Benefit Analysis on dual channel closed-loop supply chain with different power structures

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Abstract. Optimal recovery rate, price decision and system efficiency of a closed-loop supply chain are analyzed under the competition of an online retailer and a traditional retailer based on game theory. The results show that, in the market structure dominated by the manufacturer, the manufacturer's profit is higher than that of the retailer being the leadership, and the benefits of the other members of the supply chain and the total system are small. In the market structure dominated by retailers, the benefits of retailers and consumers and the total system are higher than that of the manufacturer being the leadership.

1. Introduction

With the rapid development of the retail industry, the dominant position gradually shifts from manufacturing to retail enterprises. Many large retailers have a strong dominant position in the market and they also have the right leading pricing in the supply chain. On the other hand, with the development of computer technology and network communication technology, the existence of online retailers poses a great challenge to traditional retailers. Therefore, it is very important to study the pricing strategy of closed loop supply chain under different power structure.

Some literatures studied on pricing strategies of closed-loop supply chain under different power structure. Choi¹studied the decision problem of supply chain with leading retailer and analyzed the influence of different market power structure on supply chain decision making. Choi²extended to study the decision problem of the supply chain with duopoly manufacturers and duopoly retailers. Seong and Hean³analyzed the impact of different market power structure on the supply chain decisions. Kaya⁴considered the optimal incentive determination problem in the manufacturing/remanufacturing industry using stochastic demand functions. Lin⁵established two pricing models of closed-loop supply chain which contain double sales channels and recovery channels based on the market power. Cao⁶studied the pricing strategies and coordination mechanism in closed-loop supply chain based on channel competition.

This essay studies the pricing strategies of the dual channel closed-loop supply chain with different power structures and analyzes the influence of different power structure on decision-making system.

2. Problem description and assumption

In our study, we consider a closed-loop supply chain composed of a manufacturer, an online retailer and a traditional retailer. The manufacturer has two options to meet the needs of the customer: products made by new materials and remanufactured products. The remanufactured products and new products are identical in quality and performance, and can be sold in the same market.
We assume that the unit cost of producing the end products form original materials is $c_m$, the total cost of extracting the useful parts from the returns and producing the end products using these parts in the manufacturing process is $c_r$, $c_r < c_m$. Online retailers and traditional retailers sell products to the market through different channels. We assume that the unit price of the product of online retailers is $p_1$, the unit price of the product of traditional retailers is $p_2$. The demand model is a linear model as follows:

$$D_1 = \lambda a - bp_1 + \theta(p_2 - p_1)$$  \hspace{1cm} (1)

$$D_2 = (1- \lambda)a - bp_2 + \theta(p_1 - p_2)$$  \hspace{1cm} (2)

$$D_1 + D_2 = a - bp_1 - bp_2$$  \hspace{1cm} (3)

Among above equations, $D_1$ refers the demand function of online retailers; $D_2$ refers the demand function of traditional retailers; $a$ refers the market capacity; $b$ refers the price elasticity of demand of consumers, $\lambda$ refers network channel preference, $\theta$ refers the channel demand diffusion degree.

3. Pricing strategy under market structure with leading manufacturer

This part will discuss the pricing strategy of closed-loop supply chain under market structure with leading manufacturer. The closed-loop supply chain decision order is as follows: The manufacturer determines the wholesale price of the product $w$ and the recovery rate of the waste product $\tau$ through market forecast. Then the two retailers determine their retail prices $(i = 1, 2)$ in terms of wholesale price $w$ and recovery rate $\tau$. The manufacturer’s problem is:

$$\pi_m = (w - c_m + \Delta \tau)(D_1 + D_2)$$  \hspace{1cm} (4)

$$\pi_{p_i} = (P_i - w)D_i$$  \hspace{1cm} (5)

$$\pi_{p_2} = (P_2 - w)D_2$$  \hspace{1cm} (6)

$$\pi_{p_2} = k\tau(D_1 + D_2) - B\tau^2$$  \hspace{1cm} (7)

In above equation, $k$ is the recycling subsidy, $B$ is scale parameter.

Putting $D_1$ and $D_2$ into (5) and (6), we will get

$$\pi_{p_1} = (P_1 - w)[\lambda a - bp_1 + \theta(p_2 - p_1)]$$  \hspace{1cm} (8)

$$\pi_{p_2} = (P_2 - w)[(1- \lambda)a - bp_2 + \theta(p_1 - p_2)]$$  \hspace{1cm} (9)

Solving them simultaneously, we can get

$$\begin{align*}
\lambda a - bp_1 + \theta(p_2 - p_1) + (p_1 - w)(-b - \theta) &= 0 \\
(1 - \lambda)a - bp_2 + \theta(p_1 - p_2) + (p_2 - w)(-b - \theta) &= 0
\end{align*}$$  \hspace{1cm} (10)

From this relation, we can find

$$p_1 = \frac{(2ab + a\theta)(1 + \lambda) - 2ab}{4(b + \theta)^2 - \theta^2} + \frac{b + \theta}{2b + \theta}w$$  \hspace{1cm} (11)

$$p_2 = \frac{\theta\lambda a + 2(b + \theta)(1- \lambda) a}{4(b + \theta)^2 - \theta^2} + \frac{b + \theta}{2b + \theta}w$$  \hspace{1cm} (12)

Putting (11) and (12) into $\tau = \frac{k(a - bp_1 - bp_2)}{2B}$, we can get
\[ \tau = \frac{ka(b+\theta)}{2B(2b+\theta)} - \frac{kb(b+\theta)}{B(2b+\theta)} \]

Assume \( \frac{ka(b+\theta)}{2B(2b+\theta)} = M \), \( \frac{kb(b+\theta)}{B(2b+\theta)} = N \), \( \tau = M - N \cdot w \)

Putting \( p_1 \), \( p_2 \) and \( \tau \) into \( \pi_m = (w-c_m + \Delta \tau)(a-bp_1-bp_2) \), we can find

\[ \pi_m = \left[ w - c_m + \Delta(M - N \cdot w) \right] \left[ \frac{(b+\theta)(a-2bw)}{2b+\theta} \right] \] (14)

Since it is concave in \( w \), equating \( \frac{\partial \pi_m}{\partial w} = 0 \), we can get

\[ (1 - \Delta N) \left[ \frac{(b+\theta)(a-2bw)}{2b+\theta} \right] + \left[ w - c_m + \Delta(M - N \cdot w) \right] \left( -\frac{2b^2 + 2b\theta}{2b+\theta} \right) = 0 \]

We can simplify it to get

\[ 4b(b+\theta)(1-\Delta N)w = (b+\theta)(1-\Delta N)a - 2b(b+\theta)(\Delta M - c_m) \]

Among above equation, \( w = \frac{a}{4b} \left[ \frac{\Delta M - c_m}{2(1-\Delta N)} \right] \)

Putting the value of \( M \) and \( N \) into above equation, we will get

\[ w^{MS^+} = \frac{[B(2b+\theta) - 2kb(b+\theta)\Delta]a + 2Bb(2b+\theta)c_m}{4b[B(2b+\theta) - kb(b+\theta)\Delta]} \] (15)

So we can get the optimum solution of \( p_1, p_2, \tau \).

4. Pricing strategies under market structure with leading retailer

In the dual channel closed-loop supply chain, when retailers dominate the market structure, online retailers and traditional retailers are leaders, they have more initiative in the game, so they can choose the retail price of the product according to the expectations of their earnings.

Thus we can get a new demand function:

\[ D_1 = \lambda a - b(m_1 + w) + \theta(m_2 - m_1) \] (16)
\[ D_2 = (1-\lambda) a - b(m_2 + w) + \theta(m_1 - m_2) \] (17)

The closed-loop supply chain decision order is as follows: Online retailers and traditional retailers determine the expected earnings of per unit product \( m_i (i = 1, 2) \). Then the manufacturer determines the wholesale price of the product \( w \) and the recovery rate of the used product \( \tau \). The solving process of the model is:

\[ \pi_m = (w - c_m + \Delta \tau)(a - bp_1 - bp_2) \] (18)
\[ \tau = \frac{k(a - bp_1 - bp_2)}{2B} \] (19)
\[ \pi_m = \left[ w - c_m + \Delta \frac{k(a - bp_1 - bp_2)}{2B} \right](a - bp_1 - bp_2) \] (20)

We can simplified it to get

\[ w = \left( \frac{1}{2b} \Delta \cdot \frac{k}{B} (a - bp_1 - bp_2) + c_m \right) \]
Putting the value of $w$ into (8) and (9), we can get

$$P_1^{RS^*} = \frac{(3Bb - 2kb^2\Delta)(\lambda a + \theta x) + (b + \theta)(B - 2kb\Delta)(a - bx) + 2Bbc_m}{5Bb^2 + 8Bb\theta - 2kb^2\Delta - 4kb^2\theta\Delta}$$

(21)

$$P_2^{RS^*} = x^* - P_1^{RS^*}$$

(22)

So we can get the optimum solution of $w$ and $\tau$.

5. Numerical analysis

In order to make a further analysis, this section analyzes the influence of each parameter on the decision result by assigning the parameters in the model.

From the numerical example, we can find that the total profit of the system will increase slowly with the increase of the degree of demand diffusion. We also find that the total profit of the retailer leading system is higher than that of the manufacturer. Because online retailers and traditional retailers dominate pricing, manufacturers can only give lower wholesale price, the retailer can increase sales by adjusting retail price and gain more profit, then the total system profits will be higher. Regardless of market power structure, with the increase in the degree of preference for the network channel, the total system profits decline show a downward trend at first then an upward trend next. This is because the increase in the degree of preference for online channels will make online retailers and traditional retailers in the sales market to compete, thereby reducing the total profit of the system.

6. Conclusion

In conclusion, we studied the pricing decision model of closed-loop supply chain with two channels under different market power structure and analyze the influence of different parameters on system decision-making. The results show that, in the market structure dominated by the manufacturer, the manufacturer's profit is higher than that of the retailer being the leadership, and the benefits of the other members of the supply chain and the total system are small. In the market structure dominated by retailers, the benefits of retailers and consumers and the total system are higher than that of the manufacturer being the leadership.

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