Pricing Strategy and Coordination of Closed-Loop Supply Chain with e-Commerce Platform Sales and Services

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Abstract: In the context of “Internet +”, the impact of e-commerce platform services on product market demand should be considered, we investigate a closed-loop supply chain (CLSC) with e-commerce platform sales and services. The demand depends on the price of products and service level of the e-commerce platform. Base on game theory, we derive the optimal strategies for both the centralized and the decentralized channel scenarios. Subsequently, we analyze the relationship between the optimal strategies and elasticity coefficient of service level. We find that: the optimal strategies, market demand and system's profit all increase with the increase of elasticity coefficient of service level. In contrast to that they all decrease with the increase of elasticity coefficient service cost. We finally give a coordination contract to increase social welfare.

1. Introduction

In recent years, on the one hand, the rapid renewal of products and the rapid increase of waste products lead to increasingly serious environmental problems. On the other hand, with the development of information technology and e-commerce, the consumers prefer to buy products through e-commerce platforms and the traditional supply chain can’t fully adapt to the development of economic globalization. As a result, more and more enterprises use e-commerce platforms for product sales and recycling. In fact, the excellent service of the e-commerce platform has also made a great contribution to the sales and recycling of products. All of these have greatly promoted the development of closed-loop supply chain [1-3].

At present, many research achievements have been made in the closed-loop supply chain. Savaskan et al. analyzed the optimal strategies under different recycling bodies and carried out Pareto optimization[2]. Xiong et al. analyse the performance of manufacturer-remanufacturing and supplier-remanufacturing in a decentralised CLSC [3]. Ma et al. investigated the optimal pricing decision problem in closed-loop supply chains with marketing effort and fairness concerns [4]. Wang et al. analyzed the influence of the dominant relationship of the system members and the fair concern of the third-party network sales platform on optimal strategies of the system [5]. Xiao J studied the cooperation strategy between manufacturer and retailer in e-supply chain [6]. Choi et al. constructed a three-level closed-loop supply chain model and studied the influence of the dominant position of supply chain members on the overall performance of the closed-loop supply chain [7]. Chiang et al. analyzed and compared the operation modes of traditional sales channels and e-commerce sales channels, and pointed out that e-commerce sales channels are conducive to reducing product sales prices [8].

Based on the above literatures, we construct a closed-loop supply chain (CLSC) model with e-commerce platform sales and services. Subsequently, we derive the optimal strategies for both the decentralized and the centralized channel scenarios. Moreover, we analyze the relationship between the optimal strategies and some parameters. At last, we give a coordination contract to increase

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social welfare.

2. Problem Descriptions and Model Assumptions

In this paper, we study a CLSC model with e-commerce platform sales and services. In the forward supply chain, the manufacturer can either directly use raw materials with the unit cost of production c_m, or recycle used products with the unit cost of remanufacturing c_r to produce a new product and sell it to consumers with a retail price p through the e-commerce platform. Then the e-commerce platform makes profits from sales commissions to the manufacturer. While in the reverse supply chain, the manufacturer recycles valuable used products directly. The market demand is a linear function of the retail price and service of e-commerce platform.

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$$D = \phi - p + rs \tag{1}$$

where ϕ is the market size, r is used to measure the impact of service level on demand. The total service cost of the e-commerce platform is expressed as $ks^2/2$, where k is the service cost coefficient [9]. The used product collection rate τ is introduced to reflect the collection effort and signify the reverse channel performance. In this paper, the collection rates of the manufacturer can be simplified as follows: $\tau = \sqrt{I/C_L}$, where C_L is a scalar parameter, which is the coefficient of exchange between the collection rate and the investment. I denotes the investment of the manufacturer.

There are some assumptions in this paper.

(1) New products and remanufactured products are homogeneous, and the information is symmetric.

(2) Without loss of generality, assume that the behavior of all participants is profitable.

(3) All strategies of CLSCs are considered in a single period.

(4) Agents of CLSCs are risk-neutral and the e-commerce platform is the market leader.

Based on the above problem formulation and assumptions, profits of the manufacturer and the e-commerce platform are given as follows:

$$\pi_M = \left(p - \rho - c_m + (\Delta - a)\tau\right)(\phi - p + rs) - C_L\tau^2 \tag{2}$$

$$\pi_N = \rho(\phi - p + rs) - ks^2/2 \tag{3}$$

3. Decision Models

3.1 Centralized Model

In the centralized channel, the manufacturer and the e-commerce platform cooperate with each other. It's a benchmark to compare with the decentralized models. The system profit of the CLSC can be expressed as follow:

$$\pi_{SC}^C = \left(p - c_m + (\Delta - a)\tau\right)(\phi - p + rs) - C_L\tau^2 - ks^2/2 \tag{4}$$

Lemma1 If $C_L > (\Delta - a)^2$, the profit function π_{SC}^C is strictly concave in p, s and τ.

Proof The Hessian matrix of π_{SC}^C is

$$H(p,s,\tau) = \begin{bmatrix} -2 & r & -(\Delta - a) \\ r & -k & r(\Delta - a) \\ -(\Delta - a) & r(\Delta - a) & -2C_L \end{bmatrix}$$

It is obviouss that $\partial^2\pi_{SC}^C/\partial p^2 = -2 < 0$, $\dfrac{\partial^2\pi_{SC}^C}{\partial p^2}\dfrac{\partial^2\pi_{SC}^C}{\partial s^2} - \dfrac{\partial^2\pi_{SC}^C}{\partial p\partial s}\dfrac{\partial^2\pi_{SC}^C}{\partial s\partial p} = 2k - r^2 > 0$ and $2k - r^2 > k > 0$, if $C_L > (\Delta - a)^2$, then it is easy to verify that $\left|H(p,s,\tau)\right| = -\left(2C_L\left(2k-r^2\right) - k(\Delta-a)^2\right) < 0$.

Simultaneous equations $\partial\pi_{SC}^{C}/\partial p = 0$, $\partial\pi_{SC}^{C}/\partial s = 0$ and $\partial\pi_{SC}^{C}/\partial\tau = 0$, we get the proposition1.

Proposition1 In the centralized model, if $k - r^2 > 0$, $C_L > (\Delta - a)^2$, the optimal strategies are given by

$$p^{C*} = \frac{2C_L c_m\left(k-r^2\right) + \phi k\left(2C_L - (\Delta-a)^2\right)}{2C_L\left(2k-r^2\right) - k(\Delta-a)^2}, s^{C*} = \frac{2C_L r(\phi - c_m)}{2C_L\left(2k-r^2\right) - k(\Delta-a)^2}, \tau^{C*} = \frac{k(\phi-c_m)(\Delta-a)}{2C_L\left(2k-r^2\right) - k(\Delta-a)^2}.$$

To ensure $\tau^{C*} < 1$, we should give the following assumption 1.

Assumption 1 The scale parameter $C_L > \max\left\{(\Delta-a)^2, \dfrac{k(\Delta-a)^2 + k(\phi-c_m)(\Delta-a)}{2\left(2k-r^2\right)}\right\}$.

Substituting the value of p^{C*}, s^{C*} and τ^{C*} back in the equations (1)and(4), we get the market demand and the system's profits.

$$D^{C*} = \frac{2C_L k(\phi-c_m)}{2C_L\left(2k-r^2\right) - k(\Delta-a)^2}, \pi_{SC}^{C*} = \frac{C_L k(\phi-c_m)^2}{2C_L\left(2k-r^2\right) - k(\Delta-a)^2}.$$

Corollary 1 (1) The optimal retail price, service level of the e-commerce platform and the recycling rate of the manufacturer, the market demand and the system's profit are monotonically increasing in terms of the influence coefficient *r*. (2) The optimal retail price, service level of the e-commerce platform and the recycling rate of the manufacturer, the market demand and the system's profit are monotonically decreasing in terms of the influence coefficient *k*.

3.2 Decentralized Model

As independent economic entities, the manufacturer and the e-commerce platform make decisions with the goal of maximizing profits. The decision-making sequence is as follows. First, the e-commerce platform determines the unit commission□ □ and service level *s*. Second, the manufacturer determines the retailing price *p* and the degree of investment recovery *I*, which determines the return rate of used products □.

Based on the above analysis, we get the Proposition 2-3.

Proposition2 In decentralized model, the optimal strategies of the manufacturer are given by

$$p^{D*} = \frac{C_L c_m\left(k-r^2\right) + \phi k\left(3C_L - (\Delta-a)^2\right)}{C_L\left(4k-r^2\right) - k(\Delta-a)^2}, \ \tau^{D*} = \frac{k(\phi-c_m)(\Delta-a)}{2\left(C_L\left(4k-r^2\right) - k(\Delta-a)^2\right)}.$$

Proposition3 In decentralized model, the optimal strategies of the e-commerce platform are given by

$$\rho^{D*} = \frac{k(\phi-c_m)\left(4C_L - (\Delta-a)^2\right)}{2\left(C_L\left(4k-r^2\right) - k(\Delta-a)^2\right)}, \ s^{D*} = \frac{C_L r(\phi-c_m)}{C_L\left(4k-r^2\right) - k(\Delta-a)^2}.$$

Substituting the value of $p^{D*}, \rho^{D*}, s^{D*}$ and τ^{D*} back in the equations (1)-(3), we get the market demand, the manufacturer's profit and the e-commerce platform's profit.

$$D^{D*} = \frac{C_L k(\phi-c_m)}{C_L\left(4k-r^2\right) - k(\Delta-a)^2}, \pi_M^{D*} = \frac{C_L k^2(\phi-c_m)^2\left(4C_L - (\Delta-a)^2\right)}{4\left(C_L\left(4k-r^2\right) - k(\Delta-a)^2\right)^2},$$

$$\pi_N^{D*} = \frac{C_L k(\phi-c_m)^2}{2\left(C_L\left(4k-r^2\right) - k(\Delta-a)^2\right)}, \pi_{SC}^{D*} = \frac{C_L k(\phi-c_m)^2\left(2C_L\left(6k-r^2\right) - 3k(\Delta-a)^2\right)}{4\left(C_L\left(4k-r^2\right) - k(\Delta-a)^2\right)^2}.$$

Similar to centralized model, from proposition 2 and proposition 3, we can derive corollary 2.

Corollary 2 (1) The optimal retail price, service level of the e-commerce platform and the recycling rate of the manufacturer, the market demand and the system's profit are monotonically increasing in terms of the influence coefficient *r*. (2) The optimal retail price, service level of the e-commerce platform and the recycling rate of the manufacturer, the market demand and the system's profit are monotonically decreasing in terms of the influence coefficient *k*.

4. Strategies Comparison and Analysis

In this section, we compare our results between decentralized and the centralized model. Based on the results summarized in proposition 1-3, some interesting observations can be found.

Proposition 4 (1) $p^{C*} < p^{D*}$, (2) $s^{C*} > s^{D*}$, (3) $\tau^{C*} > \tau^{D*}$, (4) $\pi_{SC}^{C*} > \pi_{SC}^{D*}$.

Proof Beacause $k > r^2$, $\phi > c_m$, $C_L > \left(\Delta - a\right)^2$, thus $C_L\left(2k - r^2\right) - k\left(\Delta - a\right)^2 > 0$, it is easy to verify that

$$(1)\ p^{C*} - p^{D*} = -\frac{C_L k\left(k - r^2\right)\left(\phi - c_m\right)\left(4C_L - \left(\Delta - a\right)^2\right)}{\left(2C_L\left(2k - r^2\right) - k\left(\Delta - a\right)^2\right)\left(C_L\left(4k - r^2\right) - k\left(\Delta - a\right)^2\right)} < 0.$$

$$(2)\ s^{C*} - s^{D*} = \frac{C_L k r\left(\phi - c_m\right)\left(\Delta - a\right)^2}{\left(2C_L\left(4k - r^2\right) - k\left(\Delta - a\right)^2\right)\left(C_L\left(4k - r^2\right) - k\left(\Delta - a\right)^2\right)} > 0.$$

$$(3)\ \tau^{C*} - \tau^{D*} = \frac{k^2\left(4C_L - \left(\Delta - a\right)^2\right)\left(\phi - c_m\right)\left(\Delta - a\right)}{2\left(2C_L\left(2k - r^2\right) - k\left(\Delta - a\right)^2\right)\left(C_L\left(4k - r^2\right) - k\left(\Delta - a\right)^2\right)} > 0.$$

$$(4)\ \pi_{SC}^{C*} - \pi_{SC}^{D*} = \frac{C_L k^3\left(\phi - c_m\right)^2\left(4C_L - \left(\Delta - a\right)^2\right)^2}{4\left(2C_L\left(2k - r^2\right) - k\left(\Delta - a\right)^2\right)^2\left(C_L\left(4k - r^2\right) - k\left(\Delta - a\right)^2\right)^2} > 0.$$

Proposition 4 confirms that the centralized mode is better than decentralized mode. That’s to say that the retail price of centralized mode is lower than that of decentralized mode, the service level of centralized mode is higher than that of decentralized mode, return rate and profits of the system are higher in the centralized mode.

5. Improvements on the Decentralized Model

From the above analysis, we know that the centralized decision model is better than the decentralized decision model for the CLSC with e-commerce platform sales and services. Because the e-commerce platform has the lead, so it needs to give a coordination contract to make the decentralized decision model better.

Generally speaking, if the supply chain system achieves coordination, the retail price, service level and the collection effort under the decentralized scenarios equal that under the centralized scenarios. According to proposition 4, we know that $p^{C*} < p^{D*}$, $s^{C*} > s^{D*}$ and $\tau^{C*} > \tau^{D*}$. Thus, the problem of the e-commerce platform is given as follows:

$$\max_{\rho,s,F} \pi_N = \rho\left(\phi - p\left(\rho, s\right) + rs\right) - \frac{k}{2}s^2 + F$$

$$\text{s.t.}\begin{cases}\left(p,\tau\right) \in \arg\max\limits_{p,\tau}\left\{\left(p - c_m - \rho + \left(\Delta - a\right)\tau\right)\left(\phi - p + rs\right) - C_L\tau^2 - F\right\} \\ \rho = 0, s = s^{C*}, \pi_M \geq \pi_M^{D*}, \pi_N \geq \pi_N^{D*}\end{cases}$$

where F is a fixed payment. $\rho = 0$ and $s = s^{C*}$ mean that the e-commerce platform makes a concession to secure the contract, $\pi_M \geq \pi_M^{D*}$ and $\pi_N \geq \pi_N^{D*}$ mean that the coordinated decision model is better than the decentralized decision model.

By solving the above model, we can get the proposition 5.

Proposition 5 In coordinated model, the optimal strategies of the manufacturer are given by

$$p^* = \frac{2C_L c_m\left(k-r^2\right)+\phi k\left(2C_L-(\Delta-a)^2\right)}{2C_L\left(2k-r^2\right)-k\left(\Delta-a\right)^2}, \rho=0, s^*=\frac{2C_L r\left(\phi-c_m\right)}{2C_L\left(2k-r^2\right)-k\left(\Delta-a\right)^2},$$

$$\tau^*=\frac{k\left(\phi-c_m\right)\left(\Delta-a\right)}{2C_L\left(2k-r^2\right)-k\left(\Delta-a\right)^2}, F^*=\frac{C_L k^3\left(\phi-c_m\right)^2\left(4C_L-\left(\Delta-a\right)^2\right)}{4\left(2C_L\left(2k-r^2\right)-k\left(\Delta-a\right)^2\right)\left(C_L\left(4k-r^2\right)-k\left(\Delta-a\right)^2\right)^2}.$$

Proposition 5 indicates that the channel profit achieves the best level when the system is fully coordinated and shows that the formulation of coordination contracts can, on the one hand, reduce the sales price of products, improve the service level of e-commerce platforms, and enable consumers to get more utility. On the other hand, the recycling rate of waste products and the profits of e-commerce platforms can be increased without reducing the profits of the manufacturer.

6. Numerical Simulation

Next, we will take numerical studies to further examine the effect of *r* on the optimal strategies, and assume that the effect of service level on product demand is less than that of sales price on product demand, i.e. $r \in (0,1)$. Let $\phi=300$, $C_L=3000$, $c_m=50$, $\Delta=35$, $k=10$, $a=5$. Figure 1-4 show the relationship between the optimal strategies and parameter *r* and validate the proposition 4.

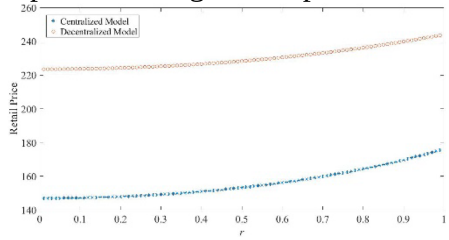

Figure 1 The relationship between the optimal retail price and parameter r

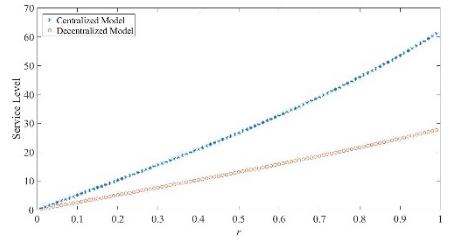

Figure 2 The relationship between the optimal service level and parameter r

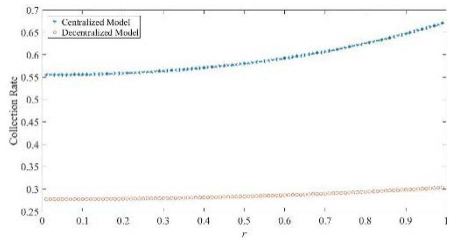

Figure 3 The relationship between the optimal collection rate and parameter r

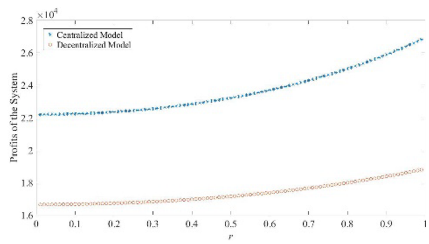

Figure 4 The relationship between the optimal profits of the clsc and parameter r

Figure 1 shows that the optimal retail price of centralized mode is lower than that of decentralized mode and the optimal prices are monotonically increasing in the parameter *r*. Figure 2 shows that the optimal service level of centralized mode is higher than that of decentralized mode and the optimal service levels are also monotonically increasing in the parameter *r*. Furthermore, the gap is widening along as *r* increases between centralized mode and decentralized mode. Figure 3 shows that the optimal collection rate of centralized mode is higher than that of decentralized mode and the optimal collection rates are also monotonically increasing in the parameter *r*. Figure 4 shows that the optimal system's profits of centralized mode is higher than that of decentralized mode and the optimal system's profits are also monotonically increasing in the parameter *r*.

7. Conclusions

In this paper, we address the optimal strategies of a CLSC with e-commerce platform sales and services. Base on game theory, the optimal strategies are derived for both the decentralized and the centralized models. It is found that the centralized decision mode is superior to the decentralized decision mode. Subsequently, we analyze the relationship between the optimal strategies and some parameters. We get that the optimal strategies, market demand and system's profit all increase with the increase of elasticity coefficient of service level. In contrast to that they all decrease with the increase of elasticity coefficient service cost. At last, we give a coordination contract to increase social welfare.

This paper only considers a single manufacturer, e-commerce platform and recycling channel. Next, the impact of manufacturers, e-commerce platforms and recycling channels competition on the optimal strategies should be studied in the future.

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