Study on the Impact of Dual-Channel Green Supply Chain Pricing Strategies Considering Government Subsidies under Information Asymmetry

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Abstract. This paper constructs a dual-channel green supply chain consisting of direct sales channels opened by manufacturers and retailers as the research object, and uses the method of signaling game to discuss the impact of different government subsidy strategies on the pricing strategies of dual-channel green supply chain under different market demands and information states. Finally, on the basis of the same amount of subsidies, the impact of different forms of government subsidies on the pricing strategy of dual-channel green supply chain is further discussed through example experiments. The research in this paper provides a new vision for the dual-channel green supply chain pricing strategy considering government subsidies under information asymmetry.

Keywords: dual-channel green supply chain;signaling game;information asymmetry government subsidy

1 Introduction

Accompanied by the rapid development of the world economy and the increasingly serious problem of environmental pollution, human society has begun to pay more and more attention to the path of sustainable development. Li[1] analyzed the dual-channel structure in the green supply chain, and investigated the pricing strategy of enterprises. He[2] et al. analyzed the impact of retailer free-riding behavior on manufacturers' green inputs and profits in a two-channel green supply chain. With the development of e-commerce platforms and the rise of live streaming, more and more manufacturers start to sell through online channels, and the information asymmetry problem arises due to the different channels for manufacturers and retailers to obtain information, which leads to a lot of resource wastage in the dual-channel supply chain in the process of competition. Shamir[3]analyze the strategies for retailers to share information within the chain in the face of a potentially competitive chain. Li [4]et al. analyzed manufacturers' subsidy strategies to achieve information sharing in an intra-chain competitive environment consisting of one supplier and two retailers. Government subsidies have become more and more common in many market environments as a means of market regulation. In terms of government subsidies, Song[6] consider the optimal decision-making of dual-channel supply chain members with fairness considerations under government

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subsidies. Ruzzier's[5] study suggests that governments can not only adopt mandatory measures such as laws and regulations, but also subsidize enterprises to invest in green innovation and improve the greenness of their products.

Existing domestic and international studies have mainly investigated the government subsidy mechanism of dual-channel green supply chains and how to regulate the information asymmetry problem in dual-channel green supply chains. Since the literature on signaling games under information asymmetry rarely takes state subsidies as a new consideration, therefore，this paper analyzes two subsidy models, government R&D subsidies and consumer price subsidies, to analyze the dual-channel green pricing strategies for supply chain products.

2 Problem description and variable assumptions

1. This paper considers a two-channel green supply chain consisting of a manufacturer and a retailer. Since retailers are closer to consumers, retailers have more information about market demand than manufacturers. Manufacturers, on the other hand, can only make decisions based on ex ante information due to lack of data and information. Manufacturers make decisions on green innovation inputs and wholesale pricing before the start of the selling season. Retailers make retail pricing decisions after the selling season begins. Without loss of generality.

2. The manufacturer produces green levels of products θ that require a commensurate cost of green innovation $\frac{1}{2}z\theta^2$ [11],where z represents the green innovation efficiency of the manufacturer.k is the subsidy rate for green technology R&D costs (0<k<1). The government price subsidy to consumers is s. Consumers receive a unit subsidy s for each unit of green product purchased.

3. This paper assumes that the retailer's cost of goods sold is 0[8] and the manufacturer's marginal production cost is 0[9]. As consumers become more aware of environmental protection, they are willing to pay higher prices for green products. Consumers' green preference is assumed to be 1.

4. a denotes market-based demand. It is assumed that there are possibilities where the market demand is higher as a_H ,but $1-\eta$ The likelihood of market demand is lower for a_L .included among these $0<\eta<1$, $E(a)=u=\eta\cdot a_H+(1-\eta)\cdot a_L$.

5. p_M is the direct price, p_R is the retail price, 3 π_M is the manufacturer's profit, 4 π_R is the retailer's profit,w is the wholesale price.d is the channel competition parameter (0<d<1).

3 Government-subsidized manufacturers

3.1 Information asymmetry

Referring to the related research on dual channels, the respective demand functions of the retail channel and the direct channel when the government subsidizes the manufacturer's R&D after the manufacturer opens the direct channel are shown in the following figure [7][11].

$$q_R = \frac{(1-d)(\theta + a_i) - p_R + dp_M}{-d^2+1} \tag{1}$$

$$q_M = \frac{(1-d)(\theta + a_i) - p_M + dp_R}{-d^2+1} \tag{2}$$

The profits for retailers and manufacturers are shown below:

$$\pi_R = (p_R - w) q_R \tag{3}$$

$$\pi_M = wq_R + p_M q_M - \frac{\theta^2 (1-k)}{2} z \tag{4}$$

According to the assumption of this paper, the other cost text 0, when the government R & D subsidy is too high, the manufacturer can be profitable no matter what kind of pricing, so the proportion of government R & D subsidy needs to be satisfied.

$$k < \frac{2zd^5 + 2zd^4 - 2d^4 - 10zd^3 + d^3 - 10zd^2 + 9d^2 + 16zd - 4d + 16z - 12}{2z\left(d^5 + d^4 - 5d^3 - 5d^2 + 8d + 8\right)}$$

The order of the game is as follows: in the first stage, the manufacturer decides on the wholesale price of the product and the greenness of the product with the objective of maximizing its own profit; in the second stage, the retailer decides on the sales price p_R of the traditional retail channel with the objective of maximizing its own utility. Stage 3 manufacturers maximize their own profits to determine the direct selling price p_M .According to the order of the game, using the reverse induction method, retailer pricing, online channel pricing, product wholesale price, and product greenness can be found:

$$p_M = \frac{(-\theta + w - a_i + p_R) d}{2} + \frac{\theta}{2} + \frac{a_i}{2} \tag{5}$$

$$p_R = \frac{(\theta + a_i) d^2 + (\theta + a_i) d - 2\theta - 2w - 2a_i}{2d^2 - 4} \tag{6}$$

$$\theta = -\frac{a_i\left(2d^4 - d^3 - 9d^2 + 4d + 12\right)}{2z(-1+k)d^5 + (2+(2k-2)z)d^4 + (-1+(-10k+10)z)d^3 + (-9+(-10k+10)z)d^2 + (4+(16k-16)z)d + 12 + (16k-16)z} \tag{7}$$

$$w = \frac{(d+1)\left(d^4 + d^3 - 6d^2 + 8\right)(-1+k) z a_i}{2z(-1+k)d^5 + (2+(2k-2)z)d^4 + (-1+(-10k+10)z)d^3 + (-9+(-10k+10)z)d^2 + (4+(16k-16)z)d + 12 + (16k-16)z} \tag{8}$$

3.2 Information asymmetry

When information is asymmetric, the retailer's pricing acts as a signal to reveal the retailer's private information. When the retail price is higher than p_R ,The manufacturer determines that market demand is higher at this time and retail prices are lower than the p_M .Manufacturers perceive the state of market demand to be low.According to backward induction, retailers do not always base their pricing on market demand information. In some scenarios retailers will disguise to gain more benefits for themselves.

Proposition 1: Retailer pricing when information is asymmetric:

When market demand is high.

$$p_{RH} = \frac{(\theta + a_H)d^2 + (\theta + a_H)d - 2\theta - 2w - 2a_H}{2d^2 - 4} \tag{9}$$

When market demand is low.if $w < \frac{(d+2)\left(\left(\theta + \frac{a_H}{2} + \frac{a_L}{2}\right)d - a_H + a_L\right)}{2(d+1)d}$

$$p^* = \frac{\sqrt{-4(-1+d)^2(a_H - a_L)\left(\left(w - \frac{\theta}{2} - \frac{a_H}{4} - \frac{a_L}{4}\right)d + w - \theta - a_L\right)}\,d + (\theta + a_H)d^2 + (\theta - a_H + 2a_L)d - 2w - 2\theta - 2a_L}{2d^2 - 4} \tag{10}$$

if $w > \frac{(d+2)\left(\left(\theta + \frac{a_H}{2} + \frac{a_L}{2}\right)d - a_H + a_L\right)}{2(d+1)d}$,

$$p_{RL} = \frac{(\theta + a_L)d^2 + (\theta + a_L)d - 2\theta - 2w - 2a_L}{2d^2 - 4} \tag{11}$$

When information is asymmetric, manufacturers cannot make optimal decisions based on their own market information, but can only decide on product greenness and wholesale prices based on past marke experience.

$$\theta = \frac{-u\left(2d^4 - d^3 - 9d^2 + 4d + 12\right)}{2z(-1+k)d^5 + \left(2 + (2k-2)z\right)d^4 + \left(-1 + (-10k+10)z\right)d^3 + \left(-9 + (-10k+10)z\right)d^2 + \left(4 + (16k-16)z\right)d + 12 + (16k-16)z} \tag{12}$$

$$w = \frac{(d+1)\left(d^4 + d^3 - 6d^2 + 8\right)(-1+k)zu}{2z(-1+k)d^5 + \left(2 + (2k-2)z\right)d^4 + \left(-1 + (-10k+10)z\right)d^3 + \left(-9 + (-10k+10)z\right)d^2 + \left(4 + (16k-16)z\right)d + 12 + (16k-16)z} \tag{13}$$

Corollary 1: From Proposition 1, it follows that when wholesale prices are higher, markets are able to separate naturally. When the wholesale price is lower in the low-demand market, retailers engage in camouflage and need to distort the retail price upwards. And the wholesale price and the threshold of natural separation are both proportional to the government R&D subsidy, and the growth rate of the threshold of natural separation as the government R&D subsidy grows is greater than the growth rate of the wholesale price as the government R&D subsidy grows, and as the government price subsidy increases it will help retailers to engage in camouflage.

Corollary 2: As the government subsidy increases, the retail price, the direct price, the wholesale price of the product, and the greenness of the product increase regardless of which state the market is in. This is because market demand increases due to the increase in product greenness. As a result of increased government subsidies for research and development, manufacturers have more money to increase the greenness of their products to stimulate market demand. With the increase in market demand and R&D costs, manufacturers will also increase their wholesale prices to gain more profit. Retailers will also increase their retail prices in order to gain more profits.

Corollary 3: Due to asymmetric demand information, manufacturers can only base their decisions on green innovations and wholesale prices on past experience, when the decisions are below the optimal value for high demand response and above the optimal value for low demand response. As increased R&D subsidies expand consumer demand, the gap between asymmetric information decisions and optimal decisions grows.

4 Government Subsidized Consumer Scenarios

4.1 Information symmetry

The demand functions for each of the retail and direct sales channels when the government subsidizes the manufacturer's price are shown below.

$$q_R = \frac{(1-d)(a_i+\theta+s)-p_R+dp_M}{-d^2+1} \tag{14}$$

$$q_M = \frac{(1-d)(a_i+\theta+s)-p_M+dp_R}{-d^2+1} \tag{15}$$

The profits of the retailer and the manufacturer are shown in the figure:

$$\pi_R = (p_R - w)q_R \tag{16}$$

$$\pi_M = wq_R + p_M q_M - \frac{z\theta^2}{2} \tag{17}$$

Using backward induction, retailer pricing, online channel pricing, wholesale product price, and product greenness can be found:

$$p_M = \frac{(-\theta-s+w-a_i+p_R)d}{2} + \frac{\theta}{2} + \frac{s}{2} + \frac{a_i}{2} \tag{18}$$

$$p_R = \frac{(\theta+s+a_i)d^2+(\theta+s+a_i)d-2\theta-2s-2w-2a_i}{2d^2-4} \tag{19}$$

$$w = \frac{(d+1)(d^4+d^3-6d^2+8)(s+a_i)z}{2d^5z+(2z-2)d^4+(-10z+1)d^3+(-10z+9)d^2+(16z-4)d+16z-12} \tag{20}$$

$$\theta = \frac{(2d^4-d^3-9d^2+4d+12)(s+a_i)}{2d^5z+(2z-2)d^4+(-10z+1)d^3+(-10z+9)d^2+(16z-4)d+16z-12} \tag{21}$$

4.2 Information asymmetry

Proposition2.The offline channel pricing can be obtained by the same reasoning as 3.2 in separating equilibrium:

When market demand is high.

$$p_{RH} = \frac{(\theta + s + a_H)d^2 + (\theta + s + a_H)d - 2\theta - 2s - 2w - 2a_H}{2d^2 - 4} \tag{22}$$

When market demand is low.if $w < \frac{\left(\left(\theta + s + \frac{a_H}{2} + \frac{a_L}{2}\right)d - a_H + a_L\right)(d+2)}{2(d+1)d}$

$$p = \frac{\sqrt{2}\sqrt{(a_H - a_L)(-1+d)^2 d\left(\left(s - 2w + \theta + \frac{a_H}{2} + \frac{a_L}{2}\right)d + 2s - 2w + 2\theta + 2a_L\right)} + (s + \theta + a_H)d^2 + (s + \theta - a_H + 2a_L)d - 2s - 2w - 2\theta - 2a_L}{2d^2 - 4} \tag{23}$$

if $w > \frac{\left(\left(\theta + s + \frac{a_H}{2} + \frac{a_L}{2}\right)d - a_H + a_L\right)(d+2)}{2(d+1)d}$,

$$p_{RL} = \frac{(\theta + s + a_L)d^2 + (\theta + s + a_L)d - 2\theta - 2s - 2w - 2a_L}{2d^2 - 4} \tag{24}$$

At this point, the optimal retail price, wholesale price, and greenness can be found:

$$w = \frac{(d+1)(d^4 + d^3 - 6d^2 + 8)(s+u)z}{2d^5 z + (2z-2)d^4 + (-10z+1)d^3 + (-10z+9)d^2 + (16z-4)d + 16z - 12} \tag{25}$$

$$\theta = \frac{(2d^4 - d^3 - 9d^2 + 4d + 12)(s+u)}{2d^5 z + (2z-2)d^4 + (-10z+1)d^3 + (-10z+9)d^2 + (16z-4)d + 16z - 12} \tag{26}$$

Corollary 4: From Proposition 2, the thresholds for both wholesale price and natural separation are proportional to the government price subsidy, and as the government price subsidy increases it will help retailers to disguise.

Corollary 5: As the government price subsidy increases, the retail price, the direct selling price, the wholesale price of the product, and the greenness of the product increase regardless of which state the market is in. This is due to the fact that consumers will increase their demand for green products after receiving the subsidy, while manufacturers have limited funds and will obtain funds for expanding production by increasing the wholesale price and online sales price in order to meet the market demand, and due to the increase in the wholesale price, retailers will also increase the retail price in the offline channel in order to avoid losses.

Corollary 6: Under the government's price subsidy strategy, the impact of information asymmetry will not be amplified.

5 Example analysis

This chapter, through numerical examples, will further analyze the impact of different types of government subsidies on the pricing decision when dual-channel green supply chains are naturally separated, based on the same amount of government subsidies and at different market demands. k is taken to vary in the interval 0 to 0.8 with a step size of 0.1. The market demand is set as $z = 4; a_H = 3; a_L = 1; d = 0.5; \eta = 0.5$

From Figures 1[1] and 2[2], When the government subsidizes the same amount of money, the R&D subsidy strategy is always better than the price subsidy to improve the greenness of products. When the market demand is the same, the greenness of products with symmetric information is always better than the greenness of products with asymmetric information. Along with the increase of government subsidy, both subsidy methods will reduce the decision error of product greenness due to information asymmetry, but the government R&D subsidy strategy has a more obvious impact on reducing the information asymmetry problem.

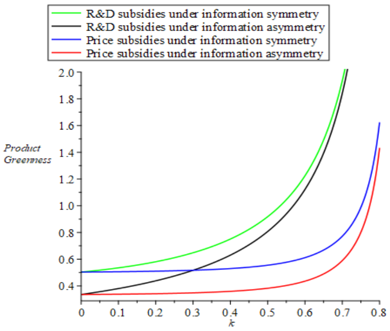

Fig. 1 Effect of government subsidies on product greenness under high market demand

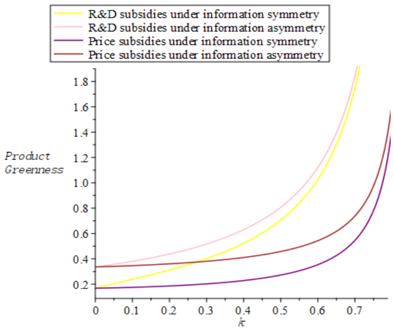

Fig. 2 Effect of Government Subsidies on Product Greenness under Low Market Demand

From Figure 3[3], it can be seen that under high market demand, retailers' profits are always higher when information is asymmetric than when information is symmetric, no matter what kind of government subsidies are provided. Retailer profits are more favorable to retailers when government subsidies are low, and as the amount of government subsidies increases, retailers prefer government price subsidies under high market demand. Under both subsidies, retailers' profits are always higher when they do not share information than when they do. As can be seen from Figure 4[4], when the market demand is low, retailers always prefer government price subsidies, but when the government carries out the R&D subsidy strategy, it will make the profit of retailers sharing the information higher than when they do not share it, and at this time, retailing prefers to take the initiative of sharing the market information to the manufacturer to gain more profit.

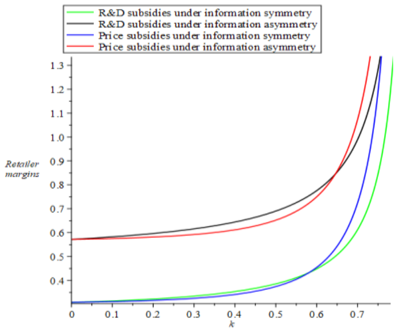

Fig. 3 Effect of Government Subsidies on Retailer Profits under High Market Demand

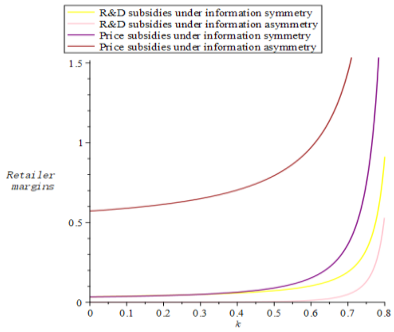

Fig. 4 Impact of Government Subsidies on Retailer Profits under Low Market Demand

6 Conclusion

Information asymmetry can make manufacturers' decisions deviate from the optimal ones, affecting their profits. The proportionate government R&D subsidy can increase the greenness input and pricing error due to information asymmetry. The same amount of government R&D subsidy can reduce the decision error due to information asymmetry. Price subsidies have less impact on the error due to information asymmetry when information asymmetry is naturally separated. When market volatility is low, too high of both subsidies may lead to retailer camouflage, making manufacturers' profits suffer. When the market demand is low, under the government R&D subsidy strategy, the retailer's profit from sharing information is higher than the profit when it does not share, when the retail is more inclined to actively share information with the manufacturer. When the government subsidy expenditure is the same amount, the government R&D subsidy enhances the greenness of the product more obviously compared to the government price subsidy.

It is not always advantageous for the government to subsidize the dual-channel supply chain when there is information asymmetry. Government subsidies should also take into account market demand fluctuations. Different subsidies have different impacts on dual-channel green supply chains, and in some cases proactive information sharing can increase retailers' profits. The government can choose the subsidy method and the amount of subsidy according to the purpose when subsidizing. Future research can further design supply chain contracting mechanisms that incentivize companies to share information, thereby reducing the impact of information asymmetry and allowing for better decision-making to promote product greenness and product sales.

References

[1] LI B, ZHU M, JIANG Y, et al. Pricing policies of a competitive dual-channel green supply chain [J]. Journal of Cleaner Production, 112: 2029-2042(2016)

[2] HE R, XIONG Y, LIN Z. Carbon emissions in a dual channel closed loop supply chain: the impact of consumer free riding behavior [J]. Journal of Cleaner Production, 134: 384-394(2016)

[3] SHAMIR N, SHIN H. Public forecast information sharing in a market with competing supply chains [J]. Management Science, 62(10): 2994-3022(2015)

[4] LI G, ZHENG H, SETHI S P, et al. Inducing downstream information sharing via manufacturer information acquisition and retailer subsidy [J]. Decision Sciences, 51(3): 691-719(2020)

[5] Hojnik，J.Ruzzier，M.The Driving Forces of Process Eco-Innovation and Its Impact on Performance: Insights from Slovenia[J].Journal of Cleaner Production,133: 812－825(2016)

[6] Song L, Xin Q, Chen H, Liao L, Chen Z. Optimal Decision-Making of Retailer-Led Dual-Channel Green Supply Chain with Fairness Concerns under Government Subsidies. Mathematics. 11(2):284(2023)

[7] ABHISHEK V, JERATH K, ZHANG Z J. Agency selling or reselling? Channel structures in electronic retailing [J]. Management Science, 62(8): 2259-2280(2015)

[8] ZHANG J, LI S, ZHANG S, et al. Manufacturer encroachment with quality decision under asymmetric demand information [J]. European Journal of Operational Research, 273(1): 217-236(2019)

[9] ZHOU J, ZHAO R, WANG W. Pricing decision of a manufacturer in a dual-channel supply chain with asymmetric information [J]. European Journal of Operational Research, 278(3): 809-820.(2019)

[10] Chen J, Liang L, Yao D Q, et al. Price and quality decisions in dual-channel supply chains[J]. European Journal of Operational Research, 259(3):935-948(2017)

[11] RAJ A, BISWAS I, SRIVASTAVA S K. Designing supply contracts for the sustainable supply chain using game theory [J]. Journal of Cleaner Production, 185: 275-284(2018)