturers, we can get:

$$\max_{\omega_1, A} \pi_{m1}^d = (\omega_1 - c)\left(\frac{Q-\omega_1}{2}\right) - \frac{A^2}{2} + \delta\left[\frac{(Q-c)^2}{16} + (s-g)\tau\left(\frac{Q-\omega_1}{2}\right)\right]$$

π_{m1}^d is the joint concave function on ω_1, A, from the first order optimal conditions, we can get:

$$\omega_1^{**} = \frac{2(Q+c) - Q\delta^2 h^2 (s-g)^2}{4 - \delta^2 h^2 (s-g)^2},\ A^{**} = \frac{h\delta(Q-c)(s-g)}{4 - \delta^2 h^2 (s-g)^2} \quad \textbf{(14)}$$

From the equation (10)-(13), the equation (8) and (9) are found:

Finally, the equation (6) is substituted to the equation (4), we can get the equation (7). To substitute the equation (8) to the equation (5), we can get the equation (9).

COORDINATION OF REVENUE SHARING CONTRACT

The revenue sharing contract indicates that the retailers return certain proportion of self sale revenue to the manufacturers to offset the loss of the manufacturers and make the profit level of the manufacturers and retailers reach the level in centralized decision when the manufacturers make the wholesale price ω_1' and ω_2' less than the cost price. This method can realize optimal whole benefits of the supply chain. Assuming that the retailers and manufacturers allocate the sale benefits of the retailers by the proportion of ϕ and $1-\phi$, we can get the following conclusions:

Statement 3: The necessary and sufficient conditions for the two-period closed-loop supply chain to reach the coordination state in the revenue sharing contract:

$$\omega_1' = \frac{2\phi c - \phi\delta^2 Q(s-g)^2 h^2}{2 - \delta^2 (s-g)^2 h^2},\ \omega_2' = \phi c \quad \textbf{(15)}$$

Proof: the proof process is similar to it of the statement 2, so it is ignored.

When ω_1', ω_2' are given by the statement 3, the sale price of the retailer’s new products and remanufacturing products reach the level in the centralized decision. The profits of the retailer and manufacturers are $\pi_r'^{d**}=\phi\pi^{c*} and \pi_m'^{d**}=(1-\phi)\pi^{c*}$. With growth of the sharing proportion ϕ, the profits of both parties increase and decrease respectively. ϕ is determined by the negotiation capability of both parties, but the personal rational constraint of both parties should be met, namely: $\pi_r'^{d**} > \pi_r^{d**}$和$\pi_m'^{d**} > \pi_m^{d**}$

NUMERICAL COMPUTING

With the vehicle engine manufacturers and retailers as one example, this section studies the influences of the scale parameter h representing the environmental benefits on decision variants and profits in two decisions. Given
$Q = 20, c = 10, c_{2R} = 5, s = 5, \delta = 0.9, g = 4, \alpha = 0.6$.

For the statement 1 and 2, the influence of scale parameter change on the sale price, wholesale price and green activities level of the new products in the first period are simulated in a numerical manner. The results are shown as the figure 1-2.

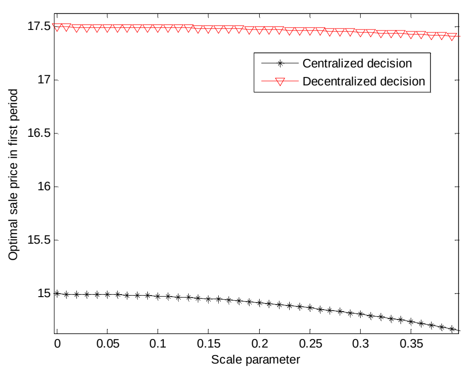

Figure 1: Influence of scale parameter on sale price in the first period under different decisions

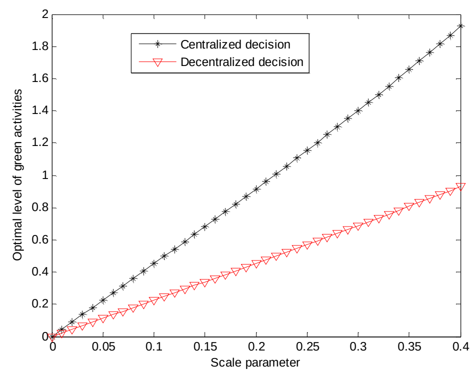

Figure 2: Influence of scale parameter on green activities level under different decisions

Conclusions: regardless of centralized decision or decentralized decision, the sale price of the new products in the first period will decrease with increase of the scale parameter and the optimal green activities level will increase with growth of the scale parameter. The wholesale price of the first period under decentralized decision will decrease with growth of the scale parameter. It indicates that the bigger scale parameter indicate smaller investment on recycling cost and lower wholesale price and sale price and more recycled waste products will facilitate remanufacturing under same green activities level.

CONCLUSION

This paper studies the optimal sale price and wholesale price, optimal green activities level and profits of the supply chain members in each period under centralized decision and decentralized decision for the two-period closed-loop supply chain in the green activities programs invested by the manufacturers. Research indicates that the manufacturers should reduce the sale price of the products in the first period to sell more new products and ensure more remanufacturing products in the second period for improving profits. The scale parameter representing the environmental benefits does not affect the sale price and wholesale price of two products in the second period under two decisions. The sale price and wholesale price will decrease with growth of the scale parameter in the first period. The optimal green activities level will increase with growth of the scale parameter. This paper only studies the two-period problem of new products and remanufacturing products without pricing difference. The remanufacturing products with pricing differences and multi-period problems can be further studied.

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