Frontiers in Business, Economics and Management
ISSN: 2766-824X | Vol. 15, No. 2, 2024

Research on Green Supply Chain Decision-Making Considering Consumers' Low Carbon Awareness and Cost Sharing

Yunjie Dai, Yao Huang

College of Economics and Management, Southwest Petroleum University, Chengdu, China

Abstract: With the global vigorous promotion of the development of green economy, advocating the practice of green concept, sustainable development has become a new problem that the world attaches great importance to. This paper considers the factors of consumers ' low-carbon awareness, discusses the pricing decisions in different situations, and looks for the optimal decisions of manufacturers and retailers. It is found that the enhancement of consumers ' low-carbon awareness is conducive to the increase of supply chain profit, and the retailer 's cost sharing ratio can improve the supply chain profit within a certain range.

Keywords: Green supply chain, Cost sharing, Pricing decisions, Level of marketing effort.

1. Introduction

Green development has become a social consensus, and consumers' awareness of environmental protection and low-carbon awareness has increased significantly, and their consumption concepts and consumption patterns have changed. Changes in consumer demand and sustainable development strategies have driven changes in the economic development model, and a green supply chain model that takes into account resource consumption and environmental impacts on the basis of the traditional supply chain has emerged [1-2]. Compared with traditional supply chains, green supply chains take environmental protection principles into consideration, and take into account both economic and environmental benefits [3]. Green manufacturing has become a new trend in the manufacturing industry. Green manufacturing has become a new trend in the manufacturing industry, and when producing green products by improving production technology and adopting green materials, manufacturers need to invest a large amount of costs, such as the innovation and research and development costs of green products and environmental pollution control costs. Meanwhile, the practical application of cost sharing in green supply chain is beginning to receive more attention and research from scholars. Manufacturers' green innovation inputs can increase the market demand for their products and have a spillover effect on retailers, so retailers have an incentive to share some of the manufacturers' green innovation costs [4]. Therefore, retailers have the incentive to share part of the green innovation costs of manufacturers. Min Jie [5], Liu Li [6], Guo Qiang [7], Zhou Hui [8], et al. have studied the coordination problem of cost sharing on green supply chain through differential game or Stackelberg game model, and explored the influence of cost sharing model on the optimal equilibrium decision-making of each member of green supply chain.

In summary, this paper investigates how the green supply chain members' decisions are affected when manufacturers invest in green innovation for their products and retailers make sales efforts to promote green products, and how the retailers' sharing of the manufacturers' green innovation costs affects the profitability of the manufacturers, retailers and the supply chain as a whole. In addition, numerical examples are given to illustrate the trends in the profits of manufacturers and retailers in each case.

2. Problem Description and Modeling Assumptions

2.1. Description of the Problem

This paper constructs a two-level green supply chain consisting of a single manufacturer and a single retailer, where the manufacturer is the leader and the retailer is the follower, and constructs a Stackelberg game model. The manufacturer produces green products through green innovation technology and sells them to consumers through the retailer, with the specific decision sequence as follows:

(1) The manufacturer decides on the level of green innovation E of the product and sells it to the retailer at the wholesale price w;

(2) The retailer decides the level of product marketing effort F based on the product's level of green innovation E and the wholesale price, and determines the retail price p of the product.

2.2. Model Assumptions and Notation Description

Hypothesis 1: Assume that the market demand function for green products is $D = a - bp + kE + \beta F$, i.e., the market demand for green products is affected by the retail price of the product p, the level of green innovation of the manufacturer E and the level of marketing efforts of the retailer F. Assume that $a - bp \geq 0$, i.e., the market demand is not negative when the product does not undergo green innovation and the retailer does not engage in marketing campaigns.

Where the character a denotes the market capacity, b denotes the sensitivity coefficient of consumers to the price of the product; k denotes the low-carbon awareness of consumers, reflecting the sensitivity of consumers to the level of green innovation of the product; and β denotes the sensitivity coefficient of consumers to the level of marketing promotion.

Hypothesis 2: The manufacturer's production cost per unit

of product is c; assuming that the level of green innovation is E, the corresponding additional green R & D costs are $c(E) = \frac{1}{2} E^2$, and the cost of promotional inputs when the level of retailer marketing effort is F is $c(F) = \frac{1}{2} F^2$[9-10].

Hypothesis 3: The green innovation input cost of the product can be shared by the manufacturer and the retailer, and the marketing and promotion cost of the product is borne by the retailer alone. It is also assumed that the proportion of green innovation input costs shared by retailers is θ.

Hypothesis 4: Information symmetry is assumed for this green supply chain.

Table 1. Symbols and meanings.

notation	Meaning of representation	notation	Meaning of representation
a	Market volume ($a > 0$)	c	Unit cost of product produced by manufacturer (c > 0)
b	Coefficient of consumer sensitivity to product price ($b > 0$)	E	Manufacturers' level of green innovation in products
k	Consumer low carbon awareness ($k > 0$)	F	Level of marketing communication efforts by retailers
β	Consumer sensitivity coefficients to the level of retailers' marketing efforts ($\beta > 0$)	π	Overall Supply Chain Profit
p	Retail price per unit of product (p > 0)	π_r	Retailer margins
w	Wholesale price per unit of product (w > 0)	π_m	Manufacturers' profits
θ	Proportion of green innovation input costs shared by retailers ($\theta \in (0,1)$)		

3. No cost-sharing

3.1. Centralized Decision-Making

Under centralized decision-making, members of the green supply chain form a whole, and retailers and manufacturers no longer make decisions based on maximizing their own interests, but aim to maximize the profit of the entire supply chain, deciding on the optimal retail price, the level of green innovation of the products, and the level of marketing and promotional efforts of the entire supply chain. At this time, the profit of the whole supply chain is:

$$\pi = (p - c)(a - bp + kE + \beta F) - \frac{1}{2} E^2 - \frac{1}{2} F^2 \quad (1)$$

The Hessian matrices of the three decision variables are obtained by taking the first-order partial derivatives and second-order partial derivatives of the functions with respect to the price, the level of green innovation and the level of marketing effort, respectively: $H = \begin{pmatrix} -2b & k & \beta \\ k & -1 & 0 \\ \beta & 0 & -1 \end{pmatrix}$. It can be obtained by calculation that when $0 < k < \sqrt{2b - \beta^2}$, the Hessian matrix is negative definite, and there is an optimal equilibrium solution. This condition indicates that the degree of consumers' low-carbon awareness is not infinitely strong, and will be affected by the degree of consumers' sensitivity to the price of the product and the degree of consumers' sensitivity to the level of marketing efforts of the product.

Theorem 1: The optimal green innovation level, marketing effort level, price, and profit of the supply chain as a whole at this point are, respectively:

$$\begin{cases} {E_1}^* = \frac{k(bc-a)}{k^2+\beta^2-2b} \\ {F_1}^* = \frac{\beta(bc-a)}{k^2+\beta^2-2b} \\ {p_1}^* = \frac{c(k^2+\beta^2-b)-a}{k^2+\beta^2-2b} \\ {\pi_1}^* = \frac{(bc-a)^2}{4b-2k^2-2\beta^2} \end{cases} \quad (2)$$

Corollary 1: Theorem 1 yields $bc - a < 0$. According to Theorem 1, taking the first order partial derivatives of the above four functions with respect to k and β respectively, it can be obtained that their first order derivatives are all greater than 0, i.e., with the increase of consumers' low carbon awareness k, ${E_1}^*$, ${F_1}^*$, ${p_1}^*$ and π_1 all increase; and as the marketing effort level β increases, ${E_1}^*$, ${F_1}^*$, ${p_1}^*$ and π_1 all increase. It indicates that as consumers' low-carbon awareness increases, and as the sensitivity coefficient of consumers' marketing efforts increases, the supply chain, in order to cater to consumers' preferences, will increase the investment in green innovation technology and marketing promotion, which leads to an increase in costs, and then increase the retail price, and make the overall profit of the supply chain grow.

3.2. Decentralized decision-making

Under decentralized decision making, manufacturers and retailers are fully rational in their decision making, i.e., they are not concerned about the profit of the whole supply chain, and the supply chain members make decisions with the goal of maximizing their own interests. At this time, the profits of the two are respectively:

$$\pi_r = (p - w)(a - bp + kE + \beta F) - \frac{1}{2} F^2 \quad (3)$$

$$\pi_m = (w - c)(a - bp + kE + \beta F) - \frac{1}{2} E^2 \quad (4)$$

Find the first and second order partial derivatives with respect to the decision variables for both functions and solve for the optimal results for p, w, E, and F according to inverse induction. And the same condition needs to be satisfied in this case $0 < k^2 < 4b - 2\beta^2$.

Theorem 2: The optimal level of green innovation, level of marketing effort, wholesale price, retail price, and optimal profit of retailer and manufacturer, and overall profit of the supply chain of the product at this point are, respectively:

$$\begin{cases} {E_2}^* = \frac{k(bc-a)}{k^2+2\beta^2-4b} \\ {F_2}^* = \frac{\beta(bc-a)}{k^2+2\beta^2-4b} \\ {w_2}^* = \frac{a\beta^2-2b^2c+b(ck^2+c\beta^2-2a)}{b(k^2+2\beta^2-4b)} \\ {p_2}^* = \frac{a\beta^2-b^2c+b(ck^2+c\beta^2-3a)}{b(k^2+2\beta^2-4b)} \\ {\pi_{r2}}^* = \frac{(bc-a)^2(2b-\beta^2)}{2(k^2+2\beta^2-4b)^2} \\ {\pi_{m2}}^* = \frac{(bc-a)^2}{-2(k^2+2\beta^2-4b)} \\ {\pi_2}^* = \frac{(bc-a)^2(6b-3\beta^2-k^2)}{2(k^2+2\beta^2-4b)^2} \end{cases} \quad (5)$$

Corollary 2: According to Theorem 2, the first-order derivative function of the above functions with respect to k

and β, respectively, can be obtained that their first-order derivatives are all greater than 0. It can be seen that with the increase of the consumer's low-carbon awareness k, ${E_2}^*$, ${F_2}^*$, ${w_2}^*$, ${p_2}^*$, ${\pi_{r2}}^*$ and ${\pi_{m2}}^*$ all increase; and as the level of marketing effort β increases, ${E_2}^*$, ${F_2}^*$, ${w_2}^*$, ${p_2}^*$, ${\pi_{r2}}^*$ and ${\pi_{m2}}^*$ all increase. It shows that under decentralized decision-making, the coefficient of low-carbon awareness of consumers and the coefficient of sensitivity of marketing efforts also play a positive role in green supply chain.

Corollary 2 suggests that as consumers become more aware of low-carbon issues and as the sensitivity factor of consumers to marketing efforts increases, manufacturers and retailers will invest more in green innovation technologies and marketing efforts to cater to consumer preferences, leading to higher levels of green innovation and marketing efforts, which will also lead to higher costs and higher wholesale and retail prices. Increased consumer low-carbon awareness and marketing effort sensitivity will lead to increased market demand, which will have a positive impact on manufacturers' profits and retailers' profits.

4. With Cost-Sharing

When retailers engage in cost sharing, it is assumed that the proportion of green innovation input costs shared by retailers is θ and the proportion borne by the manufacturer is $1-\theta$ and the profit functions of the retailer and the manufacturer at this time are, respectively:

$$\pi_r = (p-w)(a-bp+kE+\beta F) - \frac{1}{2}F^2 - \frac{\theta}{2}E^2 \quad (6)$$

$$\pi_m = (w-c)(a-bp+kE+\beta F) - \frac{1-\theta}{2}E^2 \quad (7)$$

Find the first and second order partial derivatives with respect to the decision variables for both functions and solve for the optimal results for p, w, E, and F according to inverse induction. And the same condition needs to be satisfied in this case $0 < k^2 < (4b-2\beta^2)(1-\theta)$.

Theorem 3: The optimal level of green innovation, level of marketing effort, wholesale price, retail price, and optimal profit of retailer and manufacturer, and overall profit of the supply chain for the product at this point are, respectively:

$$\begin{cases} {E_3}^* = \frac{k(bc-a)}{(4b-2\beta^2)(\theta-1)+k^2} \\ {F_3}^* = \frac{\beta(a-bc)(\theta-1)}{(4b-2\beta^2)(\theta-1)+k^2} \\ {w_3}^* = \frac{(2b-\beta^2)(bc+a)(\theta-1)+bck^2}{b(4b-2\beta^2)(\theta-1)+bk^2} \\ {p_3}^* = \frac{(b^2c+3ab-b\beta^2c-a\beta^2)(\theta-1)+bck^2}{b(4b-2\beta^2)(\theta-1)+bk^2} \\ {\pi_{r3}}^* = \frac{(bc-a)^2[(2b-\beta^2)(\theta-1)^2-k^2\theta]}{2[(4b-2\beta^2)(\theta-1)+k^2]^2} \\ {\pi_{m3}}^* = \frac{(bc-a)^2(\theta-1)}{2[(4b-2\beta^2)(\theta-1)+k^2]} \\ {\pi_3}^* = \frac{(bc-a)^2[3(2b-\beta^2)(\theta-1)^2-k^2]}{2[(4b-2\beta^2)(\theta-1)+k^2]^2} \end{cases} \quad (8)$$

Corollary 3: According to Theorem 3, the first derivative functions of the above functions with respect to k, β and θ are obtained respectively. It can be obtained that ${E_3}^*$, ${F_3}^*$, ${w_3}^*$ and ${p_3}^*$ are all greater than 0 with respect to their first derivatives. It shows that under the decentralized decision-making of retailers in cost-sharing, the increase of consumers' low-carbon awareness coefficient, marketing effort sensitivity coefficient and retailers' cost-sharing ratio will also increase the level of product green innovation, marketing effort, wholesale price and retail price.

Corollary 3 suggests that as consumers become more aware of low-carbon issues and as the sensitivity factor of consumers to marketing efforts increases, manufacturers and retailers will increase their investment in green innovation technologies and marketing efforts to meet consumer preferences, leading to higher levels of green innovation and marketing efforts, which will also lead to higher costs and higher wholesale and retail prices. As retailers share a higher proportion of the costs, manufacturers will be more motivated to improve the level of green innovation in their products, and the costs of both will increase accordingly, and retailers will increase the level of marketing campaigns to increase market demand, and prices will rise.

5. Numerical Analysis

The impact of consumer low-carbon awareness and retailer cost-sharing ratios on manufacturers' and retailers' profits is further analyzed through a numerical example that compares profits under three decision scenarios. Assumptions $a = 20$, $b = 0.5$, $\beta = 0.4$, $c = 10$.

5.1. Impact of Low-Carbon Awareness among Consumers

Assuming that $\theta = 0.2$, the overall profit of the supply chain and the variation of the manufacturer's and retailer's profit with the value of k at decentralized decision making can be obtained by plotting, as shown in Figures 1 and 2.

As can be seen in Figure 1, as consumers' low-carbon awareness increases, the overall supply chain profit increases in all three models, and the overall profit is greatest under centralized decision-making. Under decentralized decision-making, the overall profit of the supply chain is slightly higher than that without cost sharing when the retailers share costs and the proportion of cost sharing is small.

From Figure 2, it can be seen that the increase in consumer low carbon awareness benefits both manufacturers and retailers regardless of whether retailers engage in cost sharing, and manufacturer profits are always higher than retailer profits. When retailers cost share, it can be seen that as consumers become more aware of low carbon issues, both manufacturers and retailers are more profitable than they were before cost sharing.

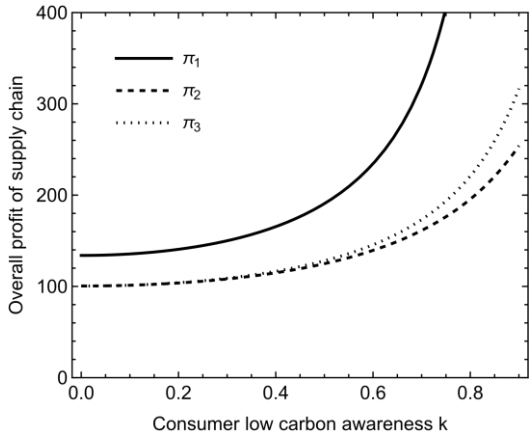

Figure 1. Impact of consumer low carbon awareness on overall supply chain profitability.

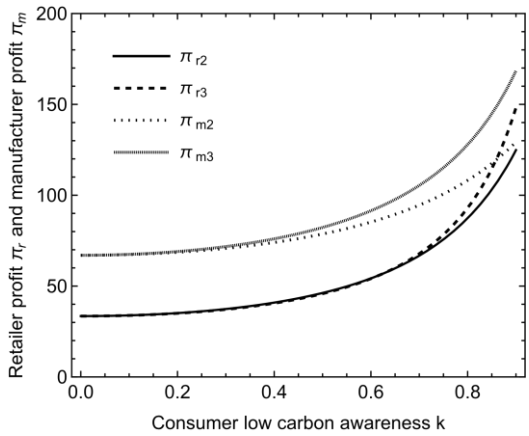

Figure 2. Impact of consumer low carbon awareness on retailers' and manufacturers' profits.

5.2. Impact of Retailer Cost-Sharing Ratios

Assuming that $k = 0.5$, the overall profit of the supply chain and the variation of the profit of the manufacturer and the retailer with the value of θ at decentralized decision making can be obtained by plotting, as shown in Fig. 3 and Fig. 4.

As can be seen in Figure 3, the overall supply chain profit is greatest in the three models when centralized decision making is in place. In decentralized decision making, the overall profit of the supply chain decreases as the proportion of cost sharing by the retailer increases. As can be seen from Figure 4, under decentralized decision making, the manufacturer's profit is always higher than the retailer's profit regardless of whether the retailer carries out cost sharing or not. And after the retailer carries out cost sharing, as the proportion of sharing increases, the manufacturer's profit gradually increases and the retailer's profit gradually decreases.

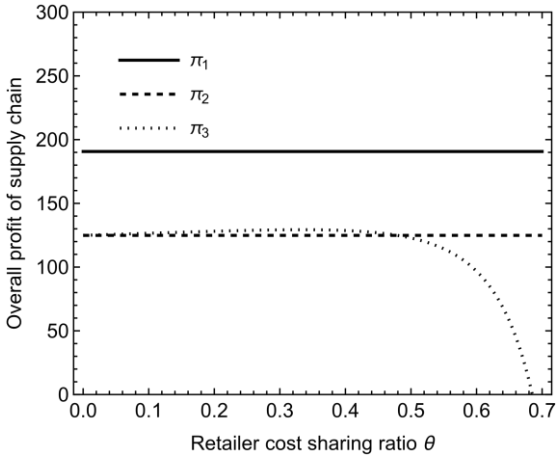

Figure 3. Impact of cost sharing ratio on overall supply chain profitability.

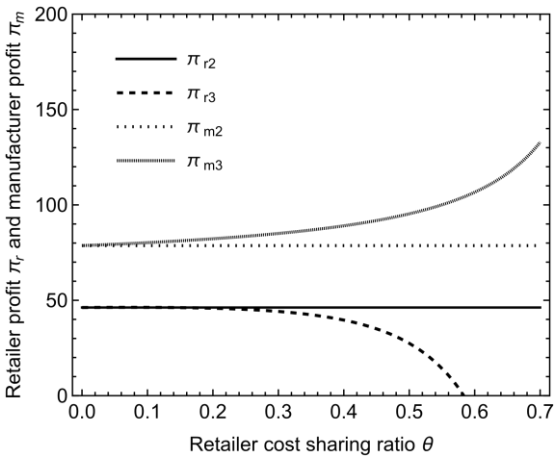

Figure 4. Impact of cost-sharing ratios on retailers' and manufacturers' profits.

6. Conclusion

This paper constructs a secondary green supply chain consisting of a manufacturer and a retailer, and studies the optimal decision-making of both when the manufacturer pays green innovation inputs for the product and the retailer pays marketing efforts to promote green products. The effects of consumers' low-carbon awareness and marketing effort sensitivity coefficients on manufacturers' and retailers' decisions are analyzed through centralized decision-making and decentralized decision-making models before and after cost sharing. And the effects of consumer low-carbon awareness and cost-sharing ratio on the change of decision-makers' profit respectively under different models are compared by numerical analysis. The main conclusions are as follows: (1) Under decentralized decision-making, when retailers' cost-sharing ratio is small, both the overall supply chain profits and the profits of manufacturers and retailers are higher than their own profits without cost-sharing, and the higher profits are greater with the stronger consumers' low-carbon awareness. (2) When the cost-sharing ratio of retailers is small, regardless of whether retailers engage in cost-sharing or not, as long as consumers' low-carbon awareness increases, the overall profits of the supply chain and the profits of manufacturers and retailers will increase. Therefore, consumers' low-carbon awareness can be further increased through environmental protection publicity and other means.

References

[1] Steve V. Walton, Robert B. Handfield, Steven A. Melnyk. The Green Supply Chain: Integrating Suppliers into Environmental Management Processes [J]. International Journal of Purchasing and Materials Management, 1998, 34: 2-11.

[2] WU Chunyou, ZHU Qinghua, GENG Yong. Green supply chain management and enterprise sustainable development [J]. China Soft Science, 2001, (03): 67-70.

[3] Pablo Becerra, Josefa Mula, Raquel Sanchis. Green supply chain quantitative models for sustainable inventory management: A review [J]. Journal of Cleaner Production, 2021, 328: 129544.

[4] Lin Qiang, Liu Mingwu. Green supply chain decision considering government subsidies and enterprise cost sharing [J]. Industrial Engineering, 2022, 25(06): 29-38.

[5] Min Jie, Yang Ran, Ou Jian, et al. Research on the operation strategy of green supply chain based on two-way cost sharing [J]. Industrial Engineering, 2021, 24(04): 36-44.

[6] Liu Li, Han Tongyin, Jin Hao. Research on differential game of green supply chain based on green technology innovation and manufacturer competition [J]. Journal of Management, 2023, 20(01): 116-126.

[7] Guo Qiang, Xu Changhao, Nie Jiajia. Effect of cost sharing in green supply chain on manufacturer's channel invasion strategy [J]. Industrial engineering, 2023, 26(05): 1-10.

[8] Zhou Hui, Liu Lu, Liu Jian. Green supply chain decision and cost sharing contract based on retailer overconfidence [J]. Journal of Systems Science, 2024, (03): 110-115, 130.

[9] Zhou Yanju, Bao Maojing, Chen Xiaohong, et al. Advertising cooperation-emission reduction cost sharing contract and coordination in low-carbon supply chain based on fairness concerns [J]. Chinese management science, 2017, 25(02): 121-129.

[10] Zhang Linghong, Liu Fangyuan, Zhu Lilong, et al. Research on carbon emission reduction strategies considering retailer's fairness concerns and advertising effort level [J]. China Management Science, 2021, 29(04): 138-148.