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Research Article

Research on Government Green Subsidy Strategy of Heterogeneous Agricultural Product Supply Chain

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To promote dual carbon targets, this study builds a heterogeneous agricultural product supply chain comprised of a green agricultural product producer, an ordinary agricultural products producer, and a retailer. This study constructs four strategic government green subsidy models, wherein the nongovernment subsidy, government subsidy for green agricultural producers, subsidy for green consumers, and dual subsidies. Based on Stackelberg's game theory, this study analyzes the impact of differentiated green subsidies on heterogeneous agricultural product supply chain decision-making. The results show that the government will provide green subsidies only when the input cost coefficient of green quality is within a certain threshold. Consumers' preference for green agricultural products will improve the level of green quality. The dual subsidy strategy of the government has the highest social welfare and can stimulate the motivation of green production. When considering the subsidy expenditure, the green consumer subsidy strategy can achieve a higher level of green quality and promote the consumption of green agricultural products. The government should combine different subsidy target effects and subsidy effects to provide appropriate green subsidy strategies. According to the corresponding subsidy strategy, the producers and retailers of heterogeneous agricultural products carry out green investment, reasonable pricing, and precision marketing.

1. Introduction

As China's consumer upgrading trend becomes more pronounced, Chinese consumers' demand for agricultural products is changing from satisfying subsistence to healthy, high-quality, green, and organic agricultural products [1–3]. In order to meet the diverse needs of consumers, the market will sell heterogeneous agricultural products with different qualities and values [4]. The government has continuously introduced policies to improve the quality of agricultural products and the development level of green agriculture. In 2023, the government issued the "No. 1 Central Document," proposing to accelerate the application of green agricultural technology, build a national agricultural green development pilot zone, and improve the monitoring system for agricultural ecological environment protection. Agriculture has become greener and more high quality.

However, green production requires advanced technology and higher production and R&D costs [5], which reduces the motivation of producers to produce green agricultural products [6], resulting in a smaller production scale and more difficult green quality improvement. To alleviate the financial pressure of green production, the Chinese government has formulated a green policy system oriented to green ecology and proposed comprehensive agricultural subsidies, direct subsidies for grain farmers, and subsidies for good crop seeds. In the face of various agricultural operators and green production technologies, the government has introduced supportive policies. However, the government has been providing green subsidies for the agricultural production process and business entities, but the subsidy link and object are relatively single.

Green agricultural products are more expensive, and Chinese consumers are less willing to pay a premium for green agricultural products [7], while it has become common for consumers in developed countries to pay a green premium for green produce [8, 9]. For instance, about 80% of German consumers are willing to buy green agricultural products at a higher premium [10]. It has somewhat hindered the expansion of the consumer market for green agricultural products in China. Among green policies, the provision of subsidies plays a crucial role in the green development process [11, 12]. For instance, the government provides green subsidies to producers and consumers in the production and sales process of green products such as new energy vehicles and green appliances [13, 14], which help green product producers while stimulating green consumers to purchase green products [15, 16]. When the market simultaneously sells heterogeneous agricultural products of ordinary quality and green quality, the government can adopt the subsidy methods of no green subsidies, subsidies for green agricultural products producers, subsidies for green consumers, and double subsidies. According to different subsidy methods, the green quality level and price of heterogeneous agricultural products are also affected by different decisions. The government takes the maximum social welfare, the improvement of green quality, the promotion of green agricultural consumption, and the consideration of subsidy expenditure as subsidy objectives, which will produce different optimal subsidy strategies.

Based on this, in response to the different needs and preferences of consumers regarding the quality of agricultural products, this study mainly investigates the following questions:

(1) Is it necessary for the government to provide green subsidies for consumers?

(2) What is the impact of green subsidies on the optimal decision of heterogeneous agricultural product supply chain?

(3) What is the optimal green subsidy strategy under different subsidy objectives?

The remainder of the paper is organized as follows. Section 2 provides a review of relevant literature. Section 3 describes the problem description. Section 4 presents the construction and solution of the green subsidy strategy model of the government of heterogeneous agricultural products. Section 5 performs the analysis of model equilibrium results. Section 6 performs numerical analysis based on actual data. Section 7 summarizes the conclusions and management insights and discusses limitations and future research.

2. Literature Review

2.1. Pricing and Quality Decisions of Heterogeneous Products. Pricing and quality decisions of heterogeneous products have received much scholarly attention in recent years. Liu and Zhang [17] investigated the dynamic pricing problem of two enterprises producing vertically differentiated products by considering strategic consumers and concluded that strategic consumers incur higher losses for low-quality enterprises than for high-quality enterprises. Li and Chen [18] investigated the product pricing problem for two manufacturers and one seller producing heterogeneous goods; when quality is an exogenous variable, price competition between the two manufacturers diminishes; when quality is an endogenous variable, manufacturers and retailers achieve a win-win situation, but price and quality competition between manufacturers increases. Rational decisions on pricing and quality of heterogeneous products increase the profits of supply chain members [19–21] and affect consumers' heterogeneous product demand and purchasing behavior [22]. To improve product competitiveness and mitigate channel conflicts, many scholars studied heterogeneous products from the dual-channel supply chain perspective. Liu et al. [23] studied the pricing of heterogeneity in a dual-channel supply chain by considering consumer acceptance of heterogeneous products. Hou et al. [24], on the other hand, considered nonprice characteristics, i.e., the impact of the "online to store" channel and product quality levels on product pricing and profitability. It has been found that the presence of both price competition and quality competition in producing heterogeneous products had impacts on the pricing and quality decisions of heterogeneous products.

Heterogeneous agricultural products are those with imperfect substitutability, which have two attributes, the performance of use to meet the basic needs of consumers (basic value function) and to meet higher quality needs and services of consumers (beyond value function) [4]. In order to simplify the description, this paper divides heterogeneous agricultural products into two categories: one is ordinary agricultural products with basic value functions to meet the quality and safety of agricultural products, and the other is green agricultural products with both attributes to meet quality and safety while satisfying consumers' pursuit of green, organic, and nutritious health. Many scholars have also discussed the pricing and quality decision of heterogeneous agricultural products. Considering consumer equilibrium, Liu et al. [5] have explored behavior-based pricing between organic and ordinary food firms, with the pricing strategies of the two enterprises being opposite as market share increases. Pu et al. [25] found that the market entry mode of organic agricultural products affects the pricing and demand of organic and ordinary agricultural products. Perlman et al. [26] considered a dual-channel supply chain consisting of organic and ordinary agricultural products to analyze the pricing of heterogeneous agricultural products under dual channels. Green agricultural products require higher costs to improve green quality levels, but producers lack sufficient incentives to improve green quality levels alone. Therefore, government subsidies play an important role as a powerful tool to increase producers' profits and the green quality level of agricultural products. Based on the heterogeneity of consumers' evaluation of service and product quality, farmers and retailers will make strategic decisions of product competition or cooperation [27]. Unlike previous studies, this paper considers the impact of differentiated government green subsidies on the pricing and green quality level decisions of heterogeneous agricultural products.

2.2. Green Supply Chain Government Subsidy Strategy and Decision. In the green supply chain, government subsidy targets include product producers and green consumers. Productively, in order to encourage manufacturers to produce more green products, the government implements subsidy policies to bring more profits to manufacturers [28]. When governments subsidize manufacturers' costs of low-carbon production innovation, retailers can adopt revenue-sharing or cost-sharing strategies to enhance supply chain cooperation [29]. Li et al. [30] studied three government subsidy strategies: a green nonsubsidy, a green product subsidy, and a green innovation subsidy and found that the green product subsidy strategy is optimal when the cost of green innovation is sufficiently high and green innovation reduces the variable production cost of the green product significantly, while the green innovation subsidy strategy is optimal when subsidy efficiency is maximum. The government's direct subsidy strategy to farmers will have an important impact on the greening of agricultural products [31].

When it comes to subsidizing green consumers, Cohen et al. [32] argued that direct government subsidies to green consumers affect green product production and pricing decisions. Both governments and manufacturers will benefit if consumers are properly sensitive to green and low-carbon subsidies [33]. Considering consumers' preferences for the environment, Wang et al. [34] constructed a three-stage Stackelberg model composed of the government, manufacturers, and retailers to analyze the incentive effect of consumers' green subsidy strategy. Zhao et al. [35] studied the problem of joint decision-making on remanufacturer pricing and subsidy shares between remanufacturers and consumers and suggested that remanufacturers can obtain higher returns by sharing subsidies with consumers.

In response to the existence of heterogeneous products in the consumer market that meets different consumer needs, scholars discussed the decision-making problem of the green subsidy strategy in a competitive market. Government subsidy strategies that take into account heterogeneous effects can bring about win-win-win results for farmers, raw material producers, and social welfare [36]. In both cases without and with government subsidies, Meng et al. [37] analyzed the supply chain decisions of two competing enterprises and found that government subsidies reduce the price of green products; in contrast to this finding, Barman et al. [38] studied the pricing decision problem of a bioligopolistic green supply chain consisting of two competing manufacturers and one retailer and found that government subsidies increase the price of green products. In agricultural supply chain, government subsidies involve a variety of subsidy strategies, including price subsidies [39], yield subsidies and innovation subsidies [40], crop insurance and premium subsidies [41], production subsidies with fixed or coefficient subsidies [42], the price loss coverage program, and the agriculture risk coverage program [43] for agricultural producers. These pieces of literature have only studied the situations of government subsidies for agricultural producers, and the target of subsidies is relatively single.

In summary, based on existing studies, this paper establishes a Stackelberg game model to analyze the differentiated green subsidy strategy and the optimal pricing and green quality level decision of heterogeneous agricultural product supply chain. The difference between this paper and other scholars' research is that first, existing studies do not consider the impact of differentiated green subsidies on ordinary agricultural producers. In real life, it is common to sell homogenous agricultural products in the consumer market, so it is important to analyze the impact of the government's green subsidy strategy on green agricultural producers and ordinary agricultural producers. Second, this paper proposes the dual subsidy strategy that provides subsidies of green agricultural producers and green consumers and compares the effects of different green subsidy strategies on heterogeneous agricultural product supply chain decisions. Finally, combining the results of comparative and arithmetic analysis, the optimal green subsidy strategy of the government is discussed for different subsidy targets.

3. Problem Description

We consider a heterogeneous agricultural supply chain model consisting of a green agricultural producer (hereafter referred to as producer 1), an ordinary agricultural producer (hereafter referred to as producer 2), and a retailer [26, 38]. The Stackelberg game process is shown in Figure 1. According to previous studies, a linear demand function was used to represent the green agricultural product market demand d_g and ordinary agricultural product market demand d_n, respectively [38, 44], with the expressions $d_g = \rho\alpha - \mathrm{p_g} + \mathrm{bp_n} + \beta\theta$ and $d_n = (1-\rho)\alpha - \mathrm{p_n} + \mathrm{bp_g}$.

Among them, $\alpha(\alpha > 0)$ represents the total market demand capacity, ρ represents the preference coefficient of consumers of green agricultural products, and $1-\rho$ represents the preference coefficient of consumers of ordinary agricultural products. Also, $b(0 < b < 1)$ represents the coefficient of cross-price elasticity between green agricultural products and ordinary agricultural products and the value of b, and the larger the value of b, the more intense the market competition between the two agricultural products. β is the coefficient of consumer sensitivity to green quality levels, and θ is the green quality level of green agricultural products. Here, the subscript g represents green agricultural products, and the subscript n represents ordinary agricultural products. Since green agricultural products need to invest more production costs, assuming $c_g > c_n$, without loss of generality, assuming $c_n = 0$, we use c to represent the unit production cost of green agricultural products [25].

In this paper, we consider green and ordinary agricultural products to be sold in the market at the same time. Different green subsidy strategies are considered to be provided by the government, including nongovernment subsidy (N), producer 1 subsidy strategy (G), green consumer subsidy strategy (C), and dual subsidy strategy (G + C). The parameters used in this paper are shown in Table 1.

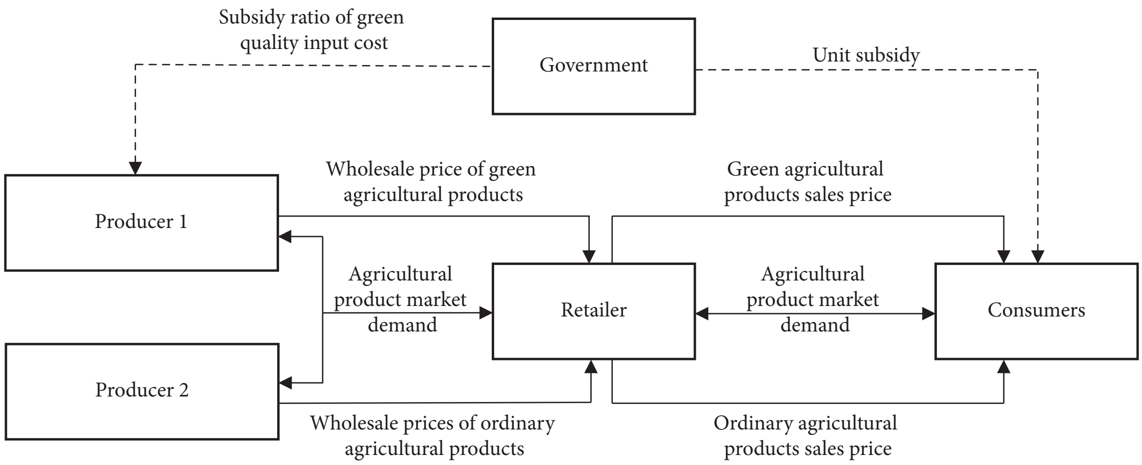

Figure 1: The main body game model diagram of agricultural product supply chain under government green subsidy.

Table 1: Descriptions for the parameters.

Parameters	Descriptions
α	The total market demand capacity
ρ	The preference coefficient of consumers of green agricultural products
b	The coefficient of cross-price elasticity
c	The unit production cost of green agricultural products
β	The coefficient of consumer sensitivity to green quality levels
k	The coefficient of green quality input cost
s_1	Percentage of government subsidies for green quality input costs
s_2	Amount of government subsidy per unit for green consumers
θ	Green quality level
w_g	The wholesale price of green agricultural products
w_n	The wholesale price of ordinary agricultural products
p_g	The sales price of green agricultural products
p_n	The sales price of ordinary agricultural products
d_g	The market demand for green agricultural products
d_n	The market demand for ordinary agricultural products
π_{Mg}	The profit of producer 1
π_{Mn}	The profit of producer 2
π_S	The profit of the retailer

4. Models and Analysis

4.1. Nongovernment Subsidy Strategy Model. When the government does not provide green subsidies, the sequence of decision-making of supply chain members is as follows: producer 1 decides the green quality level of green agricultural products θ and the wholesale price w_g^N, while producer 2 decides the wholesale price w_n^N of ordinary agricultural products, and then, the retailer decides the sales price p_g^N and p_n^N of agricultural products. Based on demand functions and research assumptions, profit functions of the agricultural product producer and the retailer can be expressed as follows:

$$\pi_{Mg}^N = \left(w_g^N - c\right)d_g^N - \frac{1}{2}k\theta^2, \tag{1}$$

$$\pi_{Mn}^N = w_n^N d_n^N, \tag{2}$$

$$\pi_S^N = \left(p_g^N - w_g^N\right)d_g^N + \left(p_n^N - w_n^N\right)d_n^N. \tag{3}$$

Lemma 1. *When the government does not provide green subsidies, π_S^N is a concave function of p_g and p_n, and the heterogeneous agricultural products' sales price has an optimal value; when $k > \beta^2/4 - b^2$ is satisfied, π_{Mg}^N is a concave function* *about θ and w_g and π_{Mn}^N is a concave function about w_n. Both the green quality level of green agricultural products and the wholesale price of heterogeneous agricultural products have the optimal value. The above optimal values are as follows (see the Proof Lemma A.1. in Appendix A for full workings):*

$$\theta^{N*} = \frac{\beta\lambda_1}{2\left[\left(4-b^2\right)k-\beta^2\right]},$$

$$w_g^{N*} = \frac{k\lambda_2-\beta^2 c}{\left(4-b^2\right)k-\beta^2},$$

$$w_n^{N*} = \frac{2k\lambda_3-\beta^2\lambda_4}{2\left[\left(4-b^2\right)k-\beta^2\right]}, \tag{4}$$

$$p_g^{N*} = \frac{2k\lambda_5-2k\left(1+2b^2\right)\lambda_2-\beta^2\lambda_6}{4\left(1-b^2\right)\left[\left(4-b^2\right)k-\beta^2\right]},$$

$$p_n^{N*} = \frac{\left(3-2b^2\right)\left(2k\lambda_3-\beta^2\lambda_4\right)+2bk\lambda_7}{4\left(1-b^2\right)\left[\left(4-b^2\right)k-\beta^2\right]},$$

where $\lambda_1 = \alpha b(1-\rho)+b^2c+2\alpha\rho-2c$, $\lambda_2 = \alpha b(1-\rho)+2\alpha\rho+2c$, $\lambda_3 = \alpha b\rho+2\alpha(1-\rho)+bc$, $\lambda_4 = \alpha(1-\rho)+bc$, $\lambda_5 = 4\alpha(b+\rho-b\rho)+b^2(\alpha\rho+2c)$, $\lambda_6 = \alpha b(1-\rho)+(4-3b^2)c$, and $\lambda_7 = \alpha b(1-\rho)+3c-8\alpha\rho-5b^2c$.

The green quality input cost coefficient is greater than a certain threshold, and the green quality level of green agricultural products and the wholesale price and the sales price of heterogeneous agricultural products have the optimal value. Since the government does not provide any green subsidies, it can only rely on green quality and preferential prices to attract customers to purchase green agricultural products. Therefore, the coefficient of cross-price elasticity and the coefficient of consumer sensitivity to the green quality level directly affect the decisions and earnings of producer 1, producer 2, and the retailer.

4.2. Government Subsidy to Producer 1 Strategy Model. When the government provides green subsidies to producer 1, the sequence of decision-making of supply chain members is as follows: producer 1 decides the green quality level of green agricultural products θ and the wholesale price w_g^G, while producer 2 decides the wholesale price w_n^G of ordinary agricultural products, and then, the retailer decides the sales price p_g^G and p_n^G of agricultural products. The government provides the s_1 ratio subsidy for the green quality input cost of producer 1. Considering that the government provides green subsidies to producer 1, the profit functions for the producer and the retailer can be obtained based on demand functions and research assumptions that

$$\pi_{Mg}^G = \left(w_g^G-c\right)d_g^G-\frac{1}{2}(1-s_1)k\theta^2, \tag{5}$$

$$\pi_{Mn}^G = w_n^G d_n^G, \tag{6}$$

$$\pi_S^G = \left(p_g^G-w_g^G\right)d_g^G+\left(p_n^G-w_n^G\right)d_n^G. \tag{7}$$

Lemma 2. *When the government provides green subsidies to producers 1, π_S^G is a concave function of p_g and p_n, and the heterogeneous agricultural products' sales price has an optimal value; when $k>\beta^2/(4-b^2)(1-s_1)$ is satisfied, π_{Mg}^G is a concave function about θ and w_g and π_{Mn}^G is a concave function about w_n. Both the green quality level of green agricultural products and the wholesale price of heterogeneous agricultural products have the optimal value. The above optimal values are as follows (see the Proof Lemma A.2. in Appendix A for full workings):*

$$\theta^{G*} = \frac{\beta\lambda_1}{2\left[\left(4-b^2\right)(1-s_1)k-\beta^2\right]},$$

$$w_g^{G*} = \frac{k(1-s_1)\lambda_2-\beta^2 c}{\left(4-b^2\right)(1-s_1)k-\beta^2},$$

$$w_n^{G*} = \frac{2k(1-s_1)\lambda_3-\beta^2\lambda_4}{2\left[\left(4-b^2\right)(1-s_1)k-\beta^2\right]},$$

$$p_g^{G*} = \frac{2(1-s_1)k\left[\lambda_5-\left(1+2b^2\right)\lambda_2\right]-\beta^2\lambda_6}{4\left(1-b^2\right)\left[\left(4-b^2\right)(1-s_1)k-\beta^2\right]},$$

$$p_n^{G*} = \frac{2(1-s_1)k\left[\left(3-2b^2\right)\lambda_3+b\lambda_7\right]-\left(3-2b^2\right)\beta^2\lambda_4}{4\left(1-b^2\right)\left[\left(4-b^2\right)(1-s_1)k-\beta^2\right]}. \tag{8}$$

If the green quality input cost coefficient is greater than a certain threshold, the government will provide green subsidies for producer 1. Due to the large capital demand for improving the level of green quality, green technology is difficult to obtain, and the government will enhance the green production motivation of producer 1 through green subsidies. Producer 1 will invest more money to improve the level of green quality. The percentage of government subsidies for green quality input costs influences the decisions and returns of producers 1, 2, and retailers.

4.3. Government Subsidy to Green Consumer Strategy Model. When the government provides green subsidies to green consumers, the sequence of decision-making of supply chain members is as follows: producer 1 decides the green quality level of green agricultural products θ and the wholesale price w_g^C, while producer 2 decides the wholesale price w_n^C of ordinary agricultural products, and then, the retailer decides the sales price p_g^C and p_n^C of agricultural products. The government provides the unit subsidy s_2 to green consumers according to the green quality level θ. Considering that the government provides green subsidies to green consumers, and at this instant, the demand functions are $d_g^C = \rho\alpha-(\mathrm{p_g}-\mathrm{s_2}\theta)+\mathrm{bp_n}+\beta\theta$ and $d_n^C = (1-\rho)\alpha-\mathrm{p_n}+b(p_g-\mathrm{s_2}\theta)$. The profit functions for the producer and the retailer can be obtained as follows:

$$\pi_{Mg}^{C} = \left(w_g^C - c\right)d_g^C - \frac{1}{2}k\theta^2, \tag{9}$$

$$\pi_{Mn}^{C} = w_n^C d_n^C, \tag{10}$$

$$\pi_S^C = \left(p_g^C - w_g^C\right)d_g^C + \left(p_n^C - w_n^C\right)d_n^C. \tag{11}$$

Lemma 3. *When the government provides green subsidies to green consumers, π_S^C is a concave function of p_g and p_n, and the heterogeneous agricultural products' sales price has an optimal value; when $k > (\beta + s_2)[(2 - b^2)s_2 + 2\beta]/2(4 - b^2)$ is satisfied, π_{Mg}^C is a concave function about θ and w_g and π_{Mn}^C is a concave function about w_n. Both the green quality level of green agricultural products and the wholesale price of heterogeneous agricultural products have the optimal value. The above optimal values are as follows (see the Proof Lemma A.3. in Appendix A for full workings):*

$$\theta^{C*} = \frac{(\beta + s_2)\lambda_1}{\left(4 - b^2\right)(2k - \beta s_2) - 2\beta^2 - \left(2 - b^2\right)s_2^2},$$

$$w_g^{C*} = c + \frac{2\left(4 - b^2\right)(1 - c)k}{\left(4 - b^2\right)(2k - \beta s_2) - 2\beta^2 - \left(2 - b^2\right)s_2^2},$$

$$w_n^{C*} = \frac{(2k - \beta s_2)\lambda_3 - \beta^2\lambda_4 - \alpha s_2^2\lambda_8}{\left(4 - b^2\right)(2k - \beta s_2) - 2\beta^2 - \left(2 - b^2\right)s_2^2},$$

$$p_g^{C*} = \frac{2k\lambda_5 - 2k\left(1 + 2b^2\right)\lambda_2 - \beta^2\lambda_6 - \beta\lambda_9 - s_2^2\lambda_{10}}{2\left(1 - b^2\right)\left[\left(4 - b^2\right)(2k - \beta s_2) - 2\beta^2 - \left(2 - b^2\right)s_2^2\right]},$$

$$p_n^{C*} = \frac{\left(3 - 2b^2\right)\left(2k\lambda_3 - \beta^2\lambda_4 - 3s_2^2\lambda_8 - s_2\beta\lambda_{11}\right) + 2bk\lambda_7}{2\left(1 - b^2\right)\left[\left(4 - b^2\right)(2k - \beta s_2) - 2\beta^2 - \left(2 - b^2\right)s_2^2\right]}, \tag{12}$$

where $\lambda_8 = 1 - \rho + b\rho$, $\lambda_9 = 2\alpha b(1 - \rho) + 8c - b^2 c - b^2[2c(4 - b^2) - \alpha\rho]$, $\lambda_{10} = \alpha b(1 - \rho + b\rho) + c[4 - 2b^2(3 - b^2)]$, and $\lambda_{11} = 2\alpha(1 - \rho) + b(\alpha\rho + c)$.

When the green quality input cost coefficient is greater than a certain threshold, the government will provide green subsidies for consumers. When the green quality level of green agricultural products is different, the sensitivity of consumers is also affected to different degrees. The government provides green consumption subsidies to increase green consumption willingness. Consumers tend to purchase higher quality green produce. The amount of government subsidy per unit for green consumers affects the decisions and earnings of producers 1, 2, and retailers.

4.4. Government Dual Subsidy Strategy Model. When the government provides green subsidies to producer 1 and green consumers, the sequence of decision-making of supply chain members is as follows: producer 1 decides the green quality level of green agricultural products θ and the wholesale price w_g^{G+C}, while producer 2 decides the wholesale price w_n^{G+C} of ordinary agricultural products, and then, the retailer decides the sales price p_g^{G+C} and p_n^{G+C} of agricultural products. The government not only provides the s_1 ratio subsidy for the green quality input cost of producer 1 but also provides the unit subsidy s_2 to green consumers according to the green quality level θ. Considering that the government provides dual subsidies to producer 1 and green consumers, and at this instant, the demand functions are $d_g^{G+C} = \rho\alpha - (p_g - s_2\theta) + bp_n + \beta\theta$ and $d_n^{G+C} = (1 - \rho)\alpha - p_n + b(p_g - s_2\theta)$. The profit functions for the producer and the retailer can be obtained as follows:

$$\pi_{Mg}^{G+C} = \left(w_g^{G+C} - c\right)d_g^{G+C} - \frac{1}{2}(1 - s_1)k\theta^2, \tag{13}$$

$$\pi_{Mn}^{G+C} = w_n^{G+C} d_n^{G+C}, \tag{14}$$

$$\pi_S^{G+C} = \left(p_g^{G+C} - w_g^{G+C}\right)d_g^{G+C} + \left(p_n^{G+C} - w_n^{G+C}\right)d_n^{G+C}. \tag{15}$$

Lemma 4. *When the government provides dual subsidies, π_S^{G+C} is a concave function of p_g and p_n, and the heterogeneous agricultural products' sales price has an optimal value; when $k > (\beta + s_2)[(2 - b^2)s_2 + 2\beta]/2(4 - b^2)(1 - s_1)$ is satisfied, π_{Mg}^{G+C} is a concave function about θ and w_g and π_{Mn}^{G+C} is a concave function about w_n. Both the green quality level of green agricultural products and the wholesale price of heterogeneous agricultural products have the optimal value. The above optimal values are as follows (see the Proof Lemma A.4. in Appendix A for full workings):*

$$\theta^{G+C*} = \frac{(\beta + s_2)\lambda_1}{\left(4 - b^2\right)[2k(1 - s_1) - \beta s_2] - 2\beta^2 - \left(2 - b^2\right)s_2^2},$$

$$w_g^{G+C*} = c + \frac{2\left(4 - b^2\right)(1 - c)k(1 - s_1)}{\left(4 - b^2\right)[2k(1 - s_1) - \beta s_2] - 2\beta^2 - \left(2 - b^2\right)s_2^2},$$

$$w_n^{G+C*} = \frac{[2k(1 - s_1) - \beta s_2)]\lambda_3 - \beta^2\lambda_4 - \alpha s_2^2\lambda_8}{\left(4 - b^2\right)[2k(1 - s_1) - \beta s_2] - 2\beta^2 - \left(2 - b^2\right)s_2^2},$$

$$p_g^{G+C*} = \frac{2(1 - s_1)k\left[\lambda_5 - \left(1 + 2b^2\right)\lambda_2\right] - \beta^2\lambda_6 - \beta\lambda_9 - s_2^2\lambda_{10}}{2\left(1 - b^2\right)\left[\left(4 - b^2\right)(2k - 2s_1 k - \beta s_2) - 2\beta^2 - \left(2 - b^2\right)s_2^2\right]},$$

$$p_n^{G+C*} = \frac{2k\left[\left(3 - 2b^2\right)\lambda_3 + b\lambda_7\right] - \left(3 - 2b^2\right)\left(\beta^2\lambda_4 + 3s_2^2\lambda_8 + s_2\beta\lambda_{11}\right)}{2\left(1 - b^2\right)\left[\left(4 - b^2\right)(2k - 2s_1 k - \beta s_2) - 2\beta^2 - \left(2 - b^2\right)s_2^2\right]}. \tag{16}$$

The green quality input cost coefficient is greater than a certain threshold, and the government provides green subsidies for producers and consumers. Considering improving green production capacity and green consumption willingness of green agricultural products, the government adopts a double green subsidy strategy. The percentage of government subsidies for green quality input costs and the amount of government subsidy per unit for green consumers also affect the decision and income of producer 1, producer 2, and the retailer.

5. Analysis of Equilibrium Results

5.1. Analysis of Equilibrium Results under Nongovernment Subsidy Strategy

Proposition 5. *$\partial\theta^{N*}/\partial\rho > 0$; $\partial w_g^{N*}/\partial\rho > 0$; $\partial w_n^{N*}/\partial\rho > 0$, $\beta^2/4 - b^2 < k < \beta^2/4 - 2b$; $\partial p_g^{N*}/\partial\rho > 0$; and $\partial p_n^{N*}/\partial\rho > 0$, $\beta^2/4 - b^2 < k < \beta^2(3 - 2b)/2[(3 - 2b)(2 - b^2) - b]$.*

Proposition 5 reveals that under the nongovernment subsidy strategy, the optimal decision of the green quality level, the wholesale price, and the sales price of green agricultural products increase as the preference coefficient of consumers of green agricultural products increases. The wholesale price and the sales price of ordinary agricultural products are related to the coefficient of green quality input cost, the coefficient of consumer sensitivity to green quality levels, and the coefficient of cross-price elasticity of heterogeneous agricultural products. Because, in order to cater to the green preferences of consumers, producer 1 strives to carry out green production inputs, and the green quality level of agricultural products is improved accordingly. Due to the rising production cost, producer 1 will correspondingly increase the wholesale price, and sellers will increase the price of green agricultural products, thereby increasing their own profits. Therefore, with the increase of consumers' green preference, the level of green quality and the price of green agricultural products will increase even if producer 1 does not receive green subsidies from the government. When consumers' green preference changes, the pricing of ordinary agricultural products is affected by green quality input cost and other factors.

5.2. Analysis of Equilibrium Results under Producer 1 Subsidy Strategy

Proposition 6. *$\partial\theta^{G*}/\partial\rho > 0$; $\partial w_g^{G*}/\partial\rho > 0$; $\partial w_n^{G*}/\partial\rho > 0$, $\beta^2/(4 - b^2)(1 - s_1) < k < \beta^2/(4 - 2b)(1 - s_1)$; $\partial p_g^{G*}/\partial\rho > 0$; and $\partial p_n^{G*}/\partial\rho > 0, \beta^2/(4 - b^2)(1 - s_1) < k < \beta^2(3 - 2b)/2[(3 - 2b)(2 - b^2) - b](1 - s_1)$.*

Proposition 6 has essentially the same conclusion as Proposition 5 and will not be repeated here. When the government provides green subsidies to producer 1, the wholesale price and sales price of ordinary agricultural products are not only affected by k, β, and b but also related to the percentage of government subsidies for green quality input costs. Because producer 1 has received green subsidies from the government, the enthusiasm for green production has increased. With the increase of consumers' green preference, the green quality level and pricing of green agricultural products have been further improved. The subsidy funds received by producer 1 affect the pricing of green agricultural products and thus affect the pricing of ordinary agricultural products.

Corollary 7. *$\partial\theta^{G*}/\partial s_1 > 0$; $\partial w_g^{G*}/\partial s_1 > 0$; $\partial w_n^{G*}/\partial s_1 > 0$; $\partial p_g^{G*}/\partial s_1 > 0$; and $\partial p_n^{G*}/\partial s_1 > 0$.*

Corollary 7 reveals that under the producer 1 subsidy strategy, the optimal decisions on the green quality level of green agricultural products and the wholesale and sales prices of heterogeneous agricultural products increase as the percentage of government subsidies for green quality input costs increases. Producer 1 will increase green quality levels of agricultural products due to the increase in the subsidy percentage, which in turn will increase the pricing of their products, while ordinary agricultural products will increase their product pricing accordingly to increase their profits.

5.3. Analysis of Equilibrium Results under Green Consumer Subsidy Strategy

Proposition 8. *$\partial\theta^{C*}/\partial\rho > 0$; $\partial w_g^{C*}/\partial\rho > 0$; $\partial w_n^{C*}/\partial\rho > 0$, $(\beta + s_2)[(2 - b^2)s_2 + 2\beta]/2(4 - b^2) < k < (\beta + s_2)[(1 - b)s_2 + \beta]/2(2 - b)$; and $\partial p_g^{C*}/\partial\rho > 0$; $\partial p_n^{C*}/\partial\rho > 0$, $(\beta + s_2)[(2 - b^2)s_2 + 2\beta]/2(4 - b^2) < k < (\beta + s_2)(3 - 2b)[(1 - b)s_2 + \beta]/2[(3 - 2b)(2 - b^2) - b]$.*

When the government provides green subsidies to green consumers, as the preference coefficient of consumers of green agricultural products increases, the wholesale and sales price of ordinary agricultural products will only increase subsequently when k is satisfied within a certain threshold. As consumers receive green subsidies from the government, they are more willing to consume green. With the increase of consumers' green preference, the green quality level and pricing of green agricultural products have been further improved. Unit subsidies received by consumers according to the level of green quality affect the pricing of green agricultural products and thus affect the pricing of ordinary agricultural products.

Corollary 9. *$\partial\theta^{C*}/\partial s_2 > 0$; $\partial w_g^{C*}/\partial s_2 > 0$; $\partial w_n^{C*}/\partial s_2 > 0$, $(\beta + s_2)[(2 - b^2)s_2 + 2\beta]/2(4 - b^2) < k < \beta(\beta + s_2)^2/4s_2$; $\partial p_g^{C*}/\partial s_2 > 0$; and $\partial p_n^{C*}/\partial s_2 > 0$.*

Corollary 9 reveals that under the green consumer subsidy strategy, the green quality level and pricing of green agricultural products and the sales price of ordinary agricultural products increase as the amount of government subsidy per unit for green consumers increases. The wholesale price of traditional agricultural products is affected by the range of the green quality input cost coefficient. This strategy positively influences the decision of producer 1 and the retailer, and the decision-making of producer 2 is related to the coefficient of green quality input cost.

5.4. Analysis of Equilibrium Results under Dual Subsidies Strategy

Proposition 10. *$\partial\theta^{G+C*}/\partial\rho > 0$; $\partial w_g^{G+C*}/\partial\rho > 0$; $\partial w_n^{G+C*}/\partial\rho > 0$, $(\beta + s_2)[(2 - b^2)s_2 + 2\beta]/2(4 - b^2)(1 - s_1) < k < (\beta + s_2)[(1 - b)s_2 + \beta]/2(2 - b)(1 - s_2)$; $\partial p_g^{G+C*}/\partial\rho > 0$; and $\partial p_n^{G+C*}/\partial\rho > 0$, $(\beta + s_2)[(2 - b^2)s_2 + 2\beta]/2(4 - b^2)(1 - s_1) < k < (\beta + s_2)(3 - 2b)[(1 - b)s_2 + \beta]/2[(3 - 2b)(2 - b^2) - b](1 - s_1)$.*

Similarly, Proposition 10 illustrates that the optimal decision of green quality levels and the wholesale price and sales price of green agricultural products increase as the preference coefficient of consumers of green agricultural products increases. Also, the wholesale price and sales price of ordinary agricultural products are influenced by the coefficient of green quality input cost. Therefore, increasing consumer preference for green agricultural products can promote the level of green quality. However, with the increase of the coefficient of green quality input cost, the impact of consumer preference for green agricultural products on the pricing of ordinary agricultural products shows a trend of increasing and then decreasing. Because the input cost of green quality is too high, profit can hardly offset the high cost, production and consumption enthusiasm gradually decline, and the influence of consumers' green preference on the pricing of agricultural products will be weakened.

Corollary 11. *(1)* $\partial\theta^{G+C*}/\partial s_1 > 0$; $\partial w_g^{G+C*}/\partial s_1 > 0$; $\partial w_n^{G+C*}/\partial s_1 > 0$; $\partial p_g^{G+C*}/\partial s_1 > 0$; $\partial p_n^{G+C*}/\partial s_1 > 0$. *(2)* $\partial\theta^{G+C*}/\partial s_2 > 0$; $\partial w_g^{G+C*}/\partial s_2 > 0$; $\partial w_n^{G+C*}/\partial s_2 > 0$ $((\beta + s_2)[(2 - b^2)s_2 + 2\beta]/2(4 - b^2)(1 - s_1) < k < \beta(\beta + s_2)^2/4(1 - s_1)s_2)$; $\partial p_g^{G+C*}/\partial s_2 > 0$; *and* $\partial p_n^{G+C*}/\partial s_2 > 0$.

Corollary 11 reveals that under the dual subsidy strategy, with the increase of s_1 and s_2, the optimal decision of producer 1 and the retailer increases and promotes the green quality level, pricing, and sales price of ordinary agricultural products. However, with the increase of s_2, affected by the coefficient of green quality input cost, the wholesale prices of ordinary agriculture products show a trend of first increasing and then decreasing.

6. Numerical Analysis

This study discusses the supply chain optimal decision under differentiated government green subsidies by constructing a heterogeneous agricultural supply chain model. The impact of other key parameters on the optimal decision of the supply chain and the supply chain members' strategies under the green subsidies are further studied through numerical analysis. This study takes the Beijing Daxing watermelon industry as an example, then combines the survey data to assign reasonable values to the relevant parameters in this model, and tries to ensure the existence of a practical basis for the research parameter settings. In order to facilitate the operation, the relevant research parameter settings are appropriately reduced, and the specific data are assumed as follows: $\alpha = 100$, $\rho = 0.6$, $b = 0.5$, $c = 0.4$, $\beta = 25$, $s_1 = [0.1, 0.35]$, and $s_2 = [0, 1.5]$.

In addition, assume that the government social welfare SW is expressed as $SW = \pi_{Mg} + \pi_{Mn} + \pi_S - GS + CS + EI$ [45], where the government subsidy expenditure is GS, where $GS^G = s_1 k\theta^2/2$, $GS^C = s_2 k\theta d_g^C$, and $GS^{G+C} = s_1 k\theta^2/2 + s_2 k\theta d_g^{G+C}$. Consumer surplus is expressed as $CS = (d_g^2 + d_n^2)/2$, and environmental improvement is expressed as $EI = \theta d_g$. From Lemmas 1–4, the condition that the case of different government green subsidies holds simultaneously is $k > 286.06$.

6.1. Comparative Analysis of Government Social Welfare under Different Green Subsidy Strategies. As shown in Figure 2, we set $k = 400$, $\beta = 25$ and analyze the effect of s_1 and s_2 on the difference in social welfare functions under different green subsidy strategies. Here, $\Delta SW_1 = SW^G - SW^C$, $\Delta SW_2 = SW^C - SW^{G+C}$, and $\Delta SW_3 = SW^G - SW^{G+C}$.

Figure 2 shows that $\Delta SW_1 > 0$, $\Delta SW_2 < 0$, $\Delta SW_3 < 0$ and $|\Delta SW_2| > |\Delta SW_3|$. It can be inferred that no matter the size of subsidy ratio s_1 and unit subsidy amount s_2, government social welfare is always represented as $SW^{G+C} > SW^G > SW^C$. It shows that when the government conducts green subsidies with the goal of improving social welfare, the optimal green subsidy strategy is the dual subsidy strategy. s_1 and s_2 only affect the size of social welfare but do not affect the choice of the government's green subsidy strategy.

6.2. Influence of the Coefficient of Green Quality Input Cost on Supply Chain Decisions. By setting $s_1 = 0.3$ and $s_2 = 1.5$, this paper compares and analyzes the influence of the green quality input cost coefficient on the optimal decision of heterogeneous agricultural product supply chain under four subsidy strategies.

Table 2 describes the influence of the green quality input cost coefficient on the optimal green quality level and pricing of heterogeneous agricultural products under different government green subsidies. As shown in Table 2, increasing the coefficient of green quality input cost, the green quality level of agricultural products, and the pricing of heterogeneous agricultural products showed a decreasing trend and eventually levelled off. The results show that the coefficient of green quality input cost has the same effect on the decision of heterogeneous agricultural product supply chain members. The green quality level is expressed as $\theta^{G+C}* > \theta^G* > \theta^C* > \theta^N*$. Therefore, compared with the nongovernment subsidy, government green subsidies can improve the green quality level of agricultural products, and the green quality level under the dual subsidy strategy is the highest.

Table 3 describes the influence of the coefficient of green quality input cost on demands for heterogeneous agricultural products and the profits of supply chain members under different government green subsidies. Table 3 shows that increasing the coefficient of green quality input cost will reduce the demands for heterogeneous agricultural products and the profits of supply chain members, and the reduction will be slower and slower. The lower the green quality input cost coefficient within a certain threshold, the higher the demand for heterogeneous agricultural products and the profits of supply chain members can be maintained, so as to achieve a win-win situation in the supply chain. When the coefficient of green quality input cost is a fixed value, the demands for heterogeneous agricultural products and profits of supply chain members are the highest under the dual subsidy strategy, followed by the producer 1 subsidy

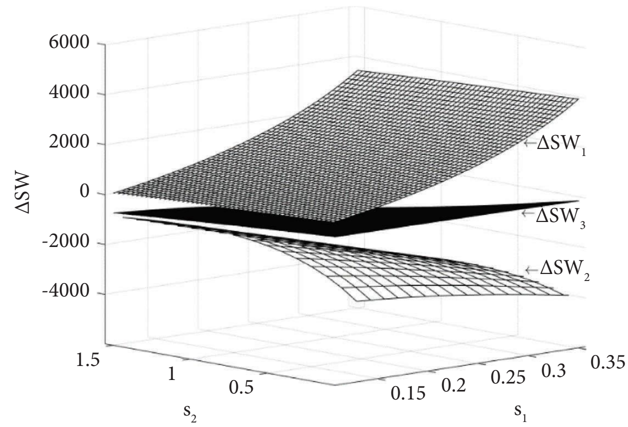

Figure 2: The influence of s_1 and s_2 on the difference in social welfare function.

Table 2: The influence of k on the optimal green quality level and price of heterogeneous agricultural products.

	Nongovernment subsidy (N)					Government subsidized to producer 1 (G)				
	θ^N*	w_g^{N*}	w_n^{N*}	p_g^{N*}	$p_n{}^N*$	θ^G*	w_g^{G*}	w_n^{G*}	p_g^{G*}	p_n^{G*}
$k=300$	3.48	83.98	41.00	153.36	96.18	10.72	180.42	65.10	322.13	168.51
$k=400$	1.99	64.08	36.02	118.54	81.26	4.10	92.17	43.04	167.70	102.33
$k=500$	1.39	56.12	34.03	104.61	75.29	2.52	71.32	37.83	131.20	86.69
$k=600$	1.07	51.83	32.96	97.11	72.08	1.83	61.99	35.50	114.87	79.69
	Government subsidized to green consumers (C)					Dual subsidies (G + C)				
	θ^C*	w_g^{C*}	w_n^{C*}	p_g^{C*}	$p_n{}^C*$	$\theta^{G+C}*$	w_g^{G+C*}	w_n^{G+C*}	p_g^{G+C*}	$p_n{}^{G+C}*$
$k=300$	4.32	98.10	42.91	177.54	104.08	20.46	324.65	93.49	571.97	263.90
$k=400$	2.30	69.81	36.59	128.29	84.12	5.23	110.98	45.78	199.96	113.17
$k=500$	1.57	59.54	34.30	110.40	76.88	3.00	79.65	38.79	145.41	91.06
$k=600$	1.19	54.23	33.11	101.15	73.13	2.10	67.06	35.98	123.49	82.18

strategy, then the green consumer subsidy strategy, and finally the nongovernment subsidy strategy.

That is, the government provides dual subsidies as the optimal green subsidy strategy expected by supply chain members, and the demands and profits of agricultural products under each green subsidy are higher than those under the nongovernment subsidy strategy. Therefore, the optimal government green subsidy strategy expected by supply chain members is dual subsidies, independent of the size of the coefficient of green quality input cost. In summary, the government's optimal green subsidy strategy is dual subsidies when the government's subsidy objective is to increase the green quality level and demands for green agricultural products.

6.3. Influence of the Government Subsidy Expenditure on the Supply Chain

6.3.1. Influence of the Government Subsidy Expenditure on the Green Quality Level. Figure 3 shows the impact of government subsidy expenditure on the green quality level of green agricultural products under different green subsidies. From Figure 2, it can be seen that the green quality level tends to increase with the increase in government subsidy expenditure. Moreover, the green quality level achieved by the green consumer subsidy strategy is the highest when the government subsidy expenditure is a fixed value. Also, all the green subsidies act directly on green consumers and motivate producer 1 to attract more consumers by improving the green quality level. Therefore, when the government considers subsidy expenditures and aims to improve the green quality level as the subsidy objective, the optimal subsidy strategy is to subsidize green consumers, and the green consumer subsidy strategy has the least subsidy expenditure at the same green quality level.

6.3.2. Influence of the Government Subsidy Expenditure on Demands for Heterogeneous Agricultural Products. As shown in Figure 4, with the increase of government subsidy expenditure, the demands for green agricultural products shows an upward trend, among which the promotion effect of the green consumer subsidy strategy is more significant, followed by the producer 1 subsidy strategy and finally the dual subsidy strategy. Although the dual subsidy strategy is more effective in promoting the demands for green agricultural products at the same coefficient of green quality input cost, it is not optimal for the same subsidy expenditure. Therefore, when the government considers the subsidy

Table 3: The influence of k on demands for heterogeneous agricultural products and profits of supply chain members.

	Nongovernment subsidy (N)					Government subsidized to producer 1 (G)				
	d_g^{N*}	d_n^{N*}	π_{Mg}^{N*}	π_{Mn}^{N*}	π_S^{N*}	d_g^{G*}	${d_n}^{G}*$	${\pi_{Mg}}^{G}*$	${\pi_{Mn}}^{G}*$	${\pi_S}^{G}*$
$k=300$	41.79	20.50	1673.64	840.30	4030.86	90.01	32.55	4147.28	2119.31	16121.76
$k=400$	31.84	18.01	1235.55	648.72	2548.78	45.89	21.52	1861.22	926.37	4741.84
$k=500$	27.86	17.02	1067.25	579.02	2052.97	35.46	18.91	1391.99	715.52	3047.62
$k=600$	25.72	16.48	978.26	543.13	1808.96	30.79	17.75	1190.88	629.99	2412.93
	Government subsidized to green consumers (C)					Dual subsidies (G + C)				
	d_g^{C*}	${d_n}^{C}*$	π_{Mg}^{C*}	${\pi_{Mn}}^{C}*$	${\pi_S}^{C}*$	d_g^{G+C*}	${d_n}^{G+C}*$	π_{Mg}^{G+C*}	${\pi_{Mn}}^{G+C}*$	${\pi_S}^{G+C}*$
$k=300$	48.85	21.45	1979.83	920.54	5193.17	162.12	46.74	8620.44	4370.14	48062.92
$k=400$	34.71	18.30	1351.76	669.46	2899.06	55.29	22.89	2280.50	1048.04	6462.32
$k=500$	29.57	17.15	1134.72	588.15	2234.05	39.62	19.39	1565.02	752.22	3619.51
$k=600$	26.91	16.56	1024.83	548.18	1925.38	33.33	17.99	1292.94	647.12	2711.80

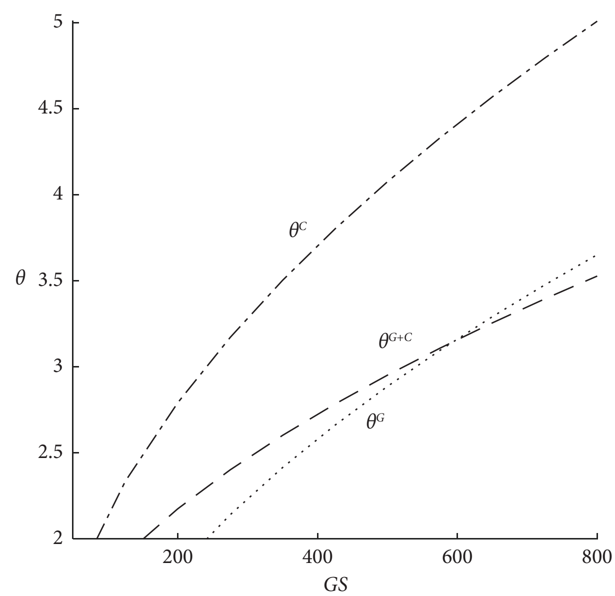

Figure 3: The relationship between GS and θ.

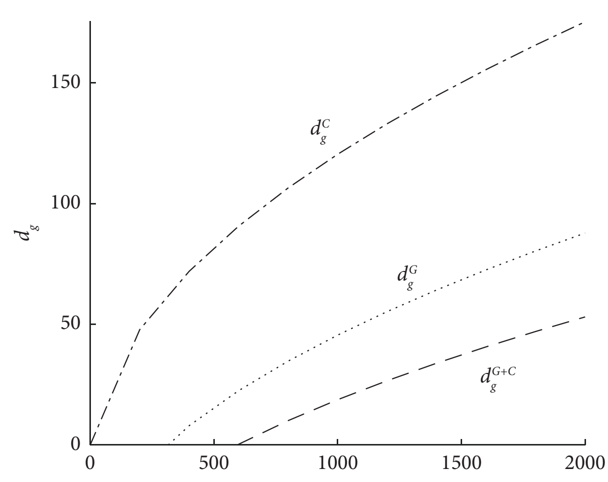

Figure 4: The relationship between GS and d_g.

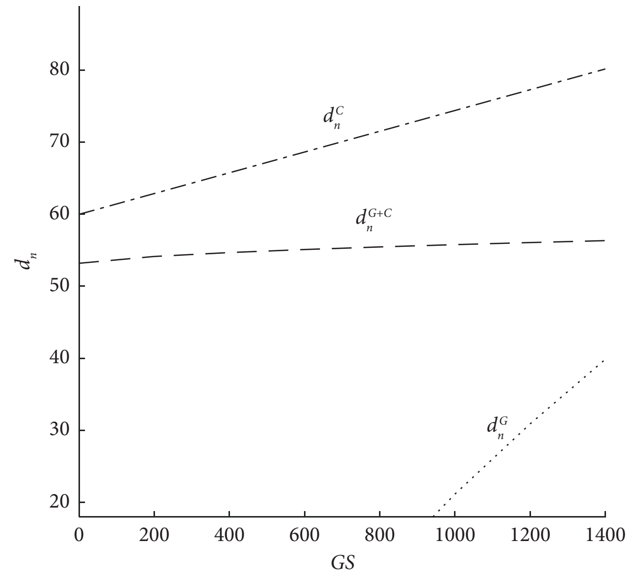

FIGURE 5: The relationship between GS and d_n.

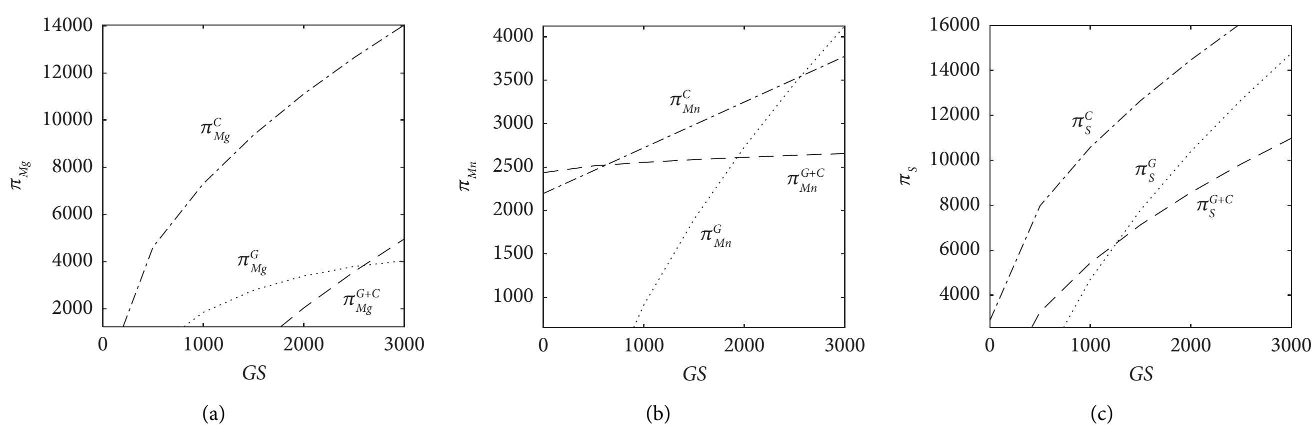

FIGURE 6: The relationship between GS and supply chain members' profits.

expenditure and promotes the demands for green agricultural products as subsidy objectives, the optimal government green subsidy strategy is to subsidize green consumers.

As shown in Figure 5, the demands for ordinary agricultural products increase with the increase in government subsidy expenditure. When the government subsidizes green consumers and provides dual subsidies, green consumers can directly get concessions for purchasing green agricultural products, and the demands for ordinary agricultural products increase more slowly. From the perspective of producer 2, it expects the government to provide the green consumer subsidy strategy, which is the same as the optimal strategy under the government subsidy objective of promoting the demands for green agricultural products.

6.3.3. Influence of the Government Subsidy Expenditure on Supply Chain Members' Profits. Figure 5 shows the impact of government subsidy expenditure on the profits of supply chain members when the government provides different green subsidy strategies. As shown in Figure 6(a), with the increase in government subsidy expenditure, the profits of producer 1 show an upward trend, which means that the green subsidy promotes profits of producer 1, among which the promotion of the green consumer subsidy strategy is more significant. When considering the subsidy expenditure and promoting the green quality level and green agricultural product demands as subsidy objectives, the optimal strategy of the government is to subsidize green consumers, and the profits of producer 1 are also optimal. As shown in Figure 6(b), the impact of government subsidy expenditure on producer 2's profits is essentially the same as its impact on demands for ordinary agricultural products. The profits of producer 2 are not necessarily optimal when the government provides the green consumer subsidy strategy. As shown in Figure 6(c), the retailer's profits increase as government subsidy expenditure increases, and the retailer's profits are higher under both the green consumer subsidy strategy than under the other two green subsidies.

7. Conclusion and Prospect

Based on a heterogeneous agricultural product supply chain consisting of producer 1, producer 2, and a retailer, this study compares the optimal decision of the supply chain under four strategies: nongovernment subsidy, the producer 1 subsidy, the green consumer subsidy, and explore the government's optimal green subsidy strategy under different subsidy targets, and the main conclusions are as follows: (1) The government will provide green subsidies only if the coefficient of green quality input cost reaches a certain threshold. (2) As the coefficient of green quality input cost increases, the decision-making of supply chain members will decrease. Compared with nongovernment subsidies, green subsidies always increase the green quality level, pricing, and demands for heterogeneous agricultural products, thus increasing supply chain members' profits. (3) The preference coefficient of consumers for green agricultural products has a positive impact on the green quality level and pricing of green agricultural products, and only under certain conditions can the pricing of ordinary agricultural products be reduced. (4) The optimal green subsidy strategy of the government differs under different subsidy objectives. The government tends to provide the dual subsidy strategy when the government has maximum social welfare as the subsidy objective. When the government only considers improving the level of green quality and promoting the consumption of green agricultural products, the government also tends to provide the dual subsidy strategy. The government prefers to provide the green consumer subsidy strategy when it considers the minimum subsidy expenditure and improving the green quality level and the demands for green agricultural products.

Based on the above research conclusions, we can obtain some managerial insights.

First, green subsidies can effectively promote the green quality of agricultural products, and with the increase of subsidies, green agricultural producers are more active in production. Therefore, it is an effective policy tool for the government to stimulate green production behavior by providing green subsidies. Government subsidy objectives will influence the choice of the green subsidy strategy, and the government should combine the green subsidy effect and subsidy objectives to clarify the green subsidy strategy and set a reasonable subsidy intensity. In addition to financial subsidies, the government can implement tax incentives for energy conservation and carbon reduction and launch agricultural carbon reduction support tools to open up green agricultural development prospects through institutional innovation.

Second, higher green quality input costs will reduce the enthusiasm for green production. Green agricultural product producers should reasonably make green inputs according to the market environment and government subsidies, control green production costs while improving green quality, and increase consumer trust and green preferences. Ordinary agricultural producers should reasonably adjust the pricing of agricultural products according to the government's green subsidy policy and ensure the quality of agricultural products, while actively transforming and upgrading to green agriculture.

Finally, retailers can always benefit from green subsidies. They can cooperate with online e-commerce platforms, offline supermarkets, community group buying, etc., to achieve omnichannel sales of heterogeneous agricultural products. Also, they can also use big data to accurately position agricultural products and identify consumer groups to realize precise marketing of heterogeneous agricultural products to improve their revenue.

This study can be extended to several promising aspects. First, we only studied a heterogeneous agricultural supply chain consisting of two producers and one retailer, and future research could be extended to a network of agricultural supply chains with multiple producers and retailers. Second, the government's green subsidy decisions deserve further study. Third, future research can explore the decision-making of heterogeneous agricultural supply chains under imperfectly competitive markets.

Appendix

A Proof of Lemma 1–Lemma 4

Lemma A.1. *In this case, the condition that statement 1 is true is* $k > \beta^2/4 - b^2$.

The inverse induction method is adopted to solve the problem. First, according to equation (3), it can be obtained:

$$\frac{\partial \pi_S^N}{\partial p_g^N} = \rho\alpha + w_g^N - b w_n^N - 2p_g^N + 2b p_n^N + \beta\theta^N,$$

$$\frac{\partial \pi_S^N}{\partial p_n^N} = (1-\rho)\alpha - b w_g^N + w_n^N + 2b p_g^N - 2p_n^N + \beta\theta^N. \tag{A.1}$$

The Hessian matrix is obtained by further calculating the second partial derivative: $H(N)_1 = \begin{bmatrix} -2 & 2b \\ 2b & -2 \end{bmatrix}$.

On account of $D_1 = -2 < 0$, $D_2 = 4 - 4b^2 > 0$. Then, $H(N)_1$ is negative definite. π_S^N is a concave function of p_g^N and p_n^N, and there are optimal solutions for p_g^N and p_n^N. Simultaneous equations are as follows: $\partial \pi_S^N / \partial p_g^N = 0$, $\partial \pi_S^N / \partial p_n^N = 0$. We obtain the following equation:

$$p_g^N = \frac{\alpha b(1-\rho) + \alpha\rho + \left(1-b^2\right) w_g^N + \beta\theta^N}{2\left(1-b^2\right)},$$

$$p_n^N = \frac{\alpha b\rho + \alpha(1-\rho) + \left(1-b^2\right) w_n^N + b\beta\theta^N}{2\left(1-b^2\right)}. \tag{A.2}$$

Then, by substituting p_g^N and p_n^N into equations (2) and (3) and simplifying, we obtain the following equation:

$$\begin{aligned}\frac{\partial \pi_{Mg}^{N}}{\partial \theta^{N}} &= \frac{\left(w_g^N - c\right)\beta - 2k\theta^N}{2},\\ \frac{\partial \pi_{Mg}^{N}}{\partial w_g^{N}} &= \frac{\rho\alpha + bw_n^N + \beta\theta^N + c - 2w_g^N}{2},\\ \frac{\partial \pi_{Mg}^{N}}{\partial w_n^{N}} &= \frac{(1-\rho)\alpha + bw_g^N - 2w_n^N}{2}.\end{aligned} \tag{A.3}$$

We find the Hessian matrix for θ^N, w_g^N, and w_n^N: $H(N)_2 = \begin{bmatrix} -1 & \beta/2 & b/2 \\ \beta/2 & -k & 0 \\ b/2 & 0 & -1 \end{bmatrix}$.

When $k > \beta^2/4 - b^2$ is satisfied, $H(N)_2$ is negative definite. π_{Mg}^N is a concave function of θ^N and w_g^N, and π_{Mn}^N is a concave function of w_n^N. Simultaneous equations are as follows: $\partial\pi_{Mg}^N/\partial\theta_g^N = 0$, $\partial\pi_{Mg}^N/\partial w_g^N = 0$, and $\partial\pi_{Mn}^N/\partial w_n^N = 0$. The solution can be obtained: θ^{N*}, w_g^{N*}, and w_n^{N*}, and substituting θ^{N*}, w_g^{N*}, and w_n^{N*} into p_g^N and p_n^N yields p_g^{N*} and p_n^{N*}.

Lemma A.2. *It is also solved by backward induction, and according to equation (7), we can obtain the following equation* $\partial\pi_S^G/\partial p_g^G = \rho\alpha + w_g^G - bw_n^G - 2p_g^G + 2bp_n^G + \beta\theta^G$*:*

$$\frac{\partial \pi_S^G}{\partial p_n^G} = (1-\rho)\alpha - bw_g^G + w_n^G + 2bp_g^G - 2p_n^G + \beta\theta^G. \tag{A.4}$$

By finding the second partial derivative, the Hessian matrix is obtained: $H(G)_1 = \begin{bmatrix} -2 & 2b \\ 2b & -2 \end{bmatrix} = H(N)_1$.

We know that $H(G)_1$ is negative definite, and there is an optimal solution for p_g^G and p_n^G. Simultaneous equations $\partial\pi_S^G/\partial p_g^G = 0$ and $\partial\pi_S^G/\partial p_n^G = 0$ yield

$$\begin{aligned} p_g^G &= \frac{\alpha b(1-\rho) + \alpha\rho + \left(1-b^2\right)w_g^G + \beta\theta^G}{2\left(1-b^2\right)},\\ p_n^G &= \frac{\alpha b\rho + \alpha(1-\rho) + \left(1-b^2\right)w_n^G + b\beta\theta^G}{2\left(1-b^2\right)}.\end{aligned} \tag{A.5}$$

Substituting p_g^G and p_n^G into (5) and (6) yields

$$\begin{aligned}\frac{\partial \pi_{Mg}^{G}}{\partial \theta^{G}} &= \frac{\left(w_g^G - c\right)\beta - 2(1-s_1)k\theta^G}{2},\\ \frac{\partial \pi_{Mg}^{G}}{\partial w_g^{G}} &= \frac{\rho\alpha + bw_n^G + \beta\theta^G + c - 2w_g^G}{2},\\ \frac{\partial \pi_{Mg}^{G}}{\partial w_n^{G}} &= \frac{(1-\rho)\alpha + bw_g^G - 2w_n^G}{2}.\end{aligned} \tag{A.6}$$

Also, then, we find the Hessian matrix with respect to θ^G, w_g^G, and w_n^G: $H(G)_2 = \begin{bmatrix} -1 & \beta/2 & b/2 \\ \beta/2 & -(1-s_1)k & 0 \\ b/2 & 0 & -1 \end{bmatrix}$.

When $k > \beta^2/(4-b^2)(1-s_1)$ is satisfied, $H(G)_2$ is negative definite, and there is an optimal solution for θ^G, w_g^G, and w_n^G, Finally, the optimal decision value of θ^{G*}, w_g^{G*}, w_n^{G*}, p_g^{G*}, and p_n^{G*} is obtained.

Lemma A.3. *It is solved by backward induction, and according to equation (11),* $\partial\pi_S^C/\partial p_g^C = \rho\alpha + w_g^C - bw_n^C - 2p_g^C + 2bp_n^C + (\beta + s_2)\theta^C$ *is obtained:*

$$\frac{\partial \pi_S^C}{\partial p_n^C} = (1-\rho)\alpha - bw_g^C + w_n^C + 2bp_g^C - 2p_n^C - bs_2\theta^C. \tag{A.7}$$

We obtain $H(C)_1 = \begin{bmatrix} -2 & 2b \\ 2b & -2 \end{bmatrix} = H(N)_1$. We know that $H(C)_1$ is negative definite, and there is an optimal solution for p_g^C and p_n^C. Simultaneous equations $\partial\pi_S^C/\partial p_n^C = 0$ and $\partial\pi_S^C/\partial p_n^C = 0$ yield

$$\begin{aligned} p_g^C &= \frac{\alpha b(1-\rho) + \alpha\rho + \left(1-b^2\right)w_g^C + \beta\theta^C + \left(1-b^2\right)s_2\theta^C}{2\left(1-b^2\right)},\\ p_n^C &= \frac{\alpha b\rho + \alpha(1-\rho) + \left(1-b^2\right)w_n^C + b\beta\theta^C}{2\left(1-b^2\right)}.\end{aligned} \tag{A.8}$$

Substituting p_g^C and p_n^C into (9) and (10) yields

$$\begin{aligned}\frac{\partial \pi_{Mg}^{C}}{\partial \theta^{C}} &= \frac{\left(w_g^C - c\right)(\beta + s_2) - 2k\theta^C}{2},\\ \frac{\partial \pi_{Mg}^{C}}{\partial w_g^{C}} &= \frac{\rho\alpha + bw_n^C + (\beta + s_2)\theta^C + c - 2w_g^C}{2},\\ \frac{\partial \pi_{Mg}^{C}}{\partial w_n^{C}} &= \frac{(1-\rho)\alpha + bw_g^C - 2w_n^C - bs_2\theta^C}{2}.\end{aligned} \tag{A.9}$$

We get the Hessian matrix: $H(C)_2 = \begin{bmatrix} -1 & (\beta+s_2)/2 & b/2 \\ (\beta+s_2)/2 & -k & 0 \\ b/2 & -bs_2/2 & -1 \end{bmatrix}$.

When $k > (\beta + s_2)[(2-b^2)s_2 + 2\beta]/2(4-b^2)$ is satisfied, $H(C)_2$ is negative definite, and there is an optimal solution for θ^{C*}, w_g^{C*}, w_n^{C*}, p_g^{C*}, and p_n^{C*}.

Lemma A.4. *It is also solved by backward induction, and according to equation (15), we can obtain* $\partial\pi_S^{G+C}/\partial p_g^{G+C} = \rho\alpha + w_g^{G+C} - bw_n^{G+C} - 2p_g^{G+C} + 2bp_n^{G+C} + (\beta + s_2)\theta^{G+C}$*:*

$$\frac{\partial \pi_S^{G+C}}{\partial p_n^{G+C}} = (1-\rho)\alpha - bw_g^{G+C} + w_n^{G+C} + 2bp_g^{G+C} - 2p_n^{G+C} - bs_2\theta^{G+C}. \tag{A.10}$$

We can obtain $H(G+C)_1 = \begin{bmatrix} -2 & 2b \\ 2b & -2 \end{bmatrix} = H(N)_1$, $H(D)_1$ is negative definite, and there is an optimal solution for p_g^{G+C} and p_n^{G+C}. Substituting $\partial \pi_S^{G+C}/\partial p_g^{G+C} = 0$ and $\partial \pi_S^{G+C}/\partial p_n^{G+C} = 0$ yields

$$p_g^{G+C} = \frac{\alpha b(1-\rho) + \alpha\rho + (1-b^2)w_g^{G+C} + \beta\theta^{G+C} + (1-b^2)s_2\theta^{G+C}}{2(1-b^2)},$$
$$p_n^{G+C} = \frac{\alpha b\rho + \alpha(1-\rho) + (1-b^2)w_n^{G+C} + b\beta\theta^{G+C}}{2(1-b^2)}. \tag{A.11}$$

Substituting p_g^{G+C} and p_n^{G+C} into (15) and (16) yields

$$\frac{\partial \pi_{Mg}^{G+C}}{\partial \theta^{G+C}} = \frac{(w_g^{G+C} - c)(\beta + s_2) - 2k(1-s_1)\theta^{G+C}}{2},$$
$$\frac{\partial \pi_{Mg}^{G+C}}{\partial w_g^{G+C}} = \frac{\rho\alpha + bw_n^{G+C} + (\beta + s_2)\theta^{G+C} + c - 2w_g^{G+C}}{2},$$
$$\frac{\partial \pi_{Mg}^{G+C}}{\partial w_n^{G+C}} = \frac{(1-\rho)\alpha + bw_g^{G+C} - 2w_n^{G+C} - bs_2\theta^{G+C}}{2}. \tag{A.12}$$

We can obtain $H(G+C)_2 = \begin{bmatrix} -1 & (\beta+s_2)/2 & b/2 \\ (\beta+s_2)/2 & -(1-s_1)k & 0 \\ b/2 & -bs_2/2 & -1 \end{bmatrix}$.

When $k > (\beta + s_2)[(2-b^2)s_2 + 2\beta]/2(4-b^2)(1-s_1)$ is satisfied, $H(D)_2$ is negative definite, and there is an optimal solution for θ^{G+C*}, w_g^{G+C*}, w_n^{G+C*}, p_g^{G+C*}, and p_n^{G+C*}.

Data Availability

The data used to support the findings of this paper are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Authors' Contributions

The study is the result of full collaboration, and therefore, the authors accept full responsibility. Sections 1, 2, and 6 are attributable to Rong Wu; Sections 3 and 5 are attributable to Yanqi Chen, Section 4 is attributable to Man Jiang, and Section 7 is attributable to Jian Zhang. All the authors have read and agreed to the published version of the manuscript.

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References

[1] J. Barreiro-Hurle, A. Gracia, and T. De-Magistris, "The effects of multiple health and nutrition labels on consumer food choices," *Journal of Agricultural Economics*, vol. 61, no. 2, pp. 426–443, 2010.

[2] Z. F. Gao, C. G. Li, J. F. Bai, and J. Fu, "Chinese consumer quality perception and preference of sustainable milk," *China Economic Review*, vol. 59, Article ID 100939, 2020.

[3] S. Yin, M. Chen, Y. Xu, and Y. Chen, "Chinese consumers' willingness-to-pay for safety label on tomato: evidence from choice experiments," *China Agricultural Economic Review*, vol. 9, no. 1, pp. 141–155, 2017.

[4] Q. F. Jiang and S. Y. Jiang, "Nash equilibrium game model on firm's optimal strategy in heterogeneous market," *Chinese Journal of Management Science*, vol. 4, pp. 70–73, 2003.

[5] Z. Y. Zhang, D. X. Fu, and Q. Zhou, "Optimal decisions of a green supply chain under the joint action of fairness preference and subsidy to the manufacturer," *Discrete Dynamics in Nature and Society*, vol. 2020, Article ID 9610503, 18 pages, 2020.

[6] R. Yang, W. Tang, and J. Zhang, "Technology improvement strategy for green products under competition: the role of government subsidy," *European Journal of Operational Research*, vol. 289, no. 2, pp. 553–568, 2021.

[7] S. J. Yin, L. H. Wu, L. Du, and M. Chen, "Consumers' purchase intention of organic food in China," *Journal of the Science of Food and Agriculture*, vol. 90, no. 8, pp. 1361–1367, 2010.

[8] J. L. Lusk and T. C. Schroeder, "Are choice experiments incentive compatible? A test with quality differentiated beef steaks," *American Journal of Agricultural Economics*, vol. 86, no. 2, pp. 467–482, 2004.

[9] X. H. Yu, Z. F. Gao, and Y. C. Zeng, "Willingness to pay for the 'green food' in China," *Food Policy*, vol. 45, pp. 80–87, 2014.

[10] S. H. Zhong and J. Chen, "How environmental beliefs affect consumer willingness to pay for the greenness premium of low-carbon agricultural products in China: theoretical model and survey-based evidence," *Sustainability*, vol. 11, no. 3, p. 592, 2019.

[11] M. Ringel, B. Schlomann, M. Krail, and C. Rohde, "Towards a green economy in Germany? The role of energy efficiency policies," *Applied Energy*, vol. 179, pp. 1293–1303, 2016.

[12] Z. Li, Y. Pan, W. Yang, J. Ma, and M. Zhou, "Effects of government subsidies on green technology investment and green marketing coordination of supply chain under the cap-and-trade mechanism," *Energy Economics*, vol. 101, Article ID 105426, 2021.

[13] C. L. Luo, M. M. Leng, J. Huang, and L. Liang, "Supply chain analysis under a price-discount incentive scheme for electric vehicles," *European Journal of Operational Research*, vol. 235, no. 1, pp. 329–333, 2014.

[14] H. G. Nie, T. Zhou, H. Y. Lu, and S. Huang, "Evaluation of the efficiency of Chinese energy-saving household appliance subsidy policy: an economic benefit perspective," *Energy Policy*, vol. 149, Article ID 112059, 2021.

[15] L. L. Shao, J. Yang, and M. Zhang, "Subsidy scheme or price discount scheme? Mass adoption of electric vehicles under

different market structures," *European Journal of Operational Research*, vol. 262, no. 3, pp. 1181–1195, 2017.
[16] S. Zheng and L. Yu, "The government's subsidy strategy of carbon-sink fishery based on evolutionary game," *Energy*, vol. 254, Article ID 124282, 2022.
[17] Q. Liu and D. Zhang, "Dynamic pricing competition with strategic customers under vertical product differentiation," *Management Science*, vol. 59, no. 1, pp. 84–101, 2013.
[18] W. Li and J. Chen, "Pricing and quality competition in a brand-differentiated supply chain," *International Journal of Production Economics*, vol. 202, pp. 97–108, 2018.
[19] B. J. Jiang and B. C. Yang, "Quality and pricing decisions in a market with consumer information sharing," *Management Science*, vol. 65, no. 1, pp. 272–285, 2019.
[20] A. Ranjan and J. K. Jha, "Pricing and coordination strategies of a dual-channel supply chain considering green quality and sales effort," *Journal of Cleaner Production*, vol. 218, pp. 409–424, 2019.
[21] D. P. Andriani and F. S. Tseng, "Pricing and investment decisions when facing heterogeneous customers under different supply chain power structures," *Alexandria Engineering Journal*, vol. 78, pp. 390–405, 2023.
[22] J. Wang, Y. Huo, X. Guo, and Y. Xu, "The Pricing strategy of the agricultural product supply chain with farmer cooperatives as the core enterprise," *Agriculture*, vol. 12, no. 5, p. 732, 2022.
[23] Y. Liu, J. Li, W. W. Ren, and J. Y. L. Forrest, "Differentiated products pricing with consumer network acceptance in a dual-channel supply chain," *Electronic Commerce Research and Applications*, vol. 39, Article ID 100915, 2020.
[24] R. Hou, Y. Zhao, M. Q. Zhu, and X. Lin, "Price and quality decisions in a vertically-differentiated supply chain with an 'Online-to-Store' channel," *Journal of Retailing and Consumer Services*, vol. 62, no. 1, Article ID 102593, 2021.
[25] X. J. Pu, Z. M. Xu, and R. B. Huang, "Entry mode selection and its impact on the competition between organic and conventional agricultural products," *Journal of Cleaner Production*, vol. 274, Article ID 122716, 2020.
[26] Y. Perlman, Y. Ozinci, and S. Westrich, "Pricing decisions in a dual supply chain of organic and conventional agricultural products," *Annals of Operations Research*, vol. 314, no. 2, pp. 601–616, 2019.
[27] Y. Perlman, "Establishing a dual food supply chain for organic products in the presence of showrooming–A game theoretic analysis," *Journal of Cleaner Production*, vol. 321, Article ID 128816, 2021.
[28] Y. Yu, X. Han, and G. Hu, "Optimal production for manufacturers considering consumer environmental awareness and green subsidies," *International Journal of Production Economics*, vol. 182, pp. 397–408, 2016.
[29] P. Zhang, L. Jin, and Y. Wang, "Optimizing mechanisms for promoting low-carbon manufacturing industries towards carbon neutrality," *Renewable and Sustainable Energy Reviews*, vol. 183, Article ID 113516, 2023.
[30] Y. N. Li, Y. Tong, F. Ye, and J. Song, "The choice of the government green subsidy scheme: innovation subsidy vs. product subsidy," *International Journal of Production Research*, vol. 58, no. 16, pp. 4932–4946, 2020.
[31] F. Guo, T. Zhang, X. Huang, Y. Zhong, and Y. Government, "Government subsidy strategies considering greenness on agricultural product E-commerce supply chain," *Mathematics*, vol. 11, no. 7, p. 1662, 2023.
[32] M. Cohen, R. Lobel, and G. Perakis, "The impact of demand uncertainty on consumer subsidies for green technology adoption," *Management Science*, vol. 62, no. 5, pp. 1235–1258, 2016.
[33] C. Ma, H. Yang, W. Zhang, and S. Huang, "Low-carbon consumption with government subsidy under asymmetric carbon emission information," *Journal of Cleaner Production*, vol. 318, Article ID 128423, 2021.
[34] Y. Wang, Z. Wang, B. Li, and Y. Cheng, "The choice of subsidy policy for incentivizing product design for environment," *Computers & Industrial Engineering*, vol. 175, Article ID 108883, 2023.
[35] S. L. Zhao, Q. H. Zhu, and L. Cui, "A decision-making model for remanufacturers: considering both consumers' environmental preference and the government subsidy policy," *Resources, Conservation and Recycling*, vol. 128, pp. 176–186, 2018.
[36] X. Guo, L. Cheng, and Y. Yu, "Government subsidy policy for green and efficient raw materials considering farmer heterogeneity," *Production and Operations Management*, vol. 31, no. 11, pp. 4095–4112, 2022.
[37] Q. Meng, M. Li, W. Liu, Z. Li, and J. Zhang, "Pricing policies of dual-channel green supply chain: considering government subsidies and consumers' dual preferences," *Sustainable Production and Consumption*, vol. 26, pp. 1021–1030, 2021.
[38] A. Barman, R. Das, P. K. De, and S. S. Sana, "Optimal pricing and greening strategy in a competitive green supply chain: impact of government subsidy and tax policy," *Sustainability*, vol. 13, no. 16, p. 9178, 2021.
[39] L. J. Chen, S. W. Hu, V. Wang, J. Wen, and C. Ye, "The effects of purchasing and price subsidy policies for agricultural products under target zones," *Economic Modelling*, vol. 43, pp. 439–447, 2014.
[40] Y. H. Chen, X. W. Wen, B. Wang, and P. Nie, "Agricultural pollution and regulation: how to subsidize agriculture?" *Journal of Cleaner Production*, vol. 164, pp. 258–264, 2017.
[41] J. F. Xu and P. Liao, "Crop insurance, premium subsidy and agricultural output," *Journal of Integrative Agriculture*, vol. 13, no. 11, pp. 2537–2545, 2014.
[42] Z. Z. Jiang, N. He, and S. Huang, "Contracting with asymmetric information under government subsidy programmes in a bioenergy supply chain," *International Journal of Production Research*, vol. 60, no. 18, pp. 5571–5594, 2022.
[43] S. Alizamir, F. Iravani, and H. Mamani, "An analysis of price vs. revenue protection: government subsidies in the agriculture industry," *Management Science*, vol. 65, no. 1, pp. 32–49, 2019.
[44] B. Li, M. Zhu, Y. Jiang, and Z. Li, "Pricing policies of a competitive dual-channel green supply chain," *Journal of Cleaner Production*, vol. 112, no. 20, pp. 2029–2042, 2016.
[45] Q. C. Meng, Y. T. Wang, Z. Zhang, and Y. He, "Supply chain green innovation subsidy strategy considering consumer heterogeneity," *Journal of Cleaner Production*, vol. 281, Article ID 125199, 2021.