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Government Subsidies and Consumer Preferences in Dual-channel Green Supply Chains

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Abstract

This study examines the interrelationships among pricing strategies, consumer green preferences, channel preferences, and government subsidy policies in a green dual-channel supply chain (DCGSC). The study analyzes the profit differences between supply chains under centralized and decentralized decision-making models and investigates in depth the impact of government subsidies on green product production and pricing strategies. The experimental results show that government subsidies play an important role in reducing the production costs of green products and increasing market demand, especially when green products can enter the market at lower prices through government subsidies to satisfy consumers' green preferences. Consumers' green product preferences and channel preferences significantly affect pricing strategies. The centralized decision-making model is able to coordinate the interests of manufacturers and retailers to maximize the overall profit of the supply chain, while the decentralized decision-making model leads to a decrease in the overall profit due to a lack of coordination.

Keywords

Green supply chain; Dual-channel supply chain; Government subsidies

1. Introduction

As the environmental damage rises over the past few decades, the concept of environmental protection has been introduced to supply chain. In fact, in 2022, the industrial sector emitted 23% of the U.S. greenhouse gas (Environmental Protection Agency, 2024).Thus, more industries started to incorporate the development of sustainable management with their supply chains. To achieve this, industries are required to integrate supply chain management with green decisions in production to approach an optimized operation to minimize environmental impact while also maximize the profit (Lam, How, & Hong, 2015; Fahimnia, Sarkis, & Davarzani, 2015) The green decisions are often made with respect to the product's raw materials, manufacturing process, transportation, usage, and disposal.

Tesla is an excellent example in successful operational management of duan channel green supply chain. Tesla considered environmental sustainability into their product design, in ways of applying low-carbon raw materials, decreasing transportation impacts, and utilizing renewable energy resources (Zheng, 2024). Their application of dual channel green supply chain (DCGSC) successfully allows them to control the price and sell the product to maximize their profit.

Coca Cola used similar supply chain strategy, where also considered green supply chains. They focused on their intention in reducing the greenhouse gas emissions through utilizing different strategies, including sustainable sourcing, risk management, etc. Meanwhile, they also ensured the sustainability and survival of their supply chain (Babarinde & Oyebisi, 2024).

Furthermore, there are multiple factors that have been encouraging the use of green supply chains. Carbon emission trade, or "cap and trade," is one of the approaches in reducing carbon emissions and greenhouse gases pollution. Only companies with allowances and authorization will be allowed to emit a specific quantity of the pollutant, and these allowances are tradable in an allowance market. This limit ensures that the environmental goal is met and reduces the greenhouse gas emissions. Another limit that has been set on organizations is the carbon tax. The government has imposed a fee on business and individuals for each ton of greenhouse gas emission they produce (World Bank, 2019). This tax restricts organizations and individuals to emit greenhouse gas and meet the environmental goal. In addition to carbon tax, some governments also proposed the policy of carbon subsidies. To encourage businesses and organizations to reduce their carbon emissions, the government will provide subsidies to those who produce low or even zero carbon and greenhouse gases (Miron, 2024). Under these policies, businesses and organizations would start making their products green and environmentally friendly, which leads to the application of green supply chains.

However, e-commerce has also been developing rapidly in the modern society. In addition to the traditional retail, the majority of manufactures start to increase the accessibility of their products through an online channel, allowing them to directly sell products to customers. For example, global manufacturers such as Apple, Samsung, Nike, H&M, etc. have adapted the dual channel strategy, utilizing both online platforms and physical stores. This is called dual channel supply chain. With the combination of green products, DCGSC not only keep the environmental sustainability but also increases the accessibility of their products.

2. Literature Review

Environmental issues are becoming more significant in the society. To decrease the environmental impact, some governments have proposed the carbon tax policies to restrict manufacturers' environmental pollution. With government regulations, the supply chains will be eco-friendly, minimizing industrial waste and maximizing reuse in materials. Narasimhan and Schoenherr defined green production as using the best resources to produce products that are eco-friendly at the minimum cost to achieve both economic and environmental goals. Due to the increasing amount of DCGSC used by companies, research on this topic has also increased.

2.1 Dual channel supply chain

In a dual channel supply chain, the manufacturer is able to sell their product through two channels: the traditional offline channel that sells products through retailer(s), and the online channel that sells products directly to consumers. Numerous researches are conducted on the DCGSC, mostly focusing on pricing decisions and channel coordination while considering different factors. Yang et al. (2022) conducted research on the pricing and green decisions in a DCGSC considering the cap-and-trade regulation from the government. Gao et al. (2021) studied the competition and coordination in a DCGSC under the eco-label policy. Meng et al. (2021) investigated in the pricing decisions of a DCGSC considering government subsidies and consumers' dual preference. Tao et al. (2022) researched on the optimal channel structure of a DCGSC with the impact of consumers' green awareness and preference. Ghosh et al. (2024) considered the impact of consumers' channel preferences on coordination and strategy decisions in a DCGSC. From various research papers and studies, the majority investigated on the pricing strategies and channel structures in a DCGSC considering factors mainly of consumers and government. Therefore, government subsidies or carbon policies and consumer green and channel preferences should be considered as significant factors in a DCGSC.

2.2 Customer green product and channel preferences

As the environmental awareness of the public increase, the customer's green preference of a product also increases. Borin et al. (2013) concluded that the customers tend to buy more green products compared to non-green products. Similarly, Fleischmann et al. (1997) found that green products will increase the consumer demand in the market. These conclusions lead to the increase in the production of green products today. Chen et al. (2021) constructed four game models representing different situations. They discovered that the increase in consumer green preference and corporate social responsibility can improve the green degree of the product.

In a dual channel supply chain, the consumers are able to buy the products not only from physical stores but also online platforms. Thus, consumers will have subjective preferences in deciding the channel they choose to purchase the product from. In fact, Zhang et al. (2024), by adopting different financial methods in a DCGSC, states that the consumer green preference significantly influences the pricing decisions. When the consumer demand for green

products increases, the manufacturer will adjust the pricing decisions to accommodate the consumer green and channel preferences. Xu et al. (2024) studied on how consumer preferences and green quality of a product can impact the decision of different government subsidies. They concluded that when the consumer preference for online channels is greater than 50%, subsidizing the manufacturers will be a better decision for overall profit in the supply chain. On the other hand, when the preference for online channels is lower than 50%, the subsidizing strategy should be determined considering the production costs. Though consumer channel preference does not impact the product greenness, but it will impact the profits of the members in the supply chain.

2.3 Government actions on DCGSC

Borin found that purchase intentions for green products are significantly higher than those of non green products the other than carbon tax and tariffs on greenhouse gas emissions, the government also provide subsidies to businesses and organizations to encourage the production of green products. In fact, many researchers have investigated on the effects of government subsidies on the pricing decisions for manufacturers in a DCGSC. Mahmoudi et al. (2020) considered the government subsidies in a green supply chain, finding that when the government subsidies to the manufacturer increase, the degree of product greenness also increases, leading to a reduction of pollution. Yu et al. (2016) constructed a green supply chain model in which the manufacturer, under government subsidy policies, produces different products of green levels to satisfy different consumer demands for different green preferences. They claim that with the changes of consumer green preferences and government subsidy policies, manufacturers may gain more profits, regardless of the competition between products and channels. Yu and colleagues' model allows manufacturers to know when to increase and decrease the production of green products. Madani and Barzoki (2017) found the optimal solutions for members in a green supply chain. They found that raising the subsidy rates will lead to increase in product demands, green degree of product, profits of supply chain members, and decreases in pollution costs for governments. Lou et al. (2020) investigated in a two-echelon dual channel supply chain under government subsidies. Comparing the centralized and decentralized supply chains, they concluded that the product greenness in the centralized supply chain is higher than that in the decentralized supply chain, meaning that the government tends to provide subsidies to a centralized supply chain. They also found that the profit of the centralized supply chain is also higher than that of the decentralized supply chain.

3. Problem Descriptions and Assumptions

3.1 Problem description

This paper investigates a dual channel green supply chain including one manufacturer, one retailer, and the government. The manufacturer produces a green product and sells the product not only to the retailer in the offline channel but also directly to the consumer in the online channel. The government will offer subsidies to the manufacturer based on the unit green degree of the product. This paper also investigates in the comparison of centralized and decentralized models in a DCGSC.

3.2 Assumptions

Assumption 1: The manufacturer sells the product to the retailer at a wholesales price w. The retailer sells the product to the consumer through the offline channel at the price p_r. The manufacturer sells the product directly to the consumer through the online channel at the price p_m. It is assumed that p_r is always greater than p_m.

Assumption 2: The supply chain follows the Stackelberg game model, meaning that the retailer will make decisions based on the pricing decision of the manufacturer.

Assumption 3: Both the manufacturer and retailer are risk neutral and make decisions to maximize their profit.

Assumption 4: Using the formula Ghosh and Shah (2012) stated, the cost for manufacturers to develop a green product is $\frac{kg^2}{2}$, where g is the unit green degree of the product, and k is the cost coefficient of green production cost.

Assumption 5: Assume the potential demand in the market is Q. The consumer will have channel preference, which their online and offline preference is a and $1-a$ respectively, $0 < a < 1$. The cross-price elasticity of demand is represented by θ, $0 < \theta < 1$.The own-price elasticity of demand is β, $0 < \beta < 1$**.** The consumer will have green

preference, represented by γ, $0 < \gamma < 1$. Referring to Zhang et al. (2024), Xu et al. (2024), and Mahmoudi et al. (2020), the demand functions and profit functions of manufacturer and retailer are

$$D_r = (1-a)Q - \beta p_r + g\gamma + \theta p_m \quad (3\text{-}1)$$

$$D_m = aQ - \beta p_m + g\gamma + \theta p_r \quad (3\text{-}2)$$

$$\pi_r = (p_r - w) * D_r \quad (3\text{-}3)$$

$$\pi_m = (w - c) * D_r + (p_m - c) * D_m - \frac{kg^2}{2} \quad (3\text{-}4)$$

D_r and D_d represent the online and offline channels demand respectively. π_r and π_d represent the profit of retailer and manufacturer respectively.

Table 1. Notations

[1] variable	[2] remarks
[3] a	[4] Consumers online preference
[5] **1 − a**	[6] Consumer offline preference
[7] **Q**	[8] Total market demand
[9] **γ**	[10] Consumer green preference
[11] **g**	[12] Product green quality
[13] **c**	[14] Unit production cost of product
[15] **k**	[16] Cost coefficient of green quality per unit
[17] **θ**	[18] Cross-price elasticity of demand
[19] **β**	[20] Own-price elasticity of demand
[21] **w**	[22] Wholesale price of product
[23] $\mathbf{p_m}$	[24] Online sales price of product
[25] $\mathbf{p_r}$	[26] Offline sales price of product
[27] $\mathbf{D_m}$	[28] Demand function of the online channel
[29] $\mathbf{D_r}$	[30] Demand function of the offline channel
[31] $\boldsymbol{\pi_d}$	[32] Profit function of the manufacturer
[33] $\boldsymbol{\pi_r}$	[34] Profit function of the retailer
[35] $\boldsymbol{\pi_c}$	[36] Total profit function of the supply chain

4. Model Analysis

4.1 Centralized model (C model)

Under a centralized model, the manufacturer and the retailer will make decisions to maximize the total profit of the dual channel supply chain. The total profit function can be written as

$$\pi_c = \pi_r + \pi_m \quad (4\text{-}1)$$

$$\pi_c = (p_r - w)D_r + (w - c)D_r + (p_m - c)D_m - \frac{kg^2}{2} \quad (4\text{-}2)$$

$$\pi_c = (p_r - c)D_r + (p_m - c)D_m - \frac{kg^2}{2} \quad (4\text{-}3)$$

$$\pi_c = (p_r - c)[(1-a) * Q - \beta p_r + g\gamma + \theta p_m] + (p_m - c)(a * Q - \beta p_m + g\gamma + \theta p_r) - \frac{kg^2}{2} \quad (4\text{-}4)$$

Differentiate the profit function with respect to p_r^C and p_m^C,

$$\frac{\partial \pi_c}{\partial p_r} = (1-a)Q - 2\beta p_r + g\gamma + 2\theta p_m + c\beta - \theta c \quad (4\text{-}5)$$

$$\frac{\partial \pi_c}{\partial p_m} = aQ - 2\beta p_m + g\gamma + 2\theta p_r + c\beta - \theta c \quad (4\text{-}6)$$

The Hessian matrix of π_c is

$$H_c = \begin{bmatrix} \frac{\partial^2 \pi_c}{\partial p_r{}^2} & \frac{\partial^2 \pi_c}{\partial p_r \partial p_m} \\ \frac{\partial^2 \pi_c}{\partial p_m \partial p_r} & \frac{\partial^2 \pi_c}{\partial p_m{}^2} \end{bmatrix} = \begin{bmatrix} -2\beta & 2\theta \\ 2\theta & -2\beta \end{bmatrix} \tag{4-7}$$

The leading principal minors of H_1 is

$$\Delta_1 = -2\beta < 0,\ \Delta_2 = 4(\beta - \theta^2) > 0 \tag{4-8}$$

H_c is negative definite, meaning that the profit function π_c has a maximum.

Setting $\frac{\partial \pi_c}{\partial p_r}$ and $\frac{\partial \pi_c}{\partial p_m}$ to 0, the best prices will be

$$p_r = \frac{(1-a)Q + g\gamma + 2\theta p_m + c\beta - c\theta}{2\beta} \tag{4-9}$$

$$p_m = \frac{aQ + g\gamma + 2\theta p_r + c\beta - c\theta}{2\beta} \tag{4-10}$$

Solving this system of equations, the equilibrium solutions for p_r^C and p_m^C will result to be

$$p_r^C = \frac{[\beta(1-a) + \theta a]Q + (\beta + \theta)(g\gamma + c\beta - c\theta)}{2(\beta^2 - \theta^2)} \tag{4-11}$$

$$p_m^C = \frac{[\beta a + \theta(1-a)]Q + (\beta + \theta)(g\gamma + c\beta - c\theta)}{2(\beta^2 - \theta^2)} \tag{4-12}$$

Substituting p_r^C and p_m^C into the profit function, the centralized profit will be

$$\pi_c = \frac{[(\beta(1-a)+\theta a)Q + (\beta+\theta)(g\gamma + c\beta - c\theta) 2c(\beta^2-\theta^2)] * [(1-a)Q + g\gamma - c\beta + c\theta]}{4(\beta^2-\theta^2)} + \frac{[(\beta a + \theta(1-a))Q + (\beta+\theta)(g\gamma + c\beta - c\theta) - 2c(\beta^2-\theta^2)] * [aQ + g\gamma - c\beta + c\theta]}{4(\beta^2-\theta^2)} - \frac{kg^2}{2} \tag{4-13}$$

4.2 Decentralized model (D Model)

Under a decentralized model, the manufacturer and retailer will make decisions separately and maximize their own profits. Therefore, the profit functions for D model are

$$\pi_r^D = (p_r - w) * D_r \tag{4-14}$$

$$\pi_r^D = (p_r - w)[(1-a)Q - \beta p_r + g\gamma + \theta p_m] \tag{4-15}$$

$$\pi_m^D = (w - c) * D_r + (p_m - c) * D_m - \frac{kg^2}{2} \tag{4-16}$$

$$\pi_m^D = (w - c) * [(1-a)Q - \beta p_r + g\gamma + \theta p_m] + (p_m - c) * (aQ - \beta p_m + g\gamma + \theta p_r) - \frac{kg^2}{2} \tag{4-17}$$

Differentiate π_r^D with respect to p_r,

$$\frac{\partial \pi_r^D}{\partial p_r} = (1-a)Q - 2\beta p_r + g\gamma + \theta p_m + \beta w \tag{4-18}$$

Set $\frac{\partial \pi_r^D}{\partial p_r}$ equals to 0 and solve for p_r,

$$p_r = \frac{(1-a)Q + g\gamma + \theta p_m + \beta w}{2\beta} \tag{4-18}$$

Substitute p_r in for $\frac{\partial \pi_m^D}{\partial p_m}$ and $\frac{\partial \pi_m^D}{\partial w}$

$$\frac{\partial \pi_m^D}{\partial p_m} = aQ - 2\beta p_m + g\gamma + \theta p_r + c\beta + \theta(w - c) \tag{4-19}$$

$$p_m = \frac{2\beta[aQ + g\gamma + c\beta + \theta(w-c)] + \theta[(1-a)Q + g\gamma + \beta w]}{4\beta^2 - \theta^2} \tag{4-20}$$

$$\frac{\partial \pi_m^D}{\partial w} = (1-a)Q - \beta p_r + g\gamma + \theta p_m \tag{4-21}$$

$$w = \frac{(1-a)Q + g\gamma + \theta p_m}{\beta} \tag{4-22}$$

Therefore the Hessian matrix of π_m^D with respect to p_m^D and w is

$$H_D = \begin{bmatrix} \frac{\partial^2 \pi_m^D}{\partial w^2} & \frac{\partial^2 \pi_m^D}{\partial w \partial p_m^D} \\ \frac{\partial^2 \pi_m^D}{\partial p_m^D \partial w} & \frac{\partial^2 \pi_m^D}{\partial p_m^{D\,2}} \end{bmatrix} = \begin{bmatrix} -\beta & \frac{\theta}{2} \\ \frac{\theta}{2} & \frac{\theta^2 - 2\beta^2}{\beta} \end{bmatrix} \tag{4-23}$$

The leading principal minors of H_D are

$$\Delta_1 = -\beta < 0,\ \Delta_2 = \frac{8\beta^2 - 3\theta^2}{4} > 0 \tag{4-24}$$

H_D is negative define, meaning there exists the best p_m^D and w.

Set $\frac{\partial \pi_r^D}{\partial p_r^D}$, $\frac{\partial \pi_m^D}{\partial p_m^D}$, and $\frac{\partial \pi_m^D}{\partial w}$ to 0 and get the equilibrium solutions for p_r^D, p_m^D, and w.

$$p_r^D = \frac{\theta aQ+2\beta(1-a)Q+2\beta g\gamma+\theta g\gamma+c\theta(\beta-\theta)}{2(\beta^2-\theta^2)} \tag{4-25}$$

$$p_m^D = \frac{\beta aQ+2\theta(1-a)Q+\beta g\gamma+2\theta g\gamma+c\beta(\beta-\theta)}{2(\beta^2-\theta^2)} \tag{4-26}$$

$$w = \frac{\theta aQ+2\beta(1-a)Q+2\beta g\gamma+\theta g\gamma+c\theta(\beta-\theta)}{3(\beta^2-\theta^2)} \tag{4-27}$$

Susbtituting p_r^D, p_m^D, and w into the profit functions, the manufacture and retailer profit will be

$$\pi_m^D = (1-a)Q + g\gamma \tag{4-28}$$

$$\pi_r^D = \frac{[aQ+g\gamma-2c(\beta-\theta]*[\beta(aQ+g\gamma+c(\beta-\theta))+2\theta((1-a)Q+g\gamma)-2c(\beta^2-\theta^2)]}{4(\beta^2-\theta^2)} \tag{4-29}$$

4.3 Experimental simulation

In this experiment, we will focus on the pricing strategy, channel selection, and the impact of government subsidies on supply chain members in a green dual-channel supply chain (DCGSC). Through the simulation model, we will optimize the price, demand and profit of the supply chain under the following conditions:

The supply chain members include manufacturers, retailers, and the government. Manufacturers sell their products through both online and offline channels, and retailers are responsible for selling their products through offline channels. The government supports the production of green products through green subsidies.

It is assumed that the manufacturer and the retailer adopt the Stackelberg game model, in which the retailer's decision is adjusted based on the manufacturer's pricing decision.

In the simulation, we will consider the centralized supply chain decision-making model and the decentralized supply chain decision-making model separately in order to assess the impact of the two models on the overall profit.

Our model assumes that consumers have green product preferences and that their purchasing channel (online or offline) is also influenced by preferences.

The parameter settings are shown in Table 2.

Table 2. Parameter Settings

Variable	Value
Consumers online preference(a)	0.6
Consumer offline preference($1-a$)	0.4
Total market demand(Q)	1000
Consumer green preference(γ)	0.8
Unit production cost of product(c)	20
Cost coefficient of green quality per unit(k)	5
Wholesale price of product(w)	60
Online sales price of product(p_m)	90
Offline sales price of product(p_r)	110

In order to visually explore the impact of consumers' online channel preferences and unit low carbon levels on sales under different decision scenarios, python data visualization was used for further validation.

As shown in Figure 1, online prices are lower and demand is higher, showing the price sensitivity of the online channel. As the offline price increases, the demand for the offline channel decreases, but there is still some demand due to the higher preference for the offline channel.

As shown in Figure 2, the profit of the supply chain increases significantly as the level of subsidy increases. This indicates that government subsidies effectively reduce production costs and stimulate demand for green products. However, too high a level of subsidy may lead to oversupply in the market, which in turn affects prices and profits.

4.4 Results and discussion

Through the simulation results, we find the following key findings:

Pricing strategy: consumers' green preference has a significant effect on pricing strategy. When consumers' green preference increases, manufacturers tend to improve the quality of green products while keeping lower online prices in order to attract more consumers.

The role of government subsidies: Government subsidies can effectively reduce the production cost of green products and significantly increase the overall profit of the supply chain. When the government subsidy is 20%, the cost of producing green products decreases and the overall profit of the supply chain increases. The impact of subsidies on demand is obvious, especially when green products are able to enter the market at lower prices with the support of government subsidies to satisfy consumers' green preferences.

Centralized vs. Decentralized Decision Making: In the centralized decision-making model, the alignment of manufacturers and retailers drives supply chain profit maximization. In contrast, the decentralized decision-making model has lower overall profits than the centralized.

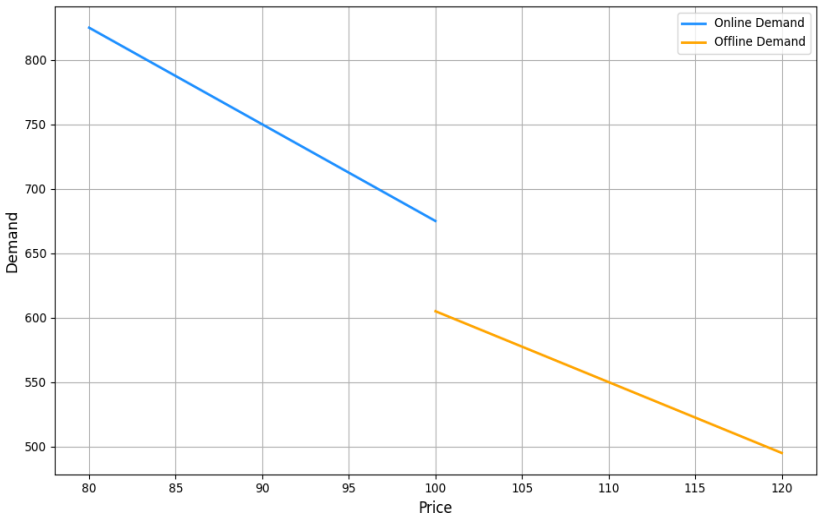

Figure 1. Price-Demand Relationship for Online and Offline Channels.

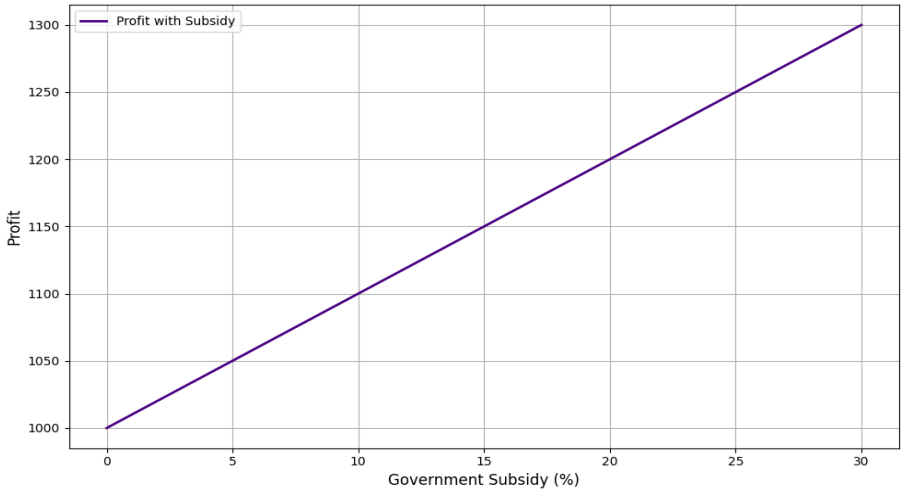

Figure 2. Effect of government subsidies on profits.

5. Conclusion

This study explores the interrelationships among pricing strategies, consumer green preferences, channel preferences and government subsidy policies in a green dual-channel supply chain (DCGSC), analyzes the profit differences

between a centralized supply chain decision-making model and a decentralized supply chain decision-making model, and thoroughly investigates the impact of government subsidies on the production and pricing strategies of green products. The experimental results show that government subsidies play an important role in promoting the production of green products, which can effectively reduce the production cost and promote the market demand of green products by regulating product prices. In addition, consumers' green preference and channel preference have a significant impact on pricing strategies, and under different consumer demand structures, companies should adopt flexible pricing strategies to optimize profits.

The experiment also shows that the centralized supply chain decision-making model is able to coordinate the interests of manufacturers and retailers to maximize the overall profit, while the decentralized decision-making model leads to profit loss due to the lack of coordination. The government subsidy policy is particularly effective under the centralized decision-making model, which not only improves the production quality of green products but also enhances the overall profitability of supply chain members.

With the growing environmental problems, green supply chain management will play an increasingly important role in future economic activities. Future research can delve into the following directions: first, as green policies continue to evolve, how to dynamically adjust green supply chain decisions according to changes in different regions and policies remains a topic of interest. Second, as consumer preference for green products continues to rise, exploring more refined pricing and channel management strategies will have a profound impact on enhancing corporate competitiveness and social and environmental benefits. Finally, studying how to optimize the green supply chain by combining big data and artificial intelligence technologies to make it more adaptive and forward-looking is also an important direction for future research on green supply chain management.

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