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Research Article

Green Investment Decisions and Coordination in a Green Agri-Product Supply Chain considering Risk Aversion and Bargaining Power under Different Channel Power Structures

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With eco-friendly green agriculture becoming the development trend of modern agriculture, how to make green investments and how to coordinate the supply chain become the key issues of agricultural green development. Using game theory and optimization theory, this paper studies the green investment decision in a two-echelon agricultural supply chain composed of a risk-averse farmer and a risk-neutral retailer under different power structures including three kinds of decentralized decision making and three kinds of cooperative decision making and conducts the supply chain coordination based on generalized Nash bargaining model. The results show that under decentralized decision making, Nash vertical, farmer-led, and retailer-led maximizes green investment level, the expected utility of farmer and retailer, respectively. In addition, the cooperative decision increases the marginal revenue, sales price, and the expected utility of the retailer and decreases the expectations of farmers. Except for retailer-led cooperative decisions, all cooperative decisions have increased the level of green investment and wholesale prices; among the six decision models, the green investment level is negatively correlated with risk aversion, while it is positively correlated with the cost-sharing contract. The optimal cost-sharing ratio is positively correlated with risk aversion and bargaining power. The cost-sharing contracts are invalid when farmers have full bargaining power. Numerical analysis shows that a cost-sharing contract with equal bargaining power can achieve perfect coordination in the supply chain.

1. Introduction

Following the improvement of consumers' awareness of environmental protection, consumers have a growing demand for green products [1]. Especially in recent years, the Chinese government has put forward the concept of "Green Development," and consumers, therefore, prefer green products [2]. According to the *Report on the Current Situation of Green Consumption by the Chinese Public* (2019 edition), more than 80% of consumers support green behavior, and consumers are more inclined to "green," "organic," and "ecological" agricultural products. Many countries in the world have taken various measures to develop green agriculture. For example, the U.S. government adopted crop rotation and organic fertilizer agricultural production mode to protect the natural ecological environment, while the European Commission introduced strict certification standards for green agriculture in the form of legislation and detailed management policies. China's government had also been supportive of green agriculture. In 2021, the No. 1 official document of China proposed that the government would take promoting green agricultural development as an important part of accelerating agricultural modernization and put forward relatively comprehensive policies and measures. The above examples indicate that promoting the green and sustainable development of agriculture has become a long-term trend of agricultural development. If the member enterprises of the agricultural supply chain want to obtain the favor of consumers and achieve better development, a green investment has become indispensable. However, in practice, due to the risk aversion of small farmers, the willingness of farmers to invest is not strong. Lu et al. [3] found that farmers, especially small farmers, have high-risk avoidance characteristics. Bellemare [4] also believed that due to the lack of funds, it is more realistic to assume that farmers are risk-averse. When faced with uncertain factors such as market risk, seasonality, climate, and epidemic situation, the risk aversion psychology of farmers is more prominent. Zheng et al. [5] found through relevant data from the Ministry of Agriculture and Rural Affairs that the number of small farmers accounted for more than 98% of Chinese agricultural business entities, and the agricultural employees of small farmers accounted for 90% of all agricultural employees. Accordingly, it is of significance to consider the risk-averse quality of farmers in green investment. Farmers' risk aversion makes them worry about the market uncertainty caused by investment, so they are willing to reduce or even refuse investment, which leads to the imbalance between supply and demand in the market. Therefore, it becomes the key issue of how to encourage farmers to invest in green development and how to further improve the green investment level of the whole supply chain.

In reality, green investment has appeared in the form of "Company and Farmer." For example, Wens Food Co. Ltd. implemented a "company + farmer" model, requiring farmers to invest in standardized farms. Consumers who like green agricultural products place orders for green agricultural products to farmers, and farmers will make green investments to satisfy consumers' green preferences. This kind of "order agriculture" is the result of bargaining with each other, which involves the bargaining game. The previous research literature on the bargaining game in the agricultural supply chain is still rare. Therefore, this is a problem worth studying on how to use the bargaining game model to motivate farmers with risk aversion to make green investments and therefore realize the maximum green investment level. Due to farmers and retailers being under different channel power structures, farmers have different positions in the channel, which will have different influences on farmers' green investment. When the retailers set policies and standards and farmers operate according to them, the retailers have a stronger dominant position. Conversely, when farmers master the core technology and have a high reputation, retailers order agricultural products from them, and farmers will have a strong leading position. Moreover, some studies are formed by bargaining based on equal power, which involves three kinds of channel power structures, including farmer-led, retailer-led, and the Nash vertical. However, under these channel power structures, farmers and retailers also face many problems. More specifically, what is the effect of bargaining power on the cost-sharing ratio? How does risk aversion affect supply chain green investment in different channel structures under three decentralized decisions and three cooperative decisions? Which channel power structure decision can maximize the optimal green investment level? How can supply chain members maximize their interests and make optimal decisions in these six channels, and the cost-sharing contract bargaining by both parties promote farmers' green investment and achieve supply chain coordination when the farmer is risk-averse?

Based on the above analysis, we mainly address the optimal decision problem of farmers and retailers that account for the maximization of both sides' income and the green investment level of the farmer. Specifically, we study the optimal decision of green investment in a supply chain of agricultural products composed of a risk-averse farmer and a risk-neutral retailer under different channel power structures including three kinds of decentralized decision making and three kinds of cooperative decision making. In the context of the optimal decision making, the generalized Nash bargaining model is used to coordinate the supply chain to improve the green investment level and income of the whole supply chain and realize Pareto improvement. To summarize, our contributions can be concluded as follows:

(a) We construct a two-echelon supply chain composed of a risk-averse farmer and a risk-neutral retailer by considering the green investment behavior of a risk-averse farmer, which is more consistent with reality. Specifically, we analyze the impact of risk aversion on green investment behavior under three decentralized decision-making modes and three cooperative decision-making modes. This study extends the existing research and makes up for the deficiency of previous literature studies by proposing a novel supply chain model by considering the green investment behavior of a risk-averse farmer.

(b) Based on three decentralized and three cooperative decisions, we utilize the generalized Nash bargaining model to implement the coordination of green investment in the agricultural supply chain with the cost-sharing contract. In the coordination, we fully considered the bargaining power, which is also not taken into account in the previous literature. Furthermore, the existing literature pays less attention to supply chain coordination methods based on the generalized Nash bargaining model in a risk-averse green supply chain.

(c) Several interesting insights in supply chain research are found in this study. Specifically, the findings indicate that when the bargaining power is considered, the optimal green investment level and bargaining power are negatively correlated with risk aversion; the optimal sharing ratio has a certain range. However, when the farmer has full bargaining power, the retailer has no profit and the cost-sharing contract is invalid. Cost-sharing contracts with equal bargaining power can perfectly coordinate the supply chain.

The rest of this paper is organized as follows. Section 2 presents the literature review related to this study. In Section 3, we describe the research questions and hypotheses and define the problem and assumptions. The equilibrium solution and the optimal decision for each variable are given in Section 4. Section 5 is mainly involved in model comparison and analysis. Section 6 is numerical analysis, which demonstrates the effectiveness of the proposed model. Finally, we summarize the results and provide recommendations for future research in Section 7.

2. Literature Review

In this section, we mainly review the literature relevant to this paper and highlight the motivation.

2.1. Cooperative Game in Supply Chain. There is an interactive relationship between supply chain members, and they are not independent individuals, which makes the operational decisions of members of the supply chain often affected by other members of the upstream and downstream. In this case, game theory needs to be used in the model. Existing studies focus on using cooperative games and less consider bargaining power. In other words, the application of the cooperative game in the agricultural supply chain is still rare. Zheng et al. [6] studied the profit distribution of retailers based on the idea of the cooperative game considering fairness in a three-echelon closed-loop supply chain. Zhao et al. [7] studied the coordination problem in the supply chain of options contracts based on the wholesale price mechanism, established the option contract model with the cooperative game method, and found that the option contract can coordinate the supply chain and realize Pareto improvement. Li et al. [8] established a cooperative game model to study the emission reduction strategy of a low-carbon supply chain based on different channel structures. But this study did not consider the risk aversion and bargaining power of the supply chain members. Li et al. [9] used a cooperative game model to study advertising cooperation strategies in an O2O supply chain and analyzed the advantages and disadvantages of three modes including centralized decision making, unilateral cooperative decision making, and bilateral cooperative decision making. Kang et al. [10] used the cooperative game to study the credit poverty alleviation problems in a green supply chain and established the optimal cooperative mechanism to solve the problems of excessively high interest rate of microcredit and the economic and environmental performance of green poverty alleviation. Ghosh and Shah [11] studied how to improve the greenness of the supply chain through cooperative games under different channel power structures in a supply chain. In terms of theoretical application, Forghani et al. [12] used rough set theory to study the influence of digital marketing strategy on online shopping customer behavior, which is different from this paper. Zhang et al. [13] studied how spillover and cooperation can impact the enterprises' green innovation decisions in the presence of a free rider. The results showed that cooperation will increase the total emission amount and long-term profits of the green supply chain. Li et al. [14] explored that different green collaborative creation strategies could improve corporate profits to a certain extent.

2.2. Different Channel Power Structures. From the perspective of channel behavior theory, the interdependent structure of channel relationship constitutes the basis of other channel behaviors, and as a result of this dependence, the channel power structure is formed. Channel power is defined as the ability of a channel member to influence the behaviors of another channel member for his purposes. Although many pieces of literature on supply chain channel structures have studied price and non-price factors such as advertising and quality, there is little literature on green investment in the agricultural supply chain based on channel behavior theory. Lou et al. [15] believed that benefits and costs should be well coordinated in the green supply chain to achieve the green goal. Ranjbar et al. [16] studied the game scenarios of three different leaders in the closed-loop supply chain and believed that the retailer-led model was the best. Huang and Fan [17] combined the three power structures and the two financing modes to study the optimal purchasing and financing policies of retailers. Zhang et al. [18] found that power structure and information structure have a decisive influence on pricing and advertising decisions. Fan et al. [19] proposed that greater channel power is conducive to supply chain members obtaining greater profits. Su et al. [20] established pricing decision-making models of the green supply chain under different power structures and different forms of subsidies and analyzed the optimal strategy of the green supply chain under the different models and discussed the influence of government subsidy coefficient on optimal decision making of green supply chain. He et al. [21] studied the channel structure and pricing decision of manufacturers selling remanufactured products through third-party companies or platforms. He et al. [22] investigated the deterioration property of products in dual-channel business models. Liu et al. [23] indicated that under different power structures, the greenness of products could be more effective through revenue sharing and cost-sharing contracts. Sana [24, 25] dealt with a dual-channel inventory model where capacity of the market of a particular product is uncertain and discussed two situations in two models to find out optimal prices and green quality in order to maximize the profit functions of individual and integrated systems.

2.3. Risk Aversion of Supply Chain Members. Our study is also related to the risk aversion of supply chain members. Research on the risk aversion of supply chain members has generally been conducted through mean-variance theory or conditional value at risk (CVaR) criteria. Liu et al. [26] found that the double-channel optimization of the supply chain channel is closely related to the attitude toward risk aversion and analyzed the influence of the risk on the channel. Huang et al. [27] studied the coordination and risk sharing in a supply chain composed of a leading retailer and a risk-averse manufacturer and studied the manufacturer's risk avoidance behavior using the CVaR criterion, proving that the contract could coordinate the supply chain. Zhao et al. [28] used buyback contracts and revenue-sharing contracts to coordinate the supply chain of retailers with risk aversion. Ma et al. [29] constructed centralized and decentralized game models when the online channel's demand is uncertain and analyzed the impacts of a set of factors, including consumer environmental awareness, product green level, and risk attitude on decision making in the supply chain. Gupta and Ivanov [30] investigated the impact of risk aversion on the profitability and pricing policy of the supply chain in the sharing economy. Liu et al. [31] focused on the supply chain composed of a risk-neutral supplier and a risk-averse retailer and analyzed the optimal decision of supply chain member enterprises considering the supply chain dominated by suppliers and by retailers, respectively. Deng and Liu [32] analyzed the impact of decision makers' risk aversion on the operation of a low-carbon supply chain and found that decision makers' risk aversion was harmful to the economic development and environmental development of the supply chain and used the contract to coordinate the supply chain. Moon et al. [33] studied the investment problem in a fresh agricultural product supply chain based on fairness concerns considering three investment scenarios and finally coordinated the supply chain through a combined strategy of cost-sharing and revenue-sharing contract.

2.4. Green Investment and Coordination in Supply Chain. Some scholars have studied green investment and the coordination of the supply chain from different perspectives. Yang et al. [34] studied how green manufacturing cost, demand sensitivity of green level, and government intervention affect channel strategy in a competitive supply chain. Sana [35] dealt with a newsvendor inventory model in light of green product marketing of socially responsible corporate firms. Das Roy et al. [36] investigated a multi-echelon green supply chain system where a regular production process is integrated with a remanufacturing process in a single-setup-multi-delivery system under setup cost reduction. Ma et al. [37] studied a supply chain system composed of one manufacturer and one retailer, where the manufacturer invests in green emission reduction technology to reduce carbon emissions, and the retailer invests in information disclosure technology to transmit the higher greenness quality of products to consumers. Wang and Song [38] studied pricing strategies under green investment channels considering sales efforts in dual-channel supply chains and analyzed the optimal decisions of manufacturers and retailers. Li et al. [39] studied a dynamic price game model in a dual-channel green supply chain and focused on the effect of parameter changes on the pricing strategies and complexity of the dynamic system in a dynamic environment. Zhijian et al. [40] examined the joint effect of overconfidence and fairness concern on supply chain decisions and designed a buyback contract to coordinate the supply chain. Zhao et al. [41] studied the pricing and coordination of green supply chains under capital constraints. Yuan et al. [42] examined different government subsidy strategies in green supply chain management. The results showed that the government's subsidy strategy can effectively not only improve the product greenness level but also increase the profits of an enterprise in a green supply chain. Zhou et al. [43] showed the supply chain balance and coordination strategy responsible for green investment under the background of the green economy. They found that the cost-sharing contract could not achieve Pareto improvement of supply chain members, while the two-part system could increase the sales of green products. Cao et al. [44] examined the effort mechanism of the fresh supply chain under bargaining and found that the bargaining cost-sharing contract under the game between the two parties was better than the cost-sharing contract proposed by retailers. However, this study did not take the influence of bargaining power into consideration. Wang [45] took the cost-sharing mechanism under the government's green R&D subsidy into consideration and believed that a cost-sharing contract could not improve the profit and social welfare level of the supply chain. Sana et al. [46] extended and corrected Sana's production-inventory model and derived optimal buffer inventory to minimize the expected costs per unit item. Li et al. [47] stated the impact of the cost-sharing contract and revenue-sharing contract on the performance of the low-carbon supply chain, analyzed the cost-sharing contract and revenue-sharing contract under bargaining power, and believed that bargaining power and consumer environmental awareness had a great impact on the profit.

To summarize, as shown in Table 1, some pieces of literature study green investment, different channel power structures, and cooperative games in the supply chain. However, they do not consider the impact of risk aversion and bargaining power in the agricultural supply chain. For example, Wang [45] and Li et al. [47] studied the risk-neutral supply chain instead of the risk-averse supply chain. Yang and Ou [49] investigated the revenue-sharing and bargaining power instead of costing-sharing and bargaining power in a risk-neutral supply chain. Cao et al. [44] did not consider the bargaining power of the supply chain. These papers did not consider the channel power structures. The studies about green investment are very rare, and they less utilize the generalized Nash bargaining model to coordinate the supply chain, especially in the agricultural supply chain. It is obvious that few papers have explored cost-sharing contracts based on the Nash bargaining model in a risk-averse green supply chain under different channel power structures. We also point out how our study differs from these streams of research.

3. Problem Description and Hypotheses

3.1. Basic Assumptions. This paper considers a two-echelon agricultural product supply chain, which consists of a risk-averse farmer and a risk-neutral retailer. The farmer produces only one type of agricultural product. The retailer places orders with the farmer for produce and sells it to consumers. To meet the requirements of national environmental protection and consumers' green preferences, the farmer must make necessary green investments to produce this kind of agricultural product. The farmer mainly introduces advanced equipment, improves technical means, and employs workers to make green investments to reduce the harm of agricultural products to the environment in the production process and increase the organic quality of agricultural products. The farmer's green investment will be passed on to consumers through information, which will

Table 1: Summary of the related literature and new contributions.

Contribution	Agricultural supply chain	Different channel power structures	Green investment	Risk aversion	Cooperative game	Bargaining power	Cost-sharing contracts
Li et al. [8]		√			√		
Kang et al. [10]			√		√		
Ghosh and Shah [11]		√		√	√		
Lou et al. [15]		√					
Gupta and Ivanov [30]				√			
Moon et al. [33]	√		√				
Yuan et al. [42]			√				
Zhou et al. [43]			√				
Cao et al. [44]					√		√
Wang [45]					√	√	√
Li et al. [47]					√		√
Liu et al. [48]			√				
Yang and Ou [49]					√	√	
This study	√	√	√	√	√	√	√

increase sales. The operation process of the supply chain is shown in Figure 1. As the dominant party of green investment, the farmer must invest a lot of capital in the process of green production. Due to market uncertainty and the characteristics of risk aversion, the farmer will reduce or not carry out green investment, thus reducing the output and green investment level. If the retailer wants to get the maximum profit, on the one hand, he should meet the market demand and expand market sales, and on the other hand, he should improve the green level of agricultural products. The farmer will try his best to reduce the cost of green investment and increase profits to pursue profit maximization, while the retailer will pay more attention to green investment and expect the farmer to increase the green investment levels. Therefore, how to coordinate the supply chain to achieve optimal green investment and maximize the interests of both sides becomes a key issue. Based on the above analysis, we constructed a Stackelberg game model of a two-echelon supply chain composed of a farmer and a retailer to analyze the optimal decision of both parties under different power structures and coordinate the supply chain.

Without loss of generality, we have made several principal assumptions, which are summarized as follows:

Assumption 1. The farmer is cautious about the market uncertainty caused by green investment and is not willing to make green investments. The farmer is risk-averse and the retailer is risk-neutral. The retailer places orders to the farmer for agricultural products and forms an order supply chain for agricultural products. We do not consider the periodicity and seasonality of agricultural production.

Assumption 2. The farmer produces only one kind of agricultural product and must make necessary green investments to meet the requirements of government regulation and consumers' green preferences. The farmer's production capacity fully meets the market demand.

Assumption 3. For the research on the consumption of agricultural products, similar to Ghosh and Shah [50], we assume that consumers are sensitive not only to the price but also to the green investment level. The higher the investment level is, the more the consumers prefer it and the higher the market sales are.

Assumption 4. Referring to Bai et al. [51], we assume that the variable unit cost of agricultural products produced by the farmer is not considered, but only the cost related to green investment is considered. The market demand uncertainty of the farmer due to green investment obeys normal distribution and meets the mean-variance theory.

Assumption 5. To ensure that the green investment cost is a convex function, we assume that the range of investment cost coefficient meets $k > \beta^2/b$.

The symbols and meanings involved in this paper are shown in Table 2.

3.2. Model Setting. Based on the above assumptions and referring to Gurnani and Erkoc [52], the market sales of agricultural products meet the linear demand function, and the market demand of agricultural products is expressed as the following equation: $q(p, g) = \alpha - \text{bp} + \beta g$. α $(\alpha > 0)$ is basic market size, b $(b > 0)$ is price elasticity coefficient, p is retail price, and β is consumer green sensitivity coefficient. The higher the retail price is, the lower the market sales are, and the bigger b is, the bigger the decline is. The bigger β is, the greater the market sales are. ω is wholesale price. Let $p > \omega > 0$, $\alpha - \text{bp} > 0$. A similar linear demand function has been widely used in the agricultural supply chains, such as Moon et al. [33].

In line with Bai et al. [51], ε is used to represent the market uncertainty caused by green investment, $\varepsilon \in (0, \sigma^2)$. Market demand function can be revised as follows: $q(p, g) = \alpha - \text{bp} + \beta g + \varepsilon$. $\eta_i (i = f, r)$ is the risk aversion degree of supply chain members. The higher η_i is, the higher the risk aversion degree is. We assume that farmer is risk-averse and the retailer is risk-neutral, namely, $\eta_f > 0$, $\eta_r = 0$.

Referring to Ghosh and Shah [11], the farmer needs to pay extra costs for green investments, which has a quadratic relationship with the green investment level: $C(g) = 1/2\,\text{kg}^2$, where k is the investment cost coefficient and $k > 0$. Similar to Liu et al. [48], k actually represents investment efficiency, when k is larger, the investment efficiency is lower, and the same green level needs to spend more costs.

The subscripts f, r, and sc represent farmer, retailer, and supply chain, respectively. Based on the above assumption, the profit function of the farmer and the retailer is as follows:

$$\begin{aligned}\pi_f &= \omega(\alpha - \text{bp} + \beta g + \varepsilon) - \frac{1}{2}\text{kg}^2,\\ \pi_r &= (p - \omega)(\alpha - \text{bp} + \beta g + \varepsilon).\end{aligned} \tag{1}$$

According to the mean-variance theory and the research of Xiao and Yang [53], when the farmer is risk-averse and the retailer is risk-neutral, the expected utility functions of both parties are

$$\begin{aligned}U(\pi_f) &= E(\pi_f) - \eta_f \text{Var}(\pi_f)\\ &= \omega(\alpha - \text{bp} + \beta g) - \frac{1}{2}\text{kg}^2 - \eta_f \omega^2 \sigma^2,\end{aligned} \tag{2}$$

$$\begin{aligned}U(\pi_r) &= E(\pi_r) - \eta_r \text{Var}(\pi_r)\\ &= (p - \omega)(\alpha - \text{bp} + \beta g).\end{aligned} \tag{3}$$

4. Model Solution and Analysis

In this paper, we consider decentralized decision making and cooperative decision making. In decentralized decision making, each decision variable in the supply chain is completed independently by members. Three channel power structures are considered including the one dominated by the farmer ("FS"), the one dominated by the retailer ("RS"), and the Nash vertical channel power structure with equal

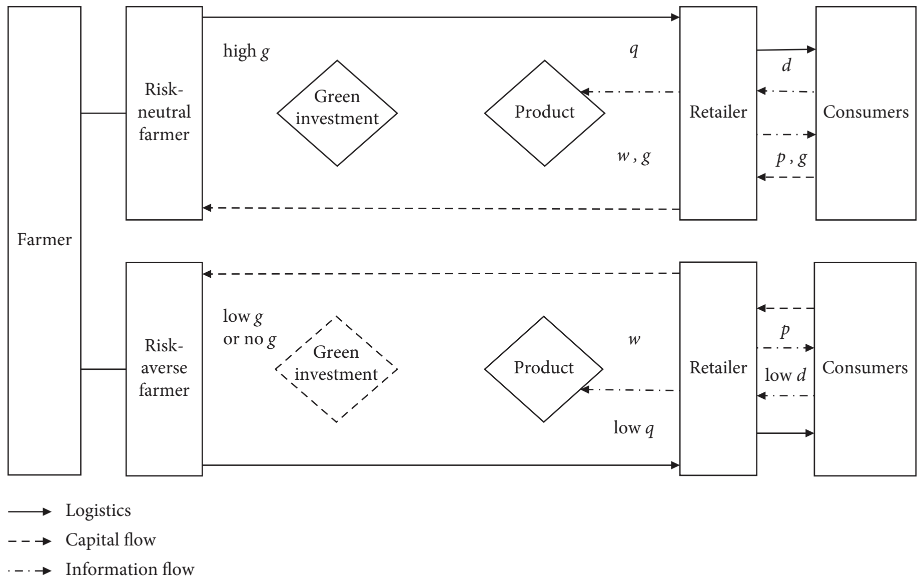

Figure 1: Comparison of supply chain operation of green investment by risk-averse and risk-neutral farmers.

Table 2: Symbols and meaning.

Symbols	Meaning
q	Market demand
ω	Wholesale price
m	Marginal profit
p	Retail price $p = \omega + m$
α	The basic size of the market
π_i	The profit $(i = f, r)$
λ	The cost-sharing ratio of green investment cost
β	Consumer green sensitivity coefficient
g	Green investment level
k	Investment cost coefficient
b	Consumer price sensitivity coefficient
γ	Bargaining power
$U(\pi_i)$	The expected utility $(i = f, r)$

power ("NN"). Under FS, the farmer takes the lead in determining the green investment level and wholesale price, and the retailer determines the marginal contribution and retail price according to the green investment level and wholesale price of the farmer. Under RS, the retailer takes the lead in deciding the retail price, while the farmer decides the green investment level and wholesale price according to the retail price of the retailer. Under NN, farmer determines green investment level and wholesale price, and retailer determines retail price according to the principle of profit maximization, respectively.

In the cooperative decision-making system, we consider three-channel power structures including the one dominated by the farmer ("FC"), the one dominated by the retailer ("RC"), and the Nash vertical channel power structure with equal power("NC"). In this system, the two sides can agree on the green investment level in line with the Nash bargaining. The other aspects are the same as the three decentralized channel strategies, respectively.

In this paper, the above marks f, r, and n represent "FS," "RS," and "NN," respectively. The above marks fc, rc, nc, and cb stand for "FC," "RC," "NC," and cost-sharing contract based on the generalized Nash bargaining model.

4.1. The Optimal Decision in the Decentralized Decision-Making System

4.1.1. The Optimal Green Investment Decision under the FS Channel Power Structure. When the farmer is the leader in the supply chain, he first determines his decision variables, and then the retailer determines his decision variable. As the core enterprise of the supply chain, the farmer has control over the supply chain. First, the farmer decides the green investment level and wholesale price. Second, the retailer will decide the retail price according to the decisions of the farmer. Using the inverse induction, the second derivative of the retailer's utility function with respect to m, $(\partial^2 U(\pi_r)/\partial m^2) = -2b < 0$, the expected utility of the retailer is a strictly concave function about marginal revenue, with a maximum, and the marginal revenue can be obtained by its first-order condition.

According to $(\partial U(\pi_r)/\partial m) = 0$, we can get

$$m = \frac{\alpha + \beta g - b\omega}{2b}. \tag{4}$$

We substitute (5) into (3), and then we get $U(\pi_f) = 1/2\omega[(\alpha - b\omega) + \beta g] - 1/2\text{k}g^2 - \eta_f \omega^2 \sigma^2$. Solve the Hessian matrix of the above equation to ω and g, and we can get $H = \begin{bmatrix} (\partial^2 U(\pi_f)/\partial g^2) & (\partial^2 U(\pi_f)/\partial g \partial \omega) \\ (\partial^2 U(\pi_f)/\partial \omega \partial g) & (\partial^2 U(\pi_f)/\partial \omega^2) \end{bmatrix} = \begin{bmatrix} -(b + 2\sigma^2 \eta_f) & \beta \\ \beta & -k \end{bmatrix}$; obviously, $|H_1| = -(b + 2\sigma^2 \eta_f) < 0$; when $|H| = k(b + 2\sigma^2 \eta_f) - \beta^2 > 0$, the Hessian matrix is negative definite with maximum value. The farmer's expected utility function is a combined concave function of ω and g. Let

$(\partial U(\pi_f)/\partial g) = 1/2(\alpha + g\beta - 2b\omega - 4\sigma^2\omega\eta_f) = 0$, $(\partial U(\pi_f)/\partial\omega) = 1/2(-2gk + \beta\omega) = 0$, solve the system of equations, and then we get $\omega^{f*} = (2\alpha k)/(4bk + 8k\sigma^2\eta_f - \beta^2)$, $g^{f*} = (\alpha\beta)/(4bk + 8k\sigma^2\eta_f - \beta^2)$. The marginal revenue and the optimal expected utility of the farmer and the retailer can be further obtained.

4.1.2. The Optimal Green Investment Decision under the RS Channel Power Structure. When the retailer is the leader of the supply chain, the retailer has control over the supply chain. The retailer takes the lead in deciding the retail price of the product, and the farmer decides the green investment and wholesale price of the product according to the decision of the retailer. Let $p = \omega + m$, substitute p into equation (2), and then

$$\begin{aligned} U(\pi_f) &= E(\pi_f) - \eta_f \mathrm{Var}(\pi_f) \\ &= \omega(\alpha - b(\omega + \mathrm{m}) + \beta g) - \frac{1}{2}kg^2 - \eta_f\omega^2\sigma^2. \end{aligned} \tag{5}$$

Solve the Hessian matrix of the above equation about ω and g, and we get $H = \begin{bmatrix} (\partial^2 U(\pi_f)/\partial g^2) & (\partial^2 U(\pi_f)/\partial g\partial\omega) \\ (\partial^2 U(\pi_f)/\partial\omega\partial g) & (\partial^2 U(\pi_f)/\partial\omega^2) \end{bmatrix} = \begin{bmatrix} -2b - 2\sigma^2\eta_f & \beta \\ \beta & -k \end{bmatrix}$. Obviously, $|H_1| - 2b - 2\sigma^2\eta_f < 0$; when $|H| = 2k(b + \sigma^2\eta_f) - \beta^2 > 0$, the farmer's expected utility function is a combined concave function about ω and g. According to the first order of ω and g, set them equal to zero, solve ω and g, respectively, and substitute them into equation (3) to find the second derivative with respect to m; when $(\partial^2 U(\pi_r)/\partial m^2) = -2b < 0$, $(\partial U(\pi_r)/\partial m) = 0$, we can get $m^{r*} = \alpha/2b$, $\omega^{r*} = (\alpha k)/(4bk + 4k\sigma^2\eta_f - 2\beta^2)$, $g^{r*} = (\alpha\beta)/(4bk + 4k\sigma^2\eta_f - 2\beta^2)$. The marginal revenue and the optimal expected utility of the farmer and the retailer can be further obtained.

4.1.3. The Optimal Green Investment Decision under the NN Channel Power Structure. When the power of both parties is equal, there is no leader or a follower in the supply chain. Both sides make simultaneous decisions based on the principle of maximizing their interests. The farmer decides the wholesale price of agricultural products and green investment level, and the retailer decides the retail price.

Similar to the previous two cases, we can get the Hessian matrix, $H = \begin{bmatrix} (\partial^2 U(\pi_f)/\partial g^2) & (\partial^2 U(\pi_f)/\partial g\partial\omega) \\ (\partial^2 U(\pi_f)/\partial\omega\partial g) & (\partial^2 U(\pi_f)/\partial\omega^2) \end{bmatrix} = \begin{bmatrix} -2b - 2\sigma^2\eta_f & \beta \\ \beta & -k \end{bmatrix}$, $|H_1| = -2b - 2\sigma^2\eta_f < 0$, $|H| = 2k(b + \sigma^2\eta_f) - \beta^2 > 0$. The utility function of the farmer is a combined strict concave function about wholesale price and green investment. Because $(\partial^2 U(\pi_r)/\partial m^2) = -2b < 0$, the retailer's utility function is a strictly concave function about marginal contribution. According to the first-order condition, let $(\partial U(\pi_f)/\partial g) = 0$, $(\partial U(\pi_f)/\partial\omega) = 0$, $(\partial U(\pi_r)/\partial m) = 0$, and the optimal value of wholesale price, green investment level, and marginal contribution can be obtained. On this basis, the optimal expected utility of both parties can be obtained.

The equilibrium values under decentralized decision making are shown in Table 3.

By analyzing the equilibrium value of sellers' marginal revenue under decentralized decision making, we can obtain Proposition 1.

Proposition 1. *In the decentralized decision dominated by the retailer, the retailer's optimal marginal returns have nothing to do with farmers' risk aversion.*

Proof. The first derivative can be proved.

According to Proposition 1**,** under the power structure dominated by the retailer, the retailer's optimal marginal returns have nothing to do with the farmer's risk aversion. The reason is that under the dominance of the retailer, the retailer completely focuses on maximizing their interests while ignoring farmers' risk aversion. □

4.2. The Optimal Decision in the Cooperative Decision-Making System. Under the decision making of bilateral cooperation mode, the farmer decides the optimal wholesale price and the retailer decides the optimal marginal revenue. The decision-making model of both parties is as follows:

$$\begin{aligned} &\max_{\omega} U(\pi_f) = \max_{\omega}\left[E(\pi_f) - \eta_f \mathrm{Var}(\pi_f)\right], \\ &\max_{m} U(\pi_r) = \max_{m} E(\pi_r). \end{aligned} \tag{6}$$

In the cooperation decision system, the two sides bargain about the green investment level. In the whole process of green investment, both sides can reach a consensus on the green investment level through bargaining which follows the Nash bargaining game. At the same time, this paper assumes that the bargaining process of both parties does not consider the bargaining power of both parties, and the model can be represented by

$$\max_{g} U(\pi_b) = \max_{g}\left[U(\pi_f)\right][U(\pi_r)]. \tag{7}$$

In this model, $[U(\pi_f)][U(\pi_r)]$ represents the Nash product which means maximizing the interests of both parties.

4.2.1. The Optimal Green Investment Decision under the FC Channel Power Structure. Farmer is the dominant party in the supply chain. According to the reverse solution method, the retailer's problem needs to be solved first, and the retailer's expected utility function can be expressed as follows:

$$U(\pi_r) = m[\alpha - b(m + \omega) + \beta g]. \tag{8}$$

$(\partial^2 U(\pi_r)/\partial m^2) = -2b < 0$. The retailer's utility function is a strictly concave function about marginal revenue. According to first-order conditions, it can be obtained that

$$m = \frac{\alpha + \beta g - b\omega}{2b}. \tag{9}$$

TABLE 3: The equilibrium value of each decision variable of three-channel structures in the decentralized decision-making system.

	FS	RS	NN
g^*	$(\alpha\beta)/(4\text{bk} + 8k\sigma^2\eta_f - \beta^2)$	$(\alpha\beta)/(4\text{bk} + 4k\sigma^2\eta_f - 2\beta^2)$	$(\alpha\beta)/(3\text{bk} + 4k\sigma^2\eta_f - \beta^2)$
m^*	$(\alpha k(b + 4\sigma^2\eta_f))/(b(4\text{bk} + 8k\sigma^2\eta_f - \beta^2))$	$\alpha/2b$	$(\alpha k(b + 2\sigma^2\eta_f))/(b(3\text{bk} + 4k\sigma^2\eta_f - \beta^2))$
ω^*	$(2\alpha k)/(4\text{bk} + 8k\sigma^2\eta_f - \beta^2)$	$(\alpha k)/(4\text{bk} + 4k\sigma^2\eta_f - 2\beta^2)$	$(\alpha k)/(3\text{bk} + 4k\sigma^2\eta_f - \beta^2)$
p^*	$(\alpha k(3b + 4\sigma^2\eta_f))/(b(4\text{bk} + 8k\sigma^2\eta_f - \beta^2))$	$(\alpha(3\text{bk} + 2k\sigma^2\eta_f - \beta^2))/(2b(2\text{bk} + 2k\sigma^2\eta_f - \beta^2))$	$(2\alpha k(b + \sigma^2\eta_f))/(b(3\text{bk} + 4k\sigma^2\eta_f - \beta^2))$
$U(\pi_f)$	$(\alpha^2 k)/(2(4\text{bk} + 8k\sigma^2\eta_f - \beta^2))$	$(\alpha^2 k)/(8(2\text{bk} + 2k\sigma^2\eta_f - \beta^2))$	$(\alpha^2 k(2bk - \beta^2 + 2k\sigma^2\eta_f))/(2(3\text{bk} + 4k\sigma^2\eta_f - \beta^2)^2)$
$U(\pi_r)$	$(\alpha^2 k^2(b + 4\sigma^2\eta_f)^2)/(b(4\text{bk} + 8k\sigma^2\eta_f - \beta^2)^2)$	$(\alpha^2 k(b + 2\sigma^2\eta_f))/(4b(2\text{bk} + 2k\sigma^2\eta_f - \beta^2))$	$(\alpha^2 k^2(b + 2\sigma^2\eta_f)^2)/(b(3\text{bk} + 4k\sigma^2\eta_f - \beta^2)^2)$

Then the optimal expected utility of the farmer is solved, and the optimal expected utility function of the farmer is

$$U\left(\pi_f\right)_{\omega} = \omega[\alpha - b(\omega + \mathrm{m}) + \beta g] - \frac{1}{2}\mathrm{kg}^2 - \eta_f \omega^2 \sigma^2. \quad (10)$$

We substitute (7) into (8) and solve the second derivative, and we get $(\partial^2 U(\pi_f)/\partial \omega^2) = -(b + 2\sigma^2 \eta_f) < 0$. According to the first-order condition, we substitute it into equation (8), and we can get $\omega = (\alpha + g\beta)/(2(b + 2\sigma^2\eta_f))$, $m = ((\alpha + g\beta)(b + 4\sigma^2\eta_f))/(4b(b + 2\sigma^2\eta_f))$. Furthermore, the optimal expected utility of both parties can be obtained when the farmer and the retailer bargain about the green investment level.

$$\begin{aligned}\max_g U(\pi_b) &= \max_g \left[U\left(\pi_f\right)\right]\left[U(\pi_r)\right]\\ &= \left(\frac{1}{8}\left(-4g^2k + \frac{(\alpha + g\beta)^2}{b + 2\sigma^2\eta_f}\right)\right)\left(\frac{(\alpha + g\beta)^2\left(b + 4\sigma^2\eta_f\right)^2}{16b\left(b + 2\sigma^2\eta_f\right)^2}\right).\end{aligned} \quad (11)$$

We can get $(\partial^2(U(\pi_b))/\partial^2 g) = (b + 4\sigma^2\eta_f)^2[2k(\alpha^2 + 6g\alpha\beta + 6g^2\beta^2)\ (b + 2\sigma^2\eta_f) - 3\beta^2(\alpha + g\beta)^2]/(-32b\ (b + 2\sigma^2\eta_f)^3)$; when $k > \beta^2/4b + 8\sigma^2\eta_f$ and $(\partial^2(U(\pi_b))/\partial^2 g) < 0$, the function is a strictly concave function about the green investment level, and we can get the optimal investment level. Then, we put the optimal investment level into other variables, and we can get the optimal wholesale price, the optimal marginal revenue, and the optimal retail price. Finally, we can get the optimal expected utility of the farmer and retailer.

4.2.2. The Optimal Green Investment Decision under the RC Channel Power Structure. When the retailer is the leader in the supply chain, he determines his decision variable first, and then the farmer determines his decision variables. Because $(\partial^2 U(\pi_f)/\partial\omega^2) = -2(b + \sigma^2\eta_f) < 0$, the expected utility function of the farmer is a strictly concave function about the wholesale price. According to first-order conditions, we can get $\omega = (-\mathrm{bm} + \alpha + g\beta)/(2(b + \sigma^2\eta_f))$. We substitute the wholesale price into the function of the retailer, and then we can obtain

$$U(\pi_r) = \frac{m(\alpha + g\beta - \mathrm{bm})\left(b + 2\sigma^2\eta_f\right)}{2\left(b + \sigma^2\eta_f\right)}. \quad (12)$$

Because $(\partial^2 U(\pi_r)/\partial m^2) = -(b(b + 2\sigma^2\eta_f))/(b + \sigma^2\eta_f) < 0$, the expected utility function of the retailer is a strictly concave function about the marginal revenue. According to first-order conditions, we can get $m = (\alpha + g\beta)/(2b)$. Substitute it into the wholesale price, and we can get $\omega = (\alpha + g\beta)/(4b + 4\sigma^2\eta_f)$. When we put the marginal revenue and the wholesale price into the expected utility function of the farmer and the retailer, we can get the optimal expected utility related to the green investment level. When the farmer and the retailer bargain about the green investment level, the optimal green investment level is determined by

$$\begin{aligned}\max_g U(\pi_b) &= \max_g \left[U\left(\pi_f\right)\right]\left[U(\pi_r)\right]\\ &= \left[\frac{1}{16}\left(-8g^2k + \frac{(\alpha + g\beta)^2}{b + \sigma^2\eta_f}\right)\right]\left[\frac{(\alpha + g\beta)^2\left(b + 2\sigma^2\eta_f\right)}{8b\left(b + \sigma^2\eta_f\right)}\right].\end{aligned} \quad (13)$$

We can derive

$$\frac{\partial^2(U(\pi_b))}{\partial^2 g} = \frac{\left(b + 2\sigma^2\eta_f\right)\left[4k\left(\alpha^2 + 6g\alpha\beta + 6g^2\beta^2\right)\left(b + \sigma^2\eta_f\right) - 3\beta^2(\alpha + g\beta)^2\right]}{-32b\left(b + 2\sigma^2\eta_f\right)^2}. \quad (14)$$

When $k \geq (3\beta^2)/(4b + 4\sigma^2\eta_f)$, the function is a strictly concave function about the green investment level. According to first-order conditions, we can get the optimal green investment level. When we substitute the optimal investment level into other variables, we can get the optimal wholesale price, the optimal marginal revenue, and the optimal retail price. Finally, we can get the optimal expected utility of the farmer and the retailer.

4.2.3. The Optimal Green Investment Decision under the NC Channel Power Structure. In the cooperative decision-making system, when both parties have equal bargaining power, they make decisions at the same time. The farmer decides the optimal wholesale price, and the retailer decides the optimal retail price. The two sides are bargaining about the optimal green investment level. It is easy to prove that the farmer's expected utility function is strictly concave about wholesale price and the retailer's expected utility function is strictly concave about marginal revenue.

According to the first-order condition, we can get $\omega = (\alpha + g\beta)/(3b + 4\sigma^2\eta_f)$, $m = (\alpha + g\beta)(b + 2\sigma^2\eta_f)/b(3b + 4\sigma^2\eta_f)$. By substituting them into the expected utility function of farmer and retailer, the expected utility function related to green investment level can be obtained. When the farmer and the retailer bargain about the green investment level, the optimal green investment level is determined by

$$\begin{aligned}\max_g U(\pi_b) &= \max_g \left[U\left(\pi_f\right)\right]\left[U(\pi_r)\right]\\ &= \left[\frac{b\left(2(\alpha + g\beta)^2 - 9\mathrm{bg}^2k\right) + 2\sigma^2\eta_f\left((\alpha + g\beta)^2 - 12\mathrm{bg}^2k - 8g^2k\sigma^2\eta_f\right)}{2\left(3b + 4\sigma^2\eta_f\right)^2}\right]\\ &\quad\times\left[\frac{(\alpha + g\beta)^2\left(b + 2\sigma^2\eta_f\right)^2}{b\left(3b + 4\sigma^2\eta_f\right)^2}\right].\end{aligned} \tag{15}$$

When $\mathrm{bk} - \beta^2 > 0$, $(\partial^2(U(\pi_b))/\partial^2 g) < 0$, equation (12) is a strictly concave function about the green investment level. According to first-order conditions, we can find the optimal green investment level. Similar to the above, other optimal decision variables can be obtained.

Table 4 shows the equilibrium values of decision-making variables of the three-channel structures under cooperative decision making.

By comparing and analyzing the equilibrium results of farmers and retailers under decentralized decisions and cooperative decisions, we can get Proposition 2.

Proposition 2. *Under any power structure, farmers' green investment level and expected utility decrease with the increase of risk aversion, while retailers' expected utility increases with the increase of farmers' risk aversion.*

Proof. The first derivative can be proved.

According to Proposition 2, the impact of farmers' risk aversion on the expected utility of both parties is different. For retailers, the greater the farmers' risk aversion is, the higher the retailers' expected utility is. The reason is that the greater the farmers' risk aversion is, the lower the green investment level is, the lower the wholesale price is, and the higher the retailers' expected utility is. □

4.3. Supply Chain Coordination Based on the Generalized Nash Bargaining Model. In this paper, we establish a cost-sharing contract based on the generalized Nash bargaining model for supply chain coordination, which has been used to derive the equilibrium results of bilateral bargaining systems by common parties, such as Yang and Ou [49]. Referring to Yang and Ou [49], the generalized Nash bargaining model in this paper can be defined as the following optimization problems.

$$\max\{\phi(\lambda)\} = \max_\lambda \left\{U\left(\pi_f\right)^\gamma U(\pi_r)^{1-\gamma}\right\}, \quad \gamma \in [0,1], \tag{16}$$

where γ represents the bargaining power of the farmer relative to the retailer and $\phi(\lambda)$ represents the Nash product which means maximizing the interests of both parties. Under the generalized Nash bargaining model, the farmer and the retailer determine the optimal cost-sharing ratio through the bargaining game. Different from the general contract, the contract is proposed by the farmer, and the two parties decide the optimal cost-sharing ratio through bargaining. The decision sequence of the supply chain is shown in Figure 2.

This model is a common method to derive the bilateral bargaining system, which can maximize the interests of both parties. In this paper, the purpose of using this model is to find the optimal cost-sharing ratio under the condition of maximizing the expected utility of the farmer and the retailer. The decision-making sequence of both parties is as follows:

(1) The cost-sharing ratio λ is determined in the bargaining game between farmer and retailer. In the bargaining process, the retailer shares the investment cost of λ proportion, and the farmer shares $(1 - \lambda)$;
(2) The farmer determines the optimal green investment level and wholesale price according to the cost-sharing ratio and retailer's response function;

Table 4: The equilibrium value of each decision variable of three-channel structures in the cooperative decision-making system.

	FS	RS	NN
g^*	$(A_1 + L_1)/(2\beta C_1)$	$(2\alpha\beta^2 - 4\mathrm{b}\alpha\mathrm{k} - 4\alpha k\sigma^2\eta_f + L_3)/2\beta(-\beta^2 + 8\mathrm{bk} + 8k\sigma^2\eta_f)$	$\alpha(b(8\beta^2 - 9\mathrm{bk}) + 8\sigma^2\eta_f C_6 + C_5L_5)/(4\beta C_4)$
m^*	$(b + 4\sigma^2\eta_f)(3\alpha\mathrm{k}(b + 2\sigma^2\eta_f) + \mathrm{L}_2)/(4b(b + 2\sigma^2\eta_f)\mathrm{A}_2)$	$(3\alpha\mathrm{k}(b + \sigma^2\eta_f) + L_4)/b(-\beta^2 + 8\mathrm{bk} + 8k\sigma^2\eta_f)$	$(\alpha(b + 2\sigma^2\eta_f)(9\mathrm{bk} + 12k\sigma^2\eta_f + L_5))/(4\mathrm{bC}_4)$
ω^*	$(\alpha^2 k)/(3\alpha k(b + 2\sigma^2\eta_f) - L_2)$	$(\alpha^2 k)/(6\alpha\mathrm{k}(b + \sigma^2\eta_f) - 2\mathrm{L}_4)$	$(2\alpha k)/(9bk + 12k\sigma^2\eta_f - \mathrm{L}_5)$
p^*	$(\alpha^2 k\mathrm{C}_6)/(6b\alpha k(b + 2\sigma^2\eta_f) - 2bL_2)$	$(3b\alpha^2 k + 2\alpha^2 k\sigma^2\eta_f)/(2b(3\mathrm{b}\alpha\mathrm{k} + 3\alpha\mathrm{k}\sigma^2\eta_f - \mathrm{L}_4))$	$4\alpha k(b + \sigma^2\eta_f)/(b(9b + 12k\sigma^2\eta_f - \mathrm{L}_5))$
$U(\pi_f)$	$(\alpha^3 k)/(4(-\alpha\beta^2 + b\alpha k + 2\alpha k\sigma^2\eta_f + \mathrm{L}_2))$	$(\alpha^3 k)/(8b\alpha k + 8\alpha k\sigma^2\eta_f - 4\alpha\beta^2 + 8\mathrm{L}_4)$	$(\alpha^2 k(8\beta^2(b + \sigma^2\eta_f) - k\mathrm{C}_5{}^2 + \mathrm{C}_5\mathrm{L}_5))/(16\beta^2 C_4)$
$U(\pi_r)$	$(\alpha^2 k(b + 4\sigma^2\eta_f)^2 C_2L_2)/(8b(b + 2\sigma^2\eta_f)\mathrm{A}_2(\mathrm{C}_2 + \mathrm{L}_2))$	$(\alpha k(b + 2\sigma^2\eta_r)(6L_4 + \alpha C_3))/(2b(\beta^2 - 8bk - 8k\sigma^2\eta_f)^2)$	$(\alpha^2(b + 2\sigma^2\eta_f)^2(9bk + 12k\sigma^2\eta_f + \mathrm{L}_5)^2)/(16bC_4^2)$

$L_1 = \sqrt{(2\alpha\beta^2 - 2b\alpha k - 4\alpha k\sigma^2\eta_f)^2 + 4\alpha^2\beta^2(4\mathrm{bk} + 8k\sigma^2\eta_f - \beta^2)}$, $A_1 = 2\alpha\beta^2 - 2b\alpha k - 4\alpha k\sigma^2\eta_f$, $A_2 = (-\beta^2 + 4\mathrm{bk} + 8k\sigma^2\eta_f)$, $C_1 = (4\mathrm{bk} + 8k\sigma^2\eta_f - \beta^2)$, $C_2 = 3\alpha k(b + 2\sigma^2\eta_f)$, $C_3 = (\beta^2 + 10\mathrm{bk} + 10k\sigma^2\eta_f)$, $C_4 = b(9\mathrm{bk} - 2\beta^2) + 2\sigma^2\eta_f(12\mathrm{bk} + 8k\sigma^2\eta_f - \beta^2)$, $C_5 = (3b + 4\sigma^2\eta_f)$, $C_6 = (\beta^2 - 3\mathrm{bk} - 2k\sigma^2\eta_f)$, $L_2 = \sqrt{\alpha^2 k(b + 2\sigma^2\eta_f)(2\beta^2 + \mathrm{bk} + 2k\sigma^2\eta_f)}$, $L_3 = \sqrt{(2\alpha\beta^2 - 4b\alpha k - 4\alpha k\sigma^2\eta_f)^2 - 4\alpha^2\beta^2(\beta^2 - 8\mathrm{bk} - 8k\sigma^2\eta_f)}$, $L_4 = \sqrt{\alpha^2 k(b + \sigma^2\eta_f)(\beta^2 + \mathrm{bk} + k\sigma^2\eta_f)}$, and $L_5 = \sqrt{k(b(16\beta^2 + 9\mathrm{bk}) + 8\sigma^2\eta_f(2\beta^2 + 3\mathrm{bk} + 2k\sigma^2\eta_f))}$.

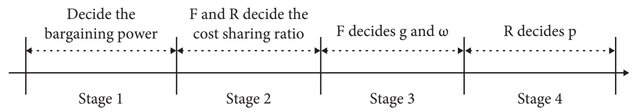

Figure 2: The decision sequence, where F and S stand for the farmer and the retailer, respectively.

(3) The retailer determines the retailer price and order quantity according to the sharing ratio, the optimal green investment level, and wholesale price.

Based on the above analysis, the expected utility functions of both parties are as follows:

$$\begin{aligned} U\left(\pi_f\right) &= \omega(\alpha - \mathrm{bp} + \beta g) - \frac{1}{2}(1-\lambda)\mathrm{kg}^2 - \eta_f \omega^2 \sigma^2, \\ U(\pi_r) &= (p-\omega)(\alpha - \mathrm{bp} + \beta g) - \frac{1}{2}\lambda \mathrm{kg}^2. \end{aligned} \tag{17}$$

Considering whether the two parties have equal power in the bargaining game, it can be divided into the bargaining cost-sharing contract with equal bargaining power and the cost-sharing contract with unequal bargaining power. The optimization problem of cost-sharing contract based on the generalized Nash bargaining model can be expressed as

$$\begin{aligned} \max\{\phi(\lambda)\} &= \max_{\lambda}\left\{\left[U\left(\pi_f\right)\right]^{\gamma}\left[U(\pi_r)\right]^{1-\gamma}\right\} \\ &= \left[\omega(\alpha - \mathrm{bp} + \beta g) - \frac{1}{2}(1-\lambda)\mathrm{kg}^2 - \eta_f\omega^2\sigma^2\right]^{\gamma}\left[(p-\omega)(\alpha - \mathrm{bp} + \beta g) - \frac{1}{2}\lambda\mathrm{kg}^2\right]^{1-\gamma} \\ &\text{s.t. } 0 < \gamma < 1. \end{aligned} \tag{18}$$

Using the inverse induction, we get $U(\pi_f)(\lambda)$ and $U(\pi_r)(\lambda)$. We substitute them into (17), and then we get $\max\{\phi(\lambda)\} = \max_{\lambda}\left\{[U(\pi_f)(\lambda)]^{\gamma}[U(\pi_r)(\lambda)]^{1-\gamma}\right\}$.

According to the first-order condition, we can get $\lambda(\gamma)^* = (b\beta^2 + 4b^2k(2-\gamma) + 32k\sigma^2\eta_f(2-\gamma)(b+2\sigma^2\eta_f) - \sqrt{b^2D + 32\mathrm{kb}\sigma^2\eta_f E})/(4\mathrm{kb}^2(4-3\gamma) + 16k\sigma^2\eta_f[b(5-3\gamma) + 4\sigma^2\eta(2-\gamma)])$, where $D = \beta^4 + 8kb\beta^2(6\gamma - 3\gamma^2 - 2) - 64b^2k^2(1-\gamma)^2$, $E = b\beta^2(6\gamma - 3\gamma^2 - 2) + 8b^2k(1-\gamma)^2 + 4\sigma^2\eta_f[\beta^2\gamma(2-\gamma) + 2bk(1-\gamma)^2]$. We substitute $\lambda(\gamma)^*$ into the expression for the green investment level, and we have

$$g(\gamma)^* = \frac{\alpha\beta\left\{b^2(4-3\gamma) + 4\sigma^2\eta_f\left[b(5-3\gamma) - 4(\gamma-2)\sigma^2\eta_f\right]\right\}}{F + G + \left(2\sigma^2\eta_f + b\right)\sqrt{\mathrm{T}}}, \tag{19}$$

where $F = b^2[\beta^2(3\gamma - 5) - 8\mathrm{bk}(\gamma - 1)]$ and

$$\begin{aligned} \mathrm{T} = {} & 32\mathrm{kb}^2\sigma^2\eta_f\left\{8\mathrm{bk}(1-\gamma)^2 - \beta^2[1 + \gamma(-2+\gamma)]\right\} + 128\mathrm{kb}\sigma^4\eta_f^2\left[2\mathrm{bk}(\gamma-1)^2 - \beta^2(\gamma-2)\gamma\right] \\ & + b^2\left\{\beta^4 - 8\mathrm{bk}\beta^2[2 + 3\gamma(\gamma-2)] + 64b^2(\gamma-1)^2k^2\right\}. \end{aligned} \tag{20}$$

Based on the above, the optimal expected utility of both sides can also be calculated, but it is very difficult to further calculate and analyze. Therefore, to make the further analysis more convenient, we focus on the analysis of the situation when both parties have equal bargaining power. In this case, the cost-sharing ratio contract between the two parties can be expressed as

$$\max \phi(\lambda) = \max_{\lambda}\ \left[U\left(\pi_f\right)(\lambda)\right]^{1/2}\left[U(\pi_r)(\lambda)\right]^{1/2}. \tag{21}$$

When $>\beta^2/b + 2\sigma^2\eta_f$, formula (21) is a strictly concave function about cost-sharing proportion. According to the first-order condition, we can get

$$\lambda^{cb*} = \frac{b\beta^2 + 6b^2k + 48k\sigma^2\eta_f\left(b + 2\sigma^2\eta_f\right) - \sqrt{\Omega}}{2k\left(5b^2 + 28b\sigma^2\eta_f + 48\sigma^4\eta_f^2\right)}, \quad (22)$$

where $\Omega = b^2\beta^4 + 2b^3\beta^2k + 16b^4k^2 + 8k\sigma^2\eta_f\,[5b\beta^2 + 8b^2k + 4\sigma^2\eta_f\,(3\beta^2 + 2bk)]$.

By substituting the optimal share ratio into the relevant variables, we can get the optimal equilibrium values as follows:

$$\begin{aligned}
g^{cb*} &= \frac{\alpha\beta\left(5b^2 + 28b\sigma^2\eta_f + 48\sigma^4\eta_f^2\right)}{16\sigma^4\eta_f^2\left(2bk - 3\beta^2\right) + 8b^3k - 7b^2\beta^2 + 32b\sigma^2\eta_f\left(bk - \beta^2\right) + 2\sqrt{\Omega}\left(b + 2\sigma^2\eta_f\right)},\\
\omega^{cb*} &= \frac{2\alpha bk}{b\left(8bk - \beta^2\right) + 16\sigma^2\eta_f - \sqrt{\Omega}},\\
p^{cb*} &= \frac{\alpha k\left(3b + 4\sigma^2\eta_f\right)}{b\left(bk - \beta^2\right) + 16kb\sigma^2\eta_f - \sqrt{\Omega}},\\
U\left(\pi_f\right)^{cb*} &= \frac{\alpha^2 bk}{2\left(8b^2k - b\beta^2 + 16kb\sigma^2\eta_f - \sqrt{\Omega}\right)},\\
U\left(\pi_r\right)^{cb*} &= \frac{\left(16k\sigma^2\eta_f + 8kb - \beta^2\right)\sqrt{\Omega} - 32b^3k^2 + 20k\beta^2 + \beta^4 - 64k\sigma^4{\eta_f}^2\left(2bk - 3\beta^2\right) - 16bk\sigma^2\eta_f\left(8kb - 7\beta^2\right)}{36\beta^2\left[\left(8b^3k - 3b^2\beta^2\right) + 4\sigma^2\eta_f\left(8b^2k - 3\beta^2 b + 8bk\sigma^2\eta_f - 4\beta^2\sigma^2\eta_f\right)\right]}.
\end{aligned} \quad (23)$$

5. Model Comparison and Analysis

5.1. The Optimal Green Investment Level and Pricing Analysis. This paper analyzes the equilibrium values of decentralized decision making, cooperative decision making, and cost-sharing contracts and obtains the following propositions.

Proposition 3. *The green investment level satisfies the following relationship: (1)* $g^{n*} > g^{r*} > g^{f*}$. *(2)* $g^{f*} < g^{fc*}$, $g^{r*} > g^{rc*}$, $g^{n*} < g^{nc*}$.

Proof process is in Appendix A Proof 3.

Proposition 3 shows that the green investment level is the lowest under the channel power structure dominated by the farmer in the decentralized decision. The green investment level is the highest under the Nash vertical channel structure than that of the decentralized decision in the other two-channel structures. In cooperative decision making, except for NC, the green investment level of the other two-channel structures is higher than that of the corresponding decentralized decision making. This is because in the cooperation decision making between the retailer and the farmer, the rational farmer will strive for a lower green investment level. After all, the farmer shares all the green investment costs.

Proposition 4. *The wholesale price satisfies the following relationship: (1)* $\omega^{f*} > \omega^{n*} > \omega^{r*}$; *(2)* $\omega^{f*} < \omega^{fc*}$, $\omega^{r*} > \omega^{rc*}$, $\omega^{n*} < \omega^{nc*}$.

Proof process is in Appendix B Proof 4.

Proposition 4 shows that in the three cases of decentralized decision making, the wholesale price dominated by the farmer is the highest, while the wholesale price dominated by the retailer is the lowest. The relationship between the wholesale price in cooperative decision making and the wholesale price in decentralized decision making is similar to the relationship between the green investment level in Proposition 1. In decentralized decision making, the farmer decides the green investment level under the leadership of the farmer. To pursue his profit and maximize the cost of green investment, the farmer must raise the wholesale price. Under the channel power structure of FC and NC, a rational farmer is bound to raise the wholesale price to make up for the increasing cost caused by green investment. Under the RC channel power structure, because the farmer is in a weak position, the green investment level is reduced to facilitate the transaction, thus reducing the wholesale price.

Proposition 5. *The marginal revenue satisfies the following relationship: (1)* $m^{r*} > m^{n*} > m^{f*}$; *(2)* $m^{f*} < m^{fc*}$, $m^{r*} < m^{rc*}$, $m^{n*} < m^{nc*}$.

Proof process is in Appendix C Proof 5.

Proposition 5 shows that in decentralized decision making, the marginal revenue under the channel power structure dominated by the retailer is the largest, while the marginal revenue under the channel power structure dominated by the farmer is the smallest. No matter what the channel structure is, for the retailer, the marginal revenue in the cooperative decision is always higher than that decentralized decision, which indicates that cooperation improves the retailer's marginal revenue. The reason is that in decentralized decision making, the retailer has more market-leading power under the channel power structure dominated by him. In the cooperative decision system, the retailer increases the marginal revenue with profit maximization as the center.

Proposition 6. *The retail price satisfies the following conditions: (1) when $\eta_f > 1/2\sigma^2(3-2\sqrt{2})b$ and $k > 1/b^2(b\beta^2 + 2\beta^2\sigma^2\eta_f)$, $p^{r*} > p^{f*} > p^{n*}$; (2) $p^{f*} < p^{fc*}$, $p^{r*} < p^{rc*}$, $p^{n*} < p^{nc*}$.*

Proof process is in Appendix D Proof 6.

Proposition 6 shows that in the decentralized decision-making system, the price under the channel power structure dominated by the retailer is greater than that under the NN channel power structure, while the price under the channel power structure is dominated by the farmer and the price under the other two channels has two threshold points, respectively, both of which are related to the risk aversion of the farmer. Therefore, under the FS channel power structure, the risk aversion of the farmer has a certain influence on the optimal retail price. When the condition in Proposition 4 is satisfied, the optimal retail price under the RS channel power structure is the highest.

In a cooperative decision-making system, the retail price of agricultural products under each channel is higher than that in decentralized decision making under the corresponding channel power structure. This suggests that consumers will have to pay higher retail prices for green products when the farmer and the retailer cooperate in making decisions. The reason is that in the cooperative decision, both sides of the supply chain seek to maximize profit and obtain the maximum marginal revenue, thus making the retail price the highest. Combined with Proposition 1, under the Nash vertical, the price and the product green level show a positive correlation, indicating that the green level is higher, and the price is higher. Compared with the retail price, there is an opposite relationship between the retailer-led green level and the retailer price; that is, consumers have to pay a higher price for the lower green investment level. Therefore, the retailer-led market structure is not better.

5.2. The Optimal Expected Utility Analysis

Proposition 7. *The expected utility of the farmer satisfies the following relationship: (1) $U(\pi_f)^{f*} > U(\pi_f)^{n*} > U(\pi_f)^{r*}$; (2) $U(\pi_f)^{f*} > U(\pi_f)^{fc*}$, $U(\pi_f)^{r*} > U(\pi_f)^{rc*}$, $U(\pi_f)^{n*} > U(\pi_f)^{nc*}$.*

Proof process is in Appendix E Proof 7.

Proposition 7 shows that in decentralized decision making, the expected utility of the farmer under the channel power structure dominated by him is the highest. In a channel structure dominated by the retailer, the expected utility of the farmer is the lowest. Channel power enables the farmer to obtain higher returns. Compared with decentralized decision making in cooperative decision making, no matter under which channel power structure, the expected utility of the farmer will be worse. It can be seen that rational farmer does not like cooperative decision making but prefers the decentralized decision-making market. Combined with the previous analysis, in cooperative decision making, the green investment of the farmer increases, and the wholesale price decreases, resulting in the decline in profits.

Proposition 8. *The expected utility of the retailer satisfies the following relationship: (1) $U(\pi_r)^{r*} > U(\pi_r)^{n*} > U(\pi_r)^{f*}$; (2) $U(\pi_r)^{f*} < U(\pi_r)^{fc*}$, $U(\pi_r)^{r*} > U(\pi_r)^{rc*}$, $U(\pi_r)^{n*} < U(\pi_r)^{nc*}$.*

Proof process is in Appendix F Proof 8.

Proposition 8 shows that in decentralized decision making, the retailer, as the dominant channel, has control of the supply chain, so the expected utility is the highest. When the bargaining power of the two sides is equal, the expected utility of the retailer takes the place, which is better than the expected utility under the channel power structure dominated by the farmer. From the previous analysis, it can be seen that under the channel power structure dominated by the retailer, the retailer has the largest expected utility. Under the Nash bargaining between the two sides, the retailer transfers part of the income to the farmer to encourage the farmer to improve the green investment level, so that the income is reduced. Compared with decentralized decision making, except that under the channel power structure dominated by the retailer, under the other two-channel structures, the retailer's expected utility in a cooperative decision-making system is better than that in a decentralized decision-making system.

Proposition 9. *The expected utility of the supply chain satisfies the following relationship: (1) $U(\pi_{sc})^{n*} > U(\pi_{sc})^{r*} > U(\pi_{sc})^{f*}$; (2) $U(\pi_{sc})^{r*} > U(\pi_{sc})^{rc*}$, $U(\pi_{sc})^{f*} < U(\pi_{sc})^{fc*}$, $U(\pi_{sc})^{n*} < U(\pi_{sc})^{nc*}$.*

Proof process is in Appendix G Proof 9.

Proposition 9 shows that for supply chain members, the profit of each member is determined by the profit level of the whole supply chain. Therefore, the expected utility of the retailer and the farmer will change according to the change in the overall expected utility of the supply chain. Proposition 7 also shows that when the retailer dominates channel powers, decentralized decision making has a higher overall expected utility than cooperative decision making in the supply chain. However, the expected utility of the supply chain under cooperative decision is higher than that under decentralized decision when the farmer is dominant and both parties have equal power. In decentralized decision making, the supply chain under the leadership of the farmer has the lowest expected utility, while the supply chain has the highest expected utility when both sides have equal power. The reason is that under the power structure dominated by the farmer, the farmer shares all the green investment costs in the supply chain. High price and low green level reduce the overall expected utility of the supply chain, while the bargaining power between the two parties on an equal footing improves the expected utility of the supply chain.

5.3. Cost-Sharing Contract Analysis

Proposition 10. *In the cost-sharing contract considering bargaining power, the optimal sharing ratio and the optimal green investment level are positively correlated with bargaining power and risk aversion, respectively.*

Proof process is in Appendix H Proof 10.

According to Proposition 10, both the optimal proportion of cost sharing and the optimal green investment level increase with the increase of bargaining power and risk aversion. The reason is that when the farmer has greater bargaining power, he has greater control over the channels. For his interests, the farmer will make the retailer share a larger proportion of the investment cost. The more the retailer takes on the burden, the more the farmer will invest, and the green investment level will increase. With the increase of the farmers' risk aversion, the retailer will take the initiative to share a larger proportion of the cost, encouraging the farmer to increase investment, to increase the green level. Proposition 1 leads to Corollary 11.

Corollary 11. *The impact of bargaining power on the optimal sharing ratio and the expected utility of the retailer is as follows:*

(1) *When* $\gamma = 0$, $\lambda^* = (b\beta^2 + 24bk\sigma^2\eta_f + 64k\sigma^4\eta_f^2)/(8k(b^2 + 5k\sigma^2\eta_f + 8\sigma^4\eta_f^2))$; *when* $\gamma = 1$, $\lambda^* = 1 - (D - b\beta^2)/(4k(b + 4\sigma^2\eta_f)^2)$, $U(\pi_r) = 0$. $D = \sqrt{b\beta^2[b(\beta^2 + 8bk) + 64k\sigma^2\eta_f(b + 2\sigma^2\eta_f)]}$.

(2) *The range of the optimal sharing ratio is* $(b\beta^2 + 24bk\sigma^2\eta_f + 64k\sigma^4\eta_f^2)/(8k(b^2 + 5k\sigma^2\eta_f + 8\sigma^4\eta_f^2)) \leq \lambda^* < (1 - D - b\beta^2)/(4k(b + 4\sigma^2\eta_f)^2)$.

Corollary 11 shows that when $\gamma = 0$, the minimum and optimal sharing ratio can be obtained, and when $\gamma = 1$, the maximum and optimal sharing ratio can be obtained, which are two extreme cases of the bargaining game between two parties. In the first case, the farmer has no bargaining power, but the retailer has all the bargaining power. In this case, only the maximization of the retailer's interests is considered, and the cost-sharing contract is carried out on the premise of guaranteeing the maximization of the retailer's interests, regardless of whether the farmer's benefits are maximized or not. In the second case, the farmer has full bargaining power, and at this time, the retailer's expected utility is zero, which indicates that the retailer completely transfers their profits to the farmer and shares the green investment cost of the farmer, while the retailer has no profit, and the cost-sharing agreement will not be reached, which does not exist in reality. Therefore, in this case, it is meaningless. Although it can be equal to 1 in theory, the range given in this paper is not equal to 1. It also shows that even if the farmer has full power, the optimal proportion of sharing will not equal 1. It also shows that there is a definite range of the optimal proportion of sharing, which is closely related to the scope of the bargaining power.

The decision-making process of cost sharing is similar to that under the channel structure dominated by the farmer. At the same time, considering that the relevant variables under the cost-sharing contract and cooperative decision are relatively complex and difficult to analyze, this part only compares and analyzes the decentralized decision making of the cost-sharing contract and the channel structure dominated by the farmer and compares it with other channels in the numerical analysis part.

Proposition 12. *The green investment level and the expected utility of the supply chain in the cost-sharing contract have the following relationship compared with the corresponding value in decentralized decision making dominated by the farmer:* $g^{f*} < g^{cb*}$; *if* $\eta_f > ((\sqrt{187} - 11)b)/(8\sigma^2)$, $U(\pi_{sc})^{f*} < U(\pi_{sc})^{cb*}$.

Proof process is in Appendix I Proof 11.

Proposition 12 shows that in the cost-sharing contract, the green investment level under the channel power structure dominated by the farmer is higher than that in the decentralized decision making. In the cost-sharing contract, the retailer shares part of the green investment cost of the farmer, and the green investment cost is borne by both parties, which improves the green investment level of the supply chain as a whole. Consumers prefer products with higher greenness, so the demand increases and the retail price rises, which improves the expected utility of the whole supply chain. In decentralized decision making, the cost of green investment is fully borne by the farmer. That is, in the overall expected income of the supply chain with decentralized decision making and cost-sharing contract, the risk aversion of the farmer has a certain impact on the expected income of both sides.

6. Numerical Analysis

The model presented in this paper is numerically analyzed by using the model optimal algorithm in Section 4. We assume $\alpha = 100, b = 2, \sigma = 1, k = 1, \beta = 0.5, \eta_f = 0.5 - 2.5$, and $\eta_f = 1$ and use *MATLAB*2016 to simulate and analyze the impact of risk aversion, bargaining power, cost investment coefficient, consumer green preference coefficient, and other factors on decision-making variables.

6.1. The Impacts of Bargaining Power and Risk Aversion on the Cost-Sharing Contract. It can be seen from Figure 3 that, in the cost-sharing contract based on the generalized Nash bargaining model, with the improvement of farmer's bargaining power relative to the retailer, the investment cost-sharing ratio by retailer gradually increases. With the increase of bargaining power and risk aversion, the maximum sharing ratio is infinitely close to 1, and the more the risk aversion, the more the cost sharing. It can also be seen from the figure that when the farmer's bargaining power is zero, the retailer is willing to share more than 40% of the investment cost. Moreover, with the improvement of the farmer's risk aversion, under the same bargaining power, the retailer is willing to share more green investment costs. The reason is that the retailer expects the farmer to improve the green investment level to obtain more profits.

6.2. The Impact of Risk Aversion. It can be seen from Figure 4 that the impact of risk aversion factors on the green investment level under the six-channel structures of decentralized decision making and cooperative decision making is different. With the increase of risk aversion factors, the green investment levels decrease, and they are negatively correlated. That is, the more risk-averse the farmer is, the lower

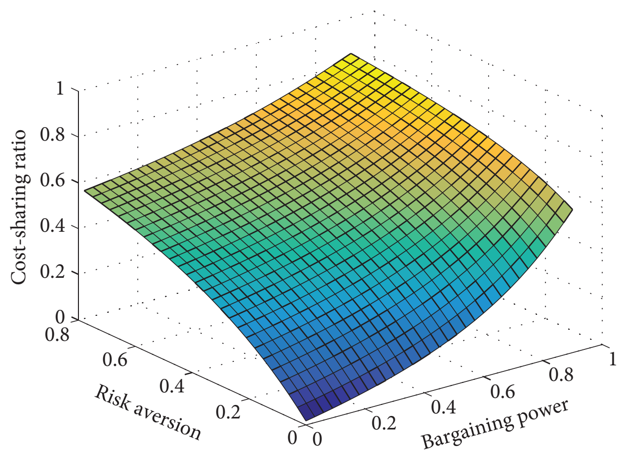

Figure 3: The impacts of risk aversion and bargaining power on cost-sharing ratio.

the green investment level will be. In the cost-sharing contract with bargaining by the two parties, the green investment level of the farmer also increases with the improvement of his risk aversion, which indicates that the contract improves the enthusiasm of the farmer for green investment and plays a significant role. In all cases, the optimal wholesale price and the optimal retail price go down as risk aversion increases. Under the RC channel structure, the retail price is the highest, while under the FC channel structure, the wholesale price is the highest. As risk aversion increases, retail prices in cost-sharing contracts fall the fastest. Therefore, for consumers, the lowest retail price and the highest greenness can be obtained in the cost-sharing contract.

It can be seen from Figure 5 that no matter under which channel power structure with the improvement of risk avoidance, the expected utility of the farmer gradually decreases. However, under the same risk avoidance, the expected utility of the farmer in the cost-sharing contract is the highest, which indicates the validity of the contract. Under various channel power structures, the expected utility of the retailer also increases with the increase of risk aversion of the farmer. Under the same risk aversion, the expected utility under the RC channel power structure is the lowest and that under the RS channel power structure is the highest among the six-channel structures. After joining the cost-sharing contract, the expected utility of the retailer in the cost contract increases with the increase of risk aversion and finally reaches the highest value. The reason is that with the improvement of risk aversion, in the cost-sharing contract, the green investment level is improved, and the profit of the retailer gradually increases. For the whole supply chain, the overall expected utility of the supply chain increases with the improvement of risk aversion. After the risk aversion reaches a certain degree, the overall expected utility of the supply chain with the cost-sharing contract realizes the maximum.

6.3. Impact of Investment Cost Coefficient. It can be seen from Figure 6 that under various channel structures, the green investment level decreases with the increase of the investment cost coefficient. In decentralized decision making, the green investment level under the RS channel power structure is the best, while the FS channel power structure is the lowest. In cooperative decision making, the optimal green investment level is the highest under the NC channel power structure and the lowest under the RC channel power structure. Compared with decentralized decision making, in cooperative decision making, the green investment level under the RC channel power structure shows a trend of decline, while under the other two structures, the green investment level shows a trend of increase. In the cost-sharing contract, when the investment cost coefficient is constant, the green investment level is higher than that under other channel structures, which also proves that the cost-sharing contract effectively improves the green investment level of the supply chain. The optimal wholesale price under the RC channel structure is the lowest, and the wholesale price under the cost-sharing contract is the highest. In the cost-sharing contract, with the increase of the investment cost coefficient, the optimal retail price decreases rapidly, and finally it is lower than the optimal retail price under the RC and RS channel structures.

It can be seen from Figure 7 that the expected utility of both sides decreases with the increase of the investment cost coefficient. In decentralized decision making, with a certain investment cost coefficient, the expected utility of the farmer under the RS channel structure is the lowest and the highest farmer under the FS channel structure. Among the three cooperative decisions, the expected utility of the farmer is the highest under the FC channel structure and the lowest under the RC channel structure. The reason is that the leading power of channels is in the hands of the farmer, who will certainly get the maximum benefits. In the cost-sharing contract, the expected utility of the farmer is maximized. The retailer has the lowest expected utility under the FS channel structure. The cost-sharing contract is consistent with the RC and the RS and is at the highest level. From the perspective of the whole supply chain, the expected utility of the supply chain is the lowest under the NC channel structure and the highest in the cost-sharing contract. The reason is that the cost-sharing contract enables both parties to jointly share the investment cost and improves the green investment level and retail price.

6.4. Impact of Green Preference Coefficient. It can be seen from Figure 8 that, with the increase of consumers' green preference coefficient, the green investment level shows an increasing trend. In decentralized decision making, the green investment level is the highest under the NN channel structure and the lowest under the FS channel structure. In cooperative decision-making, the green investment level under the FC channel structure is the highest, while under the RC channel structure, the green investment level is the lowest. The reason is that in the decentralized decision-making system when both sides have equal channel power, mutual trust is increased. Also, in cooperative decision making, cooperation makes green investment further increase. After joining the cost-sharing contract, the green

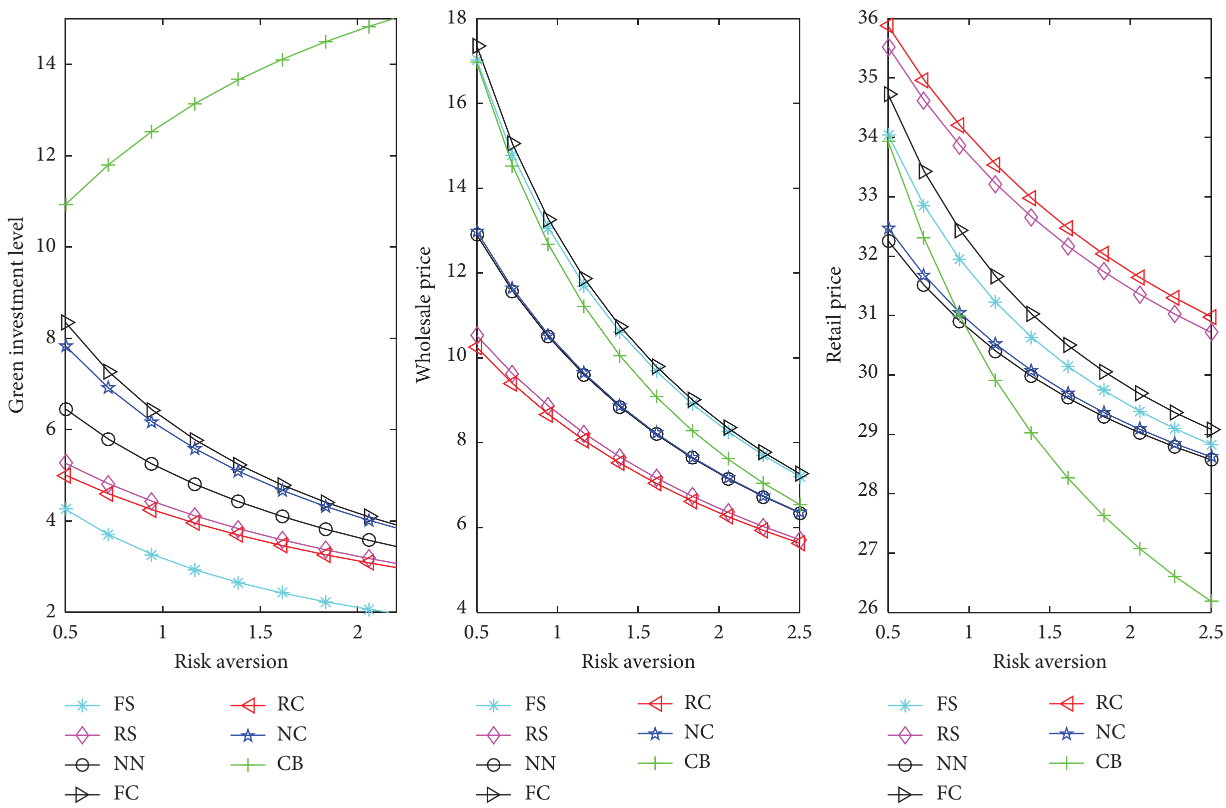

Figure 4: The impacts of risk aversion on optimal green investment level and optimal pricing.

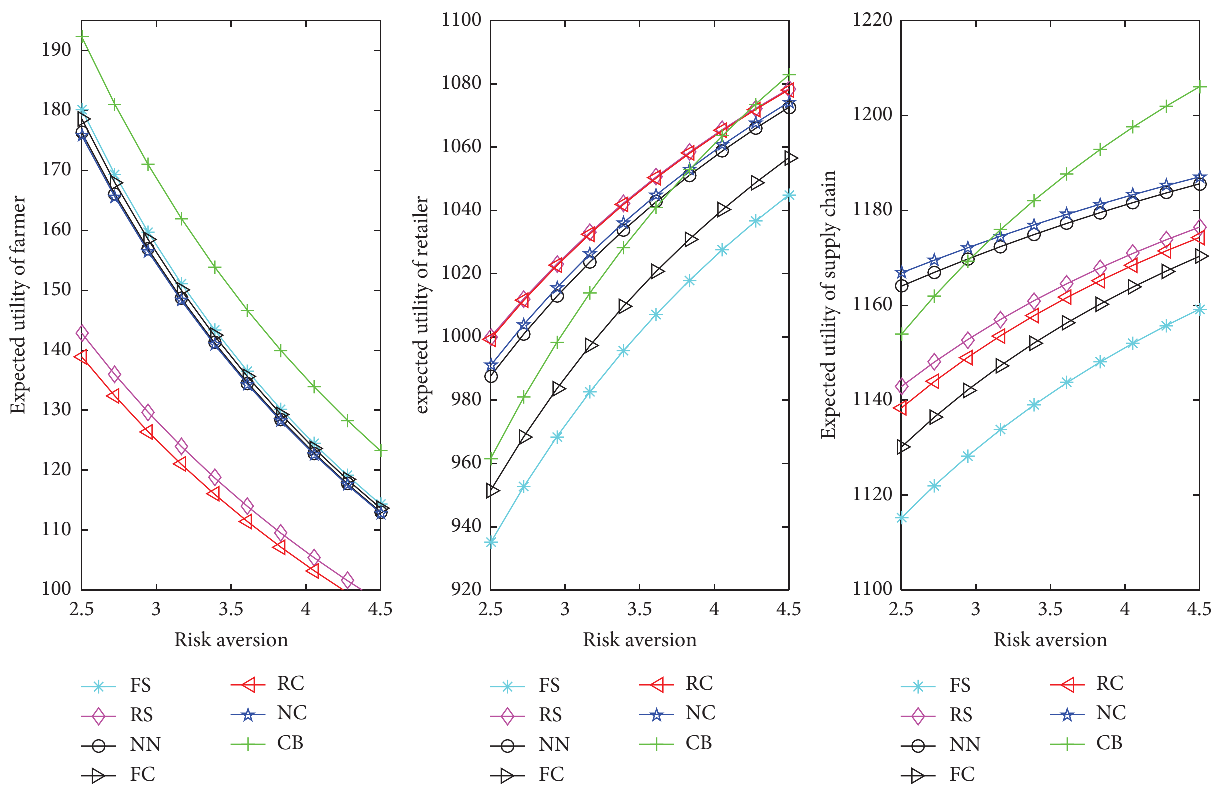

Figure 5: The impacts of risk aversion on optimal expected utility.

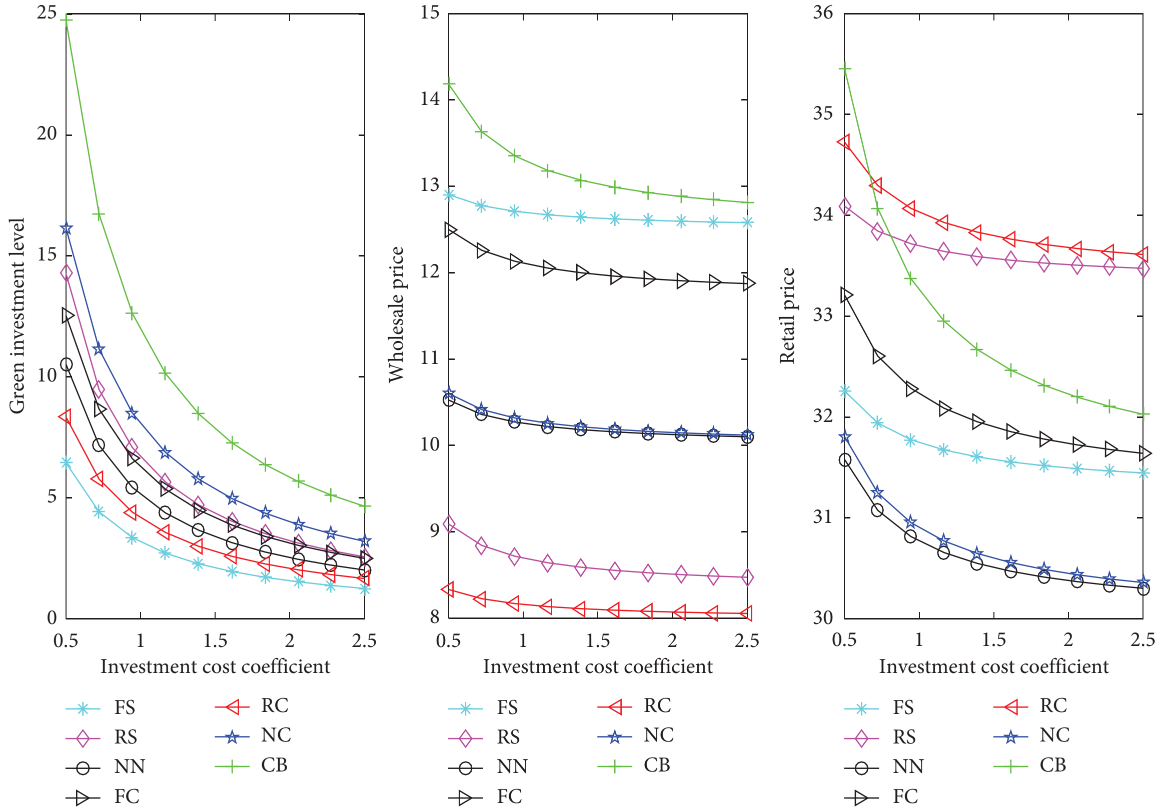

FIGURE 6: The impacts of investment cost coefficient on optimal green investment level and optimal pricing.

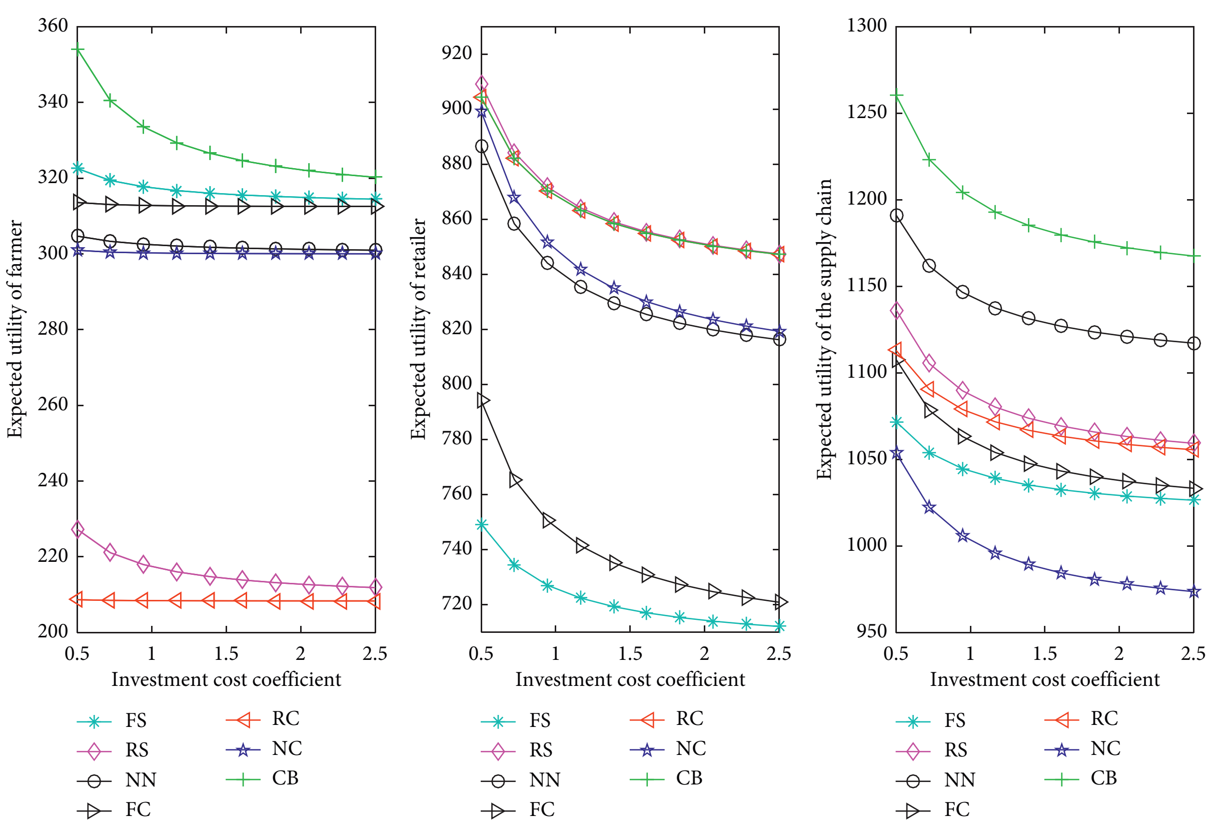

FIGURE 7: The impacts of investment cost coefficient on optimal expected utility.

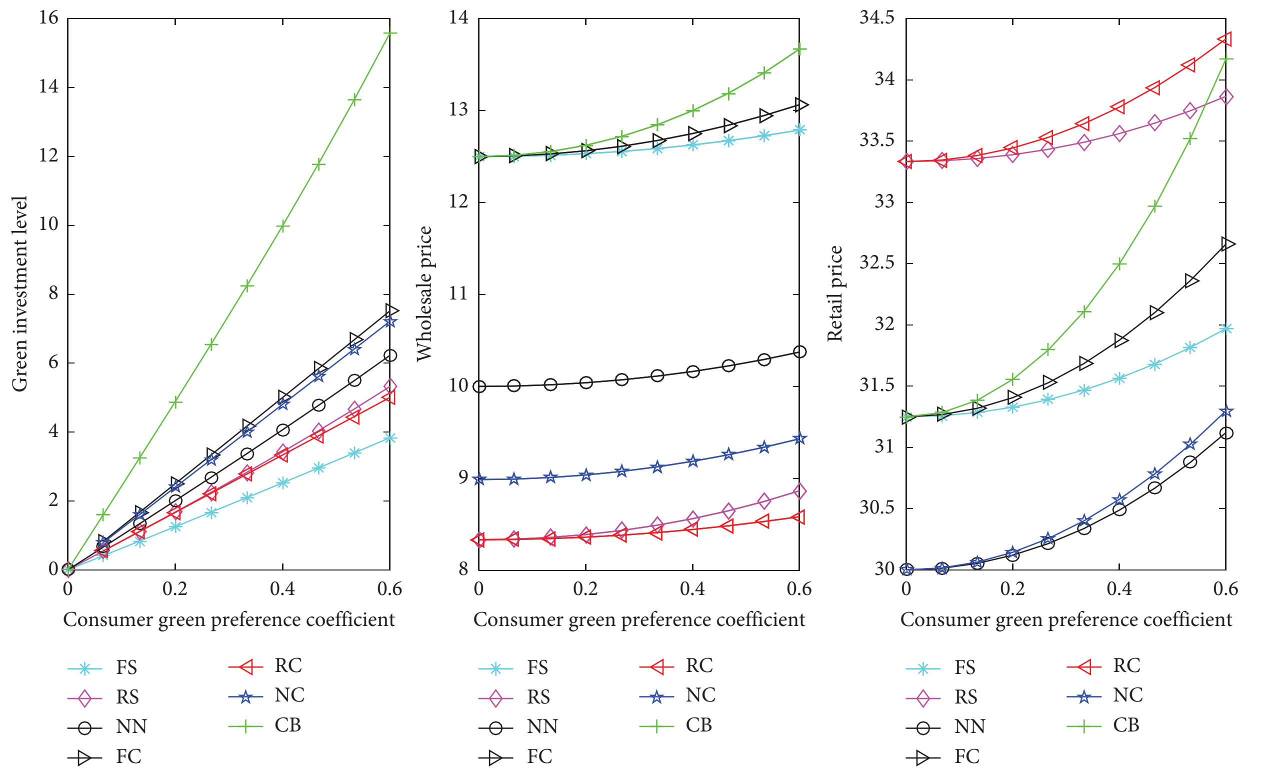

FIGURE 8: The impacts of consumer green preference coefficient on the optimal green investment level and pricing.

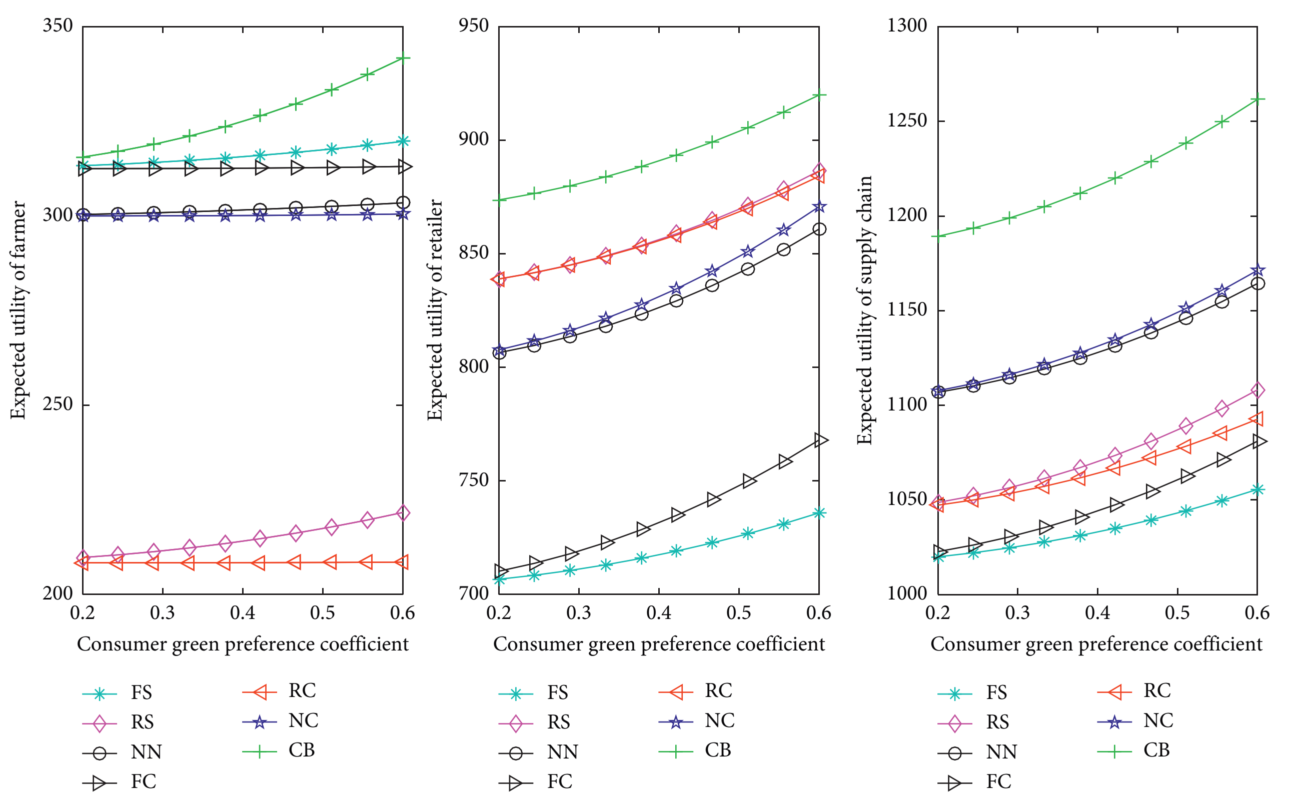

FIGURE 9: The impacts of consumer green preference coefficient on the optimal expected utility.

investment level reaches the highest level because both parties share the investment cost. The wholesale price and retailer price increase with the increase of consumers' green preference coefficient. Both sides can be expected to benefit from increased consumer green preferences. But for consumers, they will pay higher prices. To stabilize the market, the government will subsidize the farmer who makes green investments, as it does in reality. The wholesale price in the cost-sharing contract is higher than that under other channel structures. But the retail price is different, and the retail price in the cost-sharing contract is lower. With the increase of consumers' green preference, the increase of retail price in the cost-sharing contract is higher than that under other channel structures. The cost-sharing contract has significantly improved the green investment level and optimal pricing.

It can be seen from Figure 9 that the expected utility of the farmer and the retailer increases with the increase of the green preference coefficient. In decentralized decision making, the expected utility of the farmer is the highest under the FS channel structure and that of the retailer is the highest under the RS channel structure when consumers' green preference is determined. In cooperative decision making, cooperation weakens the dominant position and reduces the utility of the dominant party. In the cost-sharing contract, the expected utility of the farmer is significantly increased, which is higher than that under other channel structures. The retailer's expected utility is the same. In the cost-sharing contract, the overall expected utility of the supply chain is significantly improved, which indicates that the cost-sharing contract is effective.

7. Conclusions

This study investigated the equilibrium pricing, green investment, and supply chain coordination in a two-echelon supply chain composed of a risk-averse farmer and a risk-neutral retailer. We studied the optimal green investment strategy in three kinds of decentralized decision making and three kinds of cooperative decision making under different channel power structures when the farmer makes the green investment. The cost-sharing contract based on the generalized Nash bargaining model was constructed to coordinate the supply chain. The conclusions are as follows.

In the decentralized decision-making system, the expected utility of the farmer's green investment level and supply chain can be maximized under the NN channel structure, while the expected utility, wholesale price, and marginal contribution of the farmer and retailer can be maximized under FS and RS channel structures, respectively. As for the retail price in decentralized decision making, only when the risk aversion and investment cost coefficient of the farmer meet certain conditions can the retail price be maximized under the FS channel structure, and the corresponding value is followed under the RS channel structure. Under the NN channel power structure, the expected utility of the supply chain is maximized, while under the FS channel structure, the expected utility of the supply chain is minimized. The above findings indicate that the green investment level, the wholesale price, and the retail price decrease with the increase of risk aversion of the farmer, which is negatively related to risk aversion. The expected utility of the farmer decreases with the increase of risk aversion, while that of the retailer is just the opposite. The expected utility of the retailer increases with the increase of risk aversion of the farmer.

Under cooperative decision making, compared with decentralized decision making, except for RC channel structure, the level of green investment and wholesale price of farmers are improved in other channel structures. The marginal contribution and retail price of the retailer increase, while the expected utility of the farmers decreases. In the RC structure, the expected utility of the retailer is also reduced; under the FC and NC modes, the expected utility of the retailer is increased. Under the cooperative decision of FC and NC, the overall expected utility of the supply chain is improved.

In the cost-sharing contract based on the generalized Nash bargaining model, the cost-sharing ratio increases with the increase of the farmer's bargaining power and risk aversion. Different from decentralized decision making and cooperative decision making, the green investment level increases with the increase of risk aversion of the farmer in the cost-sharing contract. Under the same risk aversion, the cost-sharing contract maximizes the green investment level and the expected utility of the farmer. Under certain conditions, the cost-sharing contract can maximize the expected utility of the retailer and the supply chain.

Based on the above works, some valuable managerial insights are obtained as follows. First, retailers and farmers should also strive for the dominant position to pursue the maximization of interests. Consequently, retailers pursuing the optimal green investment level should take the initiative to sign cost-sharing contracts with farmers with greater risk aversion. Second, the government should actively formulate policies to promote cooperation between supply chain members, especially to promote bargaining and establish a cost-sharing mechanism to maximize the green investment level and the benefits of both sides. At the same time, the government should also control the green investment level of the supply chain of agricultural products by increasing rewards and punishments and strengthening supervision. The government should also encourage farmers and retailers to bargain and cooperate by various means and jointly promote the green transformation and upgrading of the agricultural supply chain to realize the unification of economic benefits and social benefits. Last, consumers should have a preference for the agricultural products produced under a bargaining contract, which has the highest green investment level. If there is no bargaining between the two parties, consumers should choose the agricultural products produced under the cooperation system.

Although this study has better management implications, it also has some limitations as follows. First, the model does not address seasonality in agricultural production for the convenience of research. Then, our research uses a cost-sharing contract instead of a revenue-sharing contract or other contracts for supply chain coordination in a risk-reverse supply chain. Many models that reflect the seasonality of agricultural products and coordination strategies can be applied to the risk-averse supply chain. In future research, we can use revenue-sharing contracts or other contracts to coordinate risk-averse supply chains using the Nash bargaining model. We will also use the model that can reflect the seasonality of agricultural production to study the risk-averse supply chain in the future.

Appendix

A. Proof of Proposition 3

$g^{f*} - g^{\mathrm{fc}*} = -(\sqrt{\alpha^2 k(b+2\sigma^2\eta_f)(2\beta^2+\mathrm{bk}+2k\sigma^2\eta_f)} - \alpha k(b+2\sigma^2\eta_f))/(\beta(4\mathrm{bk}+8k\sigma^2\eta_f-\beta^2))$; according to the foregoing, $\beta(4\mathrm{bk}+8k\sigma^2\eta_f-\beta^2)>0$, in which $\sqrt{\alpha^2 k(b+2\sigma^2\eta_f)(2\beta^2+\mathrm{bk}+2k\sigma^2\eta_f)}$ $\alpha k(b+2\sigma^2\eta_f)$ is positive, and their difference of squares is $2\alpha^2\beta^2 k(b+\ 2\sigma^2\eta_f)>0$, so $\sqrt{\alpha^2 k(b+2\sigma^2\eta_f)(2\beta^2+\mathrm{bk}+2k\sigma^2\eta_f)}$ $-\alpha k(b+2\sigma^2\eta_f)>0$, and we can have $g^{f*}-g^{\mathrm{fc}*}<0$, that is, $g^{f*}<g^{\mathrm{fc}*}$. With the same logic, we can get $g^{r*}>g^{\mathrm{rc}*}$, $g^{n*}<g^{\mathrm{nc}*}$, and $g^{n*}>g^{r*}>g^{f*}$; here we omit it for brevity.

$g^{r*}-g^{f*} = (\alpha\beta(\beta^2+4k\sigma^2\eta_f))/(2\ \ (4bk+8k\sigma^2\eta_f-\beta^2)(2bk+2k\sigma^2\eta_f-\beta^2))>0$, that is, $g^{r*}>g^{f*}$.

$g^{n*}-g^{r*} = (\alpha\beta(\mathrm{bk}-\beta^2))/(2(3\mathrm{bk}+4k\ \ \sigma^2\eta_f-\beta^2)(2\mathrm{bk}+2k\sigma^2\eta_f-\beta^2))>0$, that is, $g^{n*}>g^{r*}$, and we have $g^{n*}>g^{r*}>g^{f*}$. Proposition 3 is proved.

B. Proof of Proposition 4

(1) $\omega^{f*}-\omega^{\mathrm{fc}*} = (\alpha k(b+2\sigma^2\eta_f) - \sqrt{\alpha^2 k(b+2\sigma^2\eta_f)(2\beta^2+\mathrm{bk}+2k\sigma^2\eta_f)})/(2(b+2\sigma^2\eta_f)(4\mathrm{bk}+\ 8k\sigma^2\eta_f\ -\beta^2))$, and it is easy to obtain $\alpha k(b+2\sigma^2\eta_f)<\sqrt{\alpha^2 k(b+2\sigma^2\eta_f|(2\beta^2+\mathrm{bk}+2k\sigma^2\eta_f)}$, that is, $\alpha k(b+2\sigma^2\eta_f)-\sqrt{\alpha^2 k(b+2\sigma^2\eta_f)(2\beta^2+\mathrm{bk}+2k\sigma^2\eta_f)}$ <0, and we can have $\omega^{f*}-\omega^{\mathrm{fc}*}<0$; hence, $\omega^{f*}<\omega^{\mathrm{fc}*}$, and in a similar way, $\omega^{r*}>\omega^{\mathrm{rc}*}$, $\omega^{n*}<\omega^{\mathrm{nc}*}$.

(2) $\omega^{n*}-\omega^{r*} = (\alpha k(\mathrm{bk}-\beta^2))/((4\mathrm{bk}+4k\sigma^2\eta_f-2\beta^2)\ (3\ \mathrm{bk}-\beta^2+4k\sigma^2\eta_f))>0$, namely, $\omega^{n*}>\omega^{r*}$. $\omega^{f*}-\ \omega^{n*} = (\alpha k(2\mathrm{bk}-\beta^2))/((4\mathrm{bk}+8k\sigma^2\eta_f-\beta^2)(3bk-\ \beta^2+4\ k\sigma^2\eta_f))>0$; hence, $\omega^{f*}>\omega^{n*}$. To sum up, $\omega^{f*}>\omega^{n*}>\omega^{r*}$. Proposition 4 is proved.

C. Proof of Proposition 5

$m^{f*}-m^{\mathrm{fc}*} = ((b+4\sigma^2\eta_f)[\alpha k(b+2\sigma^2\eta_f) - \sqrt{\alpha^2 k(b+2\sigma^2\eta_f)(2\beta^2+\mathrm{bk}+2k\sigma^2\eta_f)}])/(4b(b+2\sigma^2\eta_f)(-\beta^2+4bk+8k\sigma^2\eta_f))$, and it is easy to verify that $\alpha k(b+2\sigma^2\eta_f)-\sqrt{\alpha^2 k(b+2\sigma^2\eta_f)(2\beta^2+\mathrm{bk}+2k\sigma^2\eta_f)}<0$; then, we can derive $m^{f*}-m^{\mathrm{fc}*}<0$, that is, $m^{f*}<m^{\mathrm{fc}*}$. Likewise, here we omit it for brevity. $m^{r*}-m^{n*} = (\alpha(\mathrm{bk}-\beta^2))/(2b(3\mathrm{bk}+4k\sigma^2\eta_f-\beta^2))>0$, and we can get $m^{r*}>m^{n*}$; $m^{n*}-m^{f*} = (\alpha k(b^2k+2\beta^2\sigma^2\eta_f))/(b(3\mathrm{bk}+4k\sigma^2\eta_f-\beta^2)(4\mathrm{bk}+8\kappa\sigma^2\eta_f-\beta^2))>0$, that is, $m^{n*}>m^{f*}$; to sum up, $m^{r*}>m^{n*}>m^{f*}$. Proposition 5 is proved.

D. Proof of Proposition 6

$$
\begin{aligned}
p^{f*}-p^{fc*} &= \frac{\alpha k\left(3b+4\sigma^2\eta_f\right)}{b\left(4\mathrm{bk}+8k\sigma^2\eta_f-\beta^2\right)} - \frac{\alpha k\left(3b+4\sigma^2\eta_f\right)}{6\mathrm{bk}\left(b+2\sigma^2\eta_f\right)-2\sqrt{k\left(b+2\sigma^2\eta_f\right)\left(2\beta^2+\mathrm{bk}+2k\sigma^2\eta_f\right)}}\\
&= \frac{\alpha k\left(3b+4\sigma^2\eta_f\right)\left[\beta^2+2\mathrm{bk}+4k\sigma^2\eta_f-2\sqrt{k\left(b+2\sigma^2\eta_f\right)\left(2\beta^2+\mathrm{bk}+2k\sigma^2\eta_f\right)}\right]}{\left(4\mathrm{bk}+8k\sigma^2\eta_f-\beta^2\right)\left[6\mathrm{bk}\left(b+2\sigma^2\eta_f\right)-2\sqrt{k\left(b+2\sigma^2\eta_f\right)\left(2\beta^2+\mathrm{bk}+2k\sigma^2\eta_f\right)}\right]},
\end{aligned}
\tag{A.1}
$$

We easily get $\beta^2+2\mathrm{bk}+4k\sigma^2\eta_f<2\sqrt{k(b+2\sigma^2\eta_f)(2\beta^2+\mathrm{bk}+2k\sigma^2\eta_f)}$; therefore, the above formula is less than zero, and we can obtain $p^{f*}>p^{\mathrm{fc}*}$; in the same way, the other two can be proved to be true.

$p^{r*}-p^{n*} = (\alpha(\mathrm{bk}-\beta^2)(\mathrm{bk}+2k\sigma^2\eta_f-\beta^2))/(2b(2\mathrm{bk}\ +\ 2k\sigma^2\eta_f-\beta^2)(3\mathrm{bk}+4k\sigma^2\eta_f-\beta^2))>0$; hence, $p^{r*}>p^{n*}$; $p^{r*}-p^{f*} = (\alpha\ \ (\beta^4-b\beta^2k-2\beta^2k\sigma^2\eta_f+4bk^2\sigma^2\eta_f))/(2b(-\beta^2+2\mathrm{bk}+2k\sigma^2\eta_f)(-\beta^2+4\mathrm{bk}+8\kappa\sigma^2\eta_f))$, and when $\eta_f>1/2\sigma^2$

$(3-2\sqrt{2})b$, $p^{r*} > p^{f*}$; $p^{f*} - p^{n*} = s$, $p^{f*} > p^{n*}$. Proposition 6 is proved.

E. Proof of Proposition 7

$$\begin{aligned} U\left(\pi_f\right)^{f*} - U\left(\pi_f\right)^{fc*} &= \frac{\alpha^2 k}{8\mathrm{bk} + 16k\sigma^2\eta_f - 2\beta^2} - \frac{\alpha^2 k}{4\left[\mathrm{bk} + 2k\sigma^2\eta_f - \beta^2 + \sqrt{k\left(b + 2\sigma^2\eta_f\right)\left(2\beta^2 + \mathrm{bk} + 2k\sigma^2\eta_f\right)}\right]} \\ &= \frac{\alpha^2 k\left[4\sqrt{k\left(b + 2\sigma^2\eta_f\right)\left(2\beta^2 + \mathrm{bk} + 2k\sigma^2\eta_f\right)} - 2\left(\beta^2 + 2\mathrm{bk} + 4k\sigma^2\eta_f\right)\right]}{4\left(8\mathrm{bk} + 16k\sigma^2\eta_f - 2\beta^2\right)\left[\mathrm{bk} + 2k\sigma^2\eta_f - \beta^2 + \sqrt{k\left(b + 2\sigma^2\eta_f\right)\left(2\beta^2 + \mathrm{bk} + 2k\sigma^2\eta_f\right)}\right]}. \end{aligned} \tag{A.2}$$

It is easy to verify that $4\sqrt{k(b + 2\sigma^2\eta_f)(2\beta^2 + \mathrm{bk} + 2k\sigma^2\eta_f)} > 2(\beta^2 + 2\mathrm{bk} + 4k\sigma^2\ \eta_f)$.

So, the above formula is greater than zero, and we can obtain $U(\pi_f)^{f*} > U(\pi_f)^{fc*}$.

The proof is similar to others and is hence omitted. Proposition 7 is proved.

F. Proof of Proposition 8

$$U\left(\pi_r\right)^{f*} - U\left(\pi_r\right)^{\mathrm{fc}*} = \frac{\alpha k\left(b + 4\sigma^2\eta_f\right)^2\left(3b\alpha k + 6\alpha k\sigma^2\eta_f - \alpha\beta^2 - 3\sqrt{\alpha^2 k\left(b + 2\sigma^2\eta_f\right)\left(2\beta^2 + \mathrm{bk} + 2k\sigma^2\eta_f\right)}\right)}{8b\left(b + 2\sigma^2\eta_f\right)\left(\beta^2 - 4\mathrm{bk} - 8k\sigma^2\eta_f\right)^2}. \tag{A.3}$$

It is easy to verify that $(3b\alpha k + 6\alpha k\sigma^2\eta_f - \alpha\beta^2) < 3\sqrt{\alpha^2 k(b + 2\sigma^2\eta_f)(2\beta^2 + \mathrm{bk} + 2k\sigma^2\eta_f)}$.

So, the above formula is greater than zero, and we can obtain $U(\pi_r)^{f*} < U(\pi_r)^{\mathrm{fc}*}$.

The proof is similar to others and is hence omitted. Proposition 8 is proved.

G. Proof of Proposition 9

$$U\left(\pi_{\mathrm{sc}}\right)^{r*} - U\left(\pi_{\mathrm{sc}}\right)^{\mathrm{rc}*} = \frac{\alpha^2 k\left[b\left(5\beta^2 + 8\mathrm{bk}\right) + 4\left(3\beta^2 + 2\mathrm{bk}\right)\sigma^2\eta_f\right]\left[\alpha\left(\beta^2 - 2\mathrm{bk} - 2k\sigma^2\eta_f\right) + 2\sqrt{\alpha^2 k\left(b + \sigma^2\eta_f\right)\left(\beta^2 + \mathrm{bk} + k\sigma^2\eta_f\right)}\right]}{8b\left(2\mathrm{bk} + 2k\sigma^2\eta_f - \beta^2\right)\left(8\mathrm{bk} + 8k\sigma^2\eta_f - \beta^2\right)\left(2b\alpha k + 2\alpha k\sigma^2\eta_f - \alpha\beta^2 + 2\sqrt{\alpha^2 k\left(b + \sigma^2\eta_f\right)\left(\beta^2 + \mathrm{bk} + k\sigma^2\eta_f\right)}\right)}. \tag{A.4}$$

It can be seen that its positive or negative value sign is determined by the molecule, and the molecule is positive after analysis. Therefore, $U(\pi_{\mathrm{sc}})^{r*} > U(\pi_{\mathrm{sc}})^{\mathrm{rc}*}$. For the proof of $U(\pi_{\mathrm{sc}})^{f*} < U(\pi_{\mathrm{sc}})^{fc*}$ and $U(\pi_{\mathrm{sc}})^{n*} < U(\pi_{\mathrm{sc}})^{\mathrm{nc}*}$, because the number of polynomial terms is more complicated, the Reduce function of the Wolfram Mathematica software in this paper is calculated and analyzed; when $k > \beta^2/b$, the above relationship is always established, and if the relationship is changed under the same conditions, it will prompt False, so the above proposition is proved.

$U(\pi_{\mathrm{sc}})^{n*} - U(\pi_{\mathrm{sc}})^{r*} = (\alpha^2 k\ \ (\beta^2 - \mathrm{bk})[b(\beta^2 - 5\mathrm{bk}) - 4(\beta^2 + \mathrm{bk})\ \sigma^2\eta_f])/(8b(\beta^2 - 3bk - 4k\sigma^2\eta_f)^2(2bk + 2k\sigma^2\eta_f - \beta^2)) > 0$; hence, $U(\pi_{\mathrm{sc}})^{n*} > U(\pi_{\mathrm{sc}})^{r*}$, $U(\pi_{\mathrm{sc}})^{f*} - U(\pi_{\mathrm{sc}})^{r*} = \alpha^2 k[b\beta^2(\beta^2 - 8\mathrm{bk}) - 4\sigma^2\eta_f\ (\beta^4 + 6b\beta^2 k + 4b^2k^2 + 16\beta^2 k\sigma^2\eta_f)]/(8b(4\mathrm{bk} + 8k\sigma^2\eta_f - \beta^2)^2\ (2\mathrm{bk} + 2k\sigma^2\eta_f - \beta^2)) < 0$, that is, $U(\pi_{\mathrm{sc}})^{r*} > U(\pi_{\mathrm{sc}})^{f*}$; to sum up, $U(\pi_{\mathrm{sc}})^{n*} > U(\pi_{\mathrm{sc}})^{r*} > U(\pi_{\mathrm{sc}})^{f*}$. Proposition 9 is proved.

H. Proof of Proposition 10

The first derivative of the optimal sharing ratio and the optimal green investment level on risk avoidance and bargaining power were obtained, respectively. For the proof of $(\partial\lambda(\gamma)^*/\partial\gamma) > 0$, $(\partial\lambda(\gamma)^*/\partial\eta_f) > 0$, $(\partial g(\gamma)^*/\partial\eta_f) > 0$, $(\partial g(\gamma)^*/\partial\gamma) > 0$, because the number of polynomial terms is more complicated, similar to Proposition 7, the Reduce function of the software in this paper is calculated and analyzed; when $k > \beta^2/b$, the above relationship is always established, and if the relationship is changed under the same conditions, it will prompt False, so the above proposition is proved. Proposition 10 is proved.

I. Proof of Proposition 12

$$\begin{aligned} g^{f*} - g^{cb*} &= \frac{\alpha\beta}{4bk + 8k\sigma^2\eta_f - \beta^2} - \frac{\alpha\beta\left(5b^2 + 28b\sigma^2\eta_f + 48\sigma^4\eta_f^2\right)}{16\left(2bk - 3\beta^2\right)\sigma^4\eta_f^2 + b\left(8b^2k - 7b\beta^2\right) + 4\sigma^2\eta_f\left(8b\beta^2 - 8b^2k\right) - \left(4\sigma^2\eta_f - 2b\right)\sqrt{\Omega}} \\ &= \frac{2\alpha\beta\left(b + 2\sigma^2\eta_f\right)\left\{\sqrt{\Omega} - \left[b\left(\beta^2 + 6bk\right) + 48k\sigma^2\eta_f\left(b + 2\sigma^2\eta_f\right)\right]\right\}}{\left(4bk + 8k\sigma^2\eta_f - \beta^2\right)\left\{16\sigma^2\eta_f\left[\sigma^2\eta_f\left(2bk - 3\beta^2\right) + 2b\left(\beta^2 - bk\right)\right] + b\left(8b^2k - 7b\beta^2\right) - \left(4\sigma^2\eta_f - 2b\right)\sqrt{\Omega}\right\}}, \end{aligned} \tag{A.5}$$

where $\Omega = b^2\beta^4 + 2b^3\beta^2k + 16b^4k^2 + 8k\sigma^2\eta_f[5b\beta^2 + 8b^2k + 4\sigma^2\eta_f(3\beta^2 + 2bk)]$, and it is easy to verify that $\sqrt{\Omega} < b(\beta^2 + 6bk) + 48k\sigma^2\eta_f(b + 2\sigma^2\eta_f)$; the above formula is less than zero, and we can get $g^{f*} < g^{cb*}$; likewise, when $\eta_f > ((\sqrt{187} - 11)b)/(8\sigma^2)$ and $k > \beta^2/b$, $U(\pi_{sc})^{f*} < U(\pi_{sc})^{cb*}$, so Proposition 12 is proved.

Data Availability

The data used to support the findings of this paper are included within the article (Numerical Analysis section).

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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