Research on Pricing Decisions in Closed-Loop Supply Chains Considering Corporate Social Responsibility and Retailer Recycling

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Abstract. In the current business landscape, the closed-loop supply chain development model is increasingly favored by enterprises. This trend is driven by its potential to optimize costs and align with principles of green development and active corporate social responsibility. In this context, this chapter assumes a single-cycle closed-loop supply chain consisting of a manufacturer and a retailer, both of which possess corporate social responsibility awareness. The chapter explores the impact of the manufacturer and retailer's joint implementation of CSR under two scenarios: manufacturer dominance and retailer dominance. Specifically, it investigates how the CSR actions of both parties, including the degree of CSR implementation and the allocation of CSR responsibilities, influence pricing decisions, recovery rates, and the overall optimal profit and utility of the closed-loop supply chain system. The conclusion indicates that under both power structures, the corporate social responsibility (CSR) actions of manufacturers and retailers can reduce wholesale and retail prices, promote the recycling of waste products, and enhance the overall utility of the closed-loop supply chain.

Keywords: Corporate Social Responsibility; Channel Power Structure; Closed-Loop Supply Chain; Retailer Recycling.

1 Introduction

As technology and the economy advance, the pace of product iteration accelerates, leading to an increase in obsolete products, resource wastage, and environmental pollution. Recycling and remanufacturing are considered effective means to improve resource utilization efficiency, making the implementation of closed-loop supply chain management an important strategy for businesses. Implementing closed-loop supply chain management is not only one way to fulfill corporate social responsibility but also promotes cost optimization for businesses.

This paper organizes and summarizes relevant literature from three aspects: corporate social responsibility, channel power structure, and closed-loop supply chain recycling. It can be observed that scholars have conducted extensive research on various issues related to closed-loop supply chains from multiple perspectives, yielding

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significant research outcomes. Panda et al.[1] quantified CSR in terms of consumer surplus and studied the effectiveness of quantity discount contracts in coordinating supply chains with CSR implementation. Chen[2] integrated government subsidies with CSR in closed-loop supply chain studies, analyzing their impact on recycling channel choices and pricing decisions. Peng [3]explored how CSR affects green innovation and risk aversion, finding that higher CSR promotes green innovation and supply chain efficiency, while strong risk aversion hampers it. DEY[4] proposed a model where cooperation between manufacturers and recyclers leads to win-win outcomes, favoring recycling by recyclers over manufacturers. Wang et al. [5]found that channel leaders' profits increase with CSR improvement in a three-tier closed-loop supply chain, with symmetric information favoring them. Kleber et al.[6]studied pricing decisions in closed-loop supply chains with competition between remanufacturers in both scrap collection and remanufactured product sales.

This paper discusses the impact of both manufacturer and retailer jointly implementing CSR on the closed-loop supply chain. Specifically, it will analyze how the CSR actions (implementation level and cost-sharing ratio) of both manufacturers and retailers, under the leadership of either party, influence pricing, recycling rate decisions, and the overall optimal utility of the closed-loop supply chain system.

2 Modeling and analysis

2.1 Problem description

This paper assumes a research focus on a single-period closed-loop supply chain composed of a manufacturer and a retailer, both of whom possess corporate social responsibility awareness. In this scenario, the manufacturer is responsible for producing new products and remanufacturing discarded products, while the retailer handles product sales and the recovery of discarded items.

2.2 Basic Assumptions

1. Demand function is $D = a - \beta p$. Considering w and p as the wholesale price and retail price respectively, the condition $p > w$ is necessary for the sales process to proceed normally.
2. Assuming a sufficiently large scale of recovery, the cost incurred by the retailer for recovery is $k\tau_r{}^2$.[7]
3. Let $\Delta = c_m - c_r$, where Δ represents the cost saving per unit for remanufacturing. Additionally, both the manufacturer and the retailer profit from the recovery and remanufacturing process, implying that $\Delta > b > A$.
4. This paper adopts the consumer surplus approach to characterize the investment of manufacturers and retailers in CSR. $CS = \int_{p_{min}}^{p_{max}}(a - \beta p) = \frac{(a-\beta p)^2}{2\beta}$ .When CSR cost-sharing ratios of the manufacturer and retailer are represented by h and $1 - h$ respectively, the additional profit increment resulting from the joint implementation

of CSR by both parties is $CS_m = h * \theta * \frac{(a-\beta p)^2}{2\beta}$ and $CS_r = (1-h) * \theta * \frac{(a-\beta p)^2}{2\beta}$ respectively.

The variable and their meanings involved in the paper are shown in Table 1.

Table 1. list of variable definitions

variable	meaning
a	potential market demand
p	unit product retail price
m	unit product profit
c_m	unit fixed cost for manufacturing
c_r	unit fixed cost for remanufacturing
w	unit product wholesale price
b	manufacturer's recycling price
A	retailer's unit recycling price
τ_r	recycling rate of recycled products
β	price sensitivity coefficient of consumer demand
θ	degree of social responsibility fulfillment
h	proportion of social responsibility
k	scale coefficient of recycled product recovery

2.3 Model Solving

The total utility function for the manufacturer is:

$$V_m = \pi_m + h * \theta * CS_m = D * (w - c_m + \Delta\tau_r - b\tau_r) + h * \theta * \frac{D^2}{2\beta} \quad (1)$$

The total utility function for the retailer is:

$$V_r = \pi_r + (1-h) * \theta * CS_r = D * (p - w - A\tau_r + b\tau_r) + (1-h) * \theta * \frac{D^2}{2\beta} \quad (2)$$

Manufacturer Dominance (MTR Model)

In the MTR model, where the manufacturer takes the lead role, the decision sequence in the closed-loop supply chain is as follows: first, the manufacturer determines the wholesale price w^{MTR}, then the retailer sets the selling price p^{MTR} and τ_r^{MTR}.

Equation (1) has an optimal solution if its second derivative is negative definite:

$$\frac{\partial^2 V_m}{\partial^2 w} = -\frac{4k\beta(k(4-(2-h)\theta) - (b-A)\beta(\Delta - A))}{(b-A)^2\beta - 2k(2-\theta+h\theta))^2} < 0$$

Equation (2) has an optimal solution if its Hessian matrix is negative definite:

$$H = \begin{bmatrix} -\beta(2-(1-h)\theta) & -(b-A)\beta \\ -(b-A)\beta & 2k \end{bmatrix}$$

Order $H_1 = -\beta(2-(1-h)\theta) < 0$, $H_2 = \beta(2k(2-\theta+h\theta)-(b-A)^2\beta) > 0$

That is, when $k > \frac{(A-b)^2\beta}{4+2(-1+h)\theta}$ is positive, equation (1)(2) has an optimal solution:

$$\begin{cases} w^{MTR*} = \frac{a(2(2-\theta)k-\xi_2)+\xi_8(2k(2-\theta(1-h))-\xi_3)}{2\beta(k(4-\theta(2-h))-\xi_1)} \\ p^{MTR*} = \frac{a+\frac{\xi_4}{k((4-\theta(2-h))-\xi_1)}}{\beta} \\ {\tau_r}^{MTR*} = \frac{\xi_9}{2k(4-(2-h)\theta)-2\xi_1} \end{cases} \tag{3}$$

Substituting formula (3) into (1) and (2), we can get:

$$V_m^{MTR*} = \frac{\xi_5}{2\beta(k(4-(2-h)\theta)-\xi_1)}$$

$$V_r^{MTR*} = \frac{(2k(2-(1-h)\theta)-\xi_3)\xi_5}{4\beta(k(4-(2-h)\theta)-\xi_1)^2}$$

Retailer Dominance (RTR Model)

In the RTR model, the decision-making sequence within the closed-loop supply chain begins with the dominant retailer determining the unit profit $m^{RTR}$and the recovery rate $\tau_r{}^{RTR}$, followed by the manufacturer adjusting the wholesale price w^{RTR} .

The process of solving when the retailer is dominant is similar to the process when the manufacturer is dominant.

when $k > \frac{\beta(\Delta-A)^2}{6+h(4-2\theta)}$ is positive, equation (1)(2) has an optimal solution:

$$\begin{cases} w^{RTR*} = \frac{\xi_8(2k(2+h(1-\theta))-\xi_1)+a(2k(1-h\theta)-\xi_1)}{\beta(k(6+h(2-4\theta)-\xi_6)} \\ p^{RTR*} = \frac{a+\frac{2\xi_4}{\beta(k(6+h(2-4\theta)-\xi_6)}}{\beta} \\ {\tau_r}^{RTR*} = \frac{\xi_{10}}{\beta(k(6+h(2-4\theta)-\xi_6)} \end{cases} \tag{4}$$

Substituting formula (4) into (1) and (2), we can get:

$$V_m^{RTR*} = \frac{2\,\xi_7(2-h\theta)}{\beta(k(6+h(2-4\theta)-\xi_6)^2}$$

$$V_r^{RTR*} = -\frac{\xi_5}{\beta(k(6+h(2-4\theta)-\xi_6)}$$

Note: $\xi_1 = \beta(b-A)(\Delta-A)$, $\xi_2 = \beta(b-A)(2\Delta-A-b)$, $\xi_3 = \beta(b-A)^2$, $\xi_4 = k(a-c\beta)$, $\xi_5 = k(a-\beta c)^2$, $\xi_6 = \beta(\Delta-A)^2$, $\xi_7 = k^2(a-c\beta)^2$, $\xi_8 = c\beta$, $\xi_9 = (b-A)(a-\beta c$

3 Numerical example

Set the relevant parameters $k = 1000, c = 60, a = 200, \beta = 0.3, A = 10, b = 20, \Delta = 30$ and analyze the impact of manufacturing CSR implementation on pricing, recovery rate, and profits in a closed-loop supply chain.

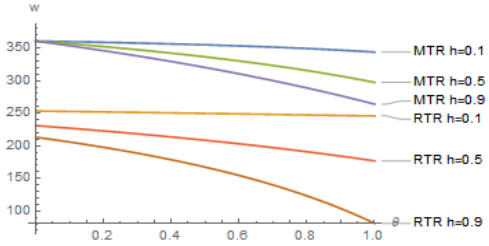

Fig. 1. The impact of corporate social responsibility behavior on w

Based on Figure 1, the wholesale price decreases as θ increases, comparing the wholesale prices in the two decision models, it is found that when both the manufacturer and the retailer jointly implement CSR, regardless of the distribution of CSR implementation, the wholesale price under the retailer-dominant power structure is always lower than that under the manufacturer-dominant power structure. Additionally, regardless of who the dominant player is, the wholesale price decreases with the increase in the manufacturer's CSR sharing ratio.

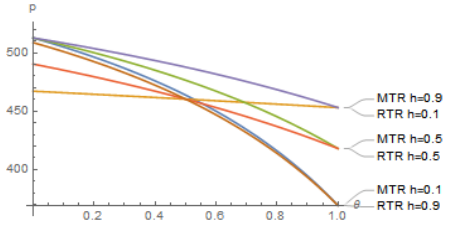

Fig. 2. The impact of corporate social responsibility behavior on p

As we can see from Figure 2, the retail price decreases as θ increases. The distribution of retail product prices is influenced by the interaction between the degree of CSR implementation θ and the power structure h in the closed-loop supply chain. When the retailer's CSR allocation ratio exceeds 0.5, the retail price is higher under manufacturer dominance; conversely, it is higher under retailer dominance. When the manufacturer dominates, the retail price decreases as the CSR sharing ratio increases; conversely, under the dominance of the retailer, the retail price increases as the CSR sharing ratio increases. This is because when the retailer bears a higher proportion of CSR and the manufacturer serves as the channel leader, the manufacturer needs to increase the retail price to compensate for its own profits.

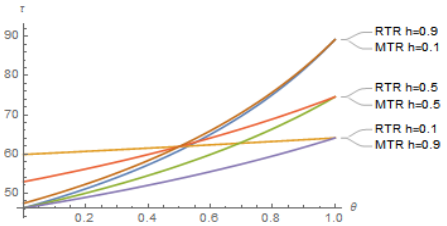

Fig. 3. The impact of corporate social responsibility behavior on τ

According to Figure 3, it can be observed that τ increases with the strengthening of θ and h under the dominance of the retailer. When the CSR sharing ratio of the retailer exceeds 0.5, the recycling rate is higher under the dominance of the retailer; conversely, it is higher under the dominance of the manufacturer.

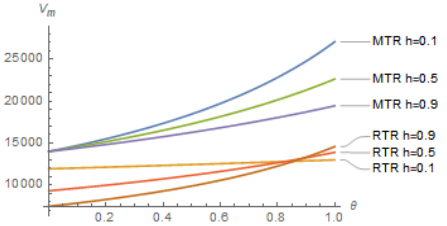

Fig. 4. The impact of corporate social responsibility behavior on V_m

According to Figure 4, when the manufacturer acts as the dominant power, the manufacturer's overall utility is always higher than that of the retailer's dominance. Furthermore, when the manufacturer dominates, the stronger the manufacturer's awareness of implementing CSR, the higher the total utility, and the same applies when the retailer dominates. When the level of CSR implementation is high ($\theta > 0.8$), the total utility of the retailer increases with the increase in h; conversely ($\theta < 0.8$), the total utility of the retailer decreases with the increase in h.

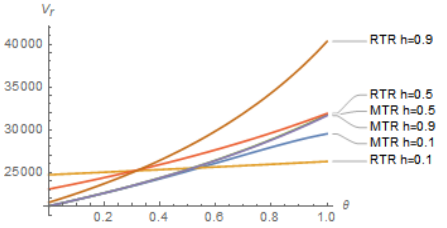

Fig. 5. The impact of corporate social responsibility behavior on V_r

As we can see from Figure 5， for the retailer, the total utility of the retailer under its own leadership is always higher than when the manufacturer dominates the leadership position. Additionally, the total utility of the retailer increases with the increase in h.

4 Conclusion

This chapter investigates the decision-making problems in closed-loop supply chains under two channel power structures when both the manufacturer and the retailer implement CSR, with the retailer as the recycling participant. The research findings suggest: (1) Regardless of the channel power structure, the CSR actions of manufacturers and retailers can reduce wholesale and retail prices, promote the sale of new products and the recovery of old products, increase consumer surplus, and enhance the overall profit of the closed-loop supply chain. (3) When the closed-loop supply chain based on the retailer's recycling model pays more attention to corporate social responsibility, the channel power structure led by the retailer should be chosen. This approach can significantly increase the total profits and social welfare of both the manufacturer and the retailer.

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