



Theory article

Green agricultural product operations strategies considering consumer skepticism under different supply chain modes

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Abstract: Due to changes in consumer perception of green agricultural products over time, consumers may raise skepticism about the greenness of agricultural products, and consumers' skepticism will affect their willingness to purchase green agricultural products. In this paper, we incorporated the greenness reference effect, consumer skepticism, and the type of agricultural products into a two-echelon supply chain consisting of one cooperative and one retailer. We used the differential game theory to analyze the improvement effects of cost sharing contract led by the retailer and members' altruistic behaviors on the supply chain. The results were as follows: First, when the reference effect was highly correlated with the retailer's advertising and protection, restrained the retailer's efforts in advertising and protecting green agricultural products. Second, the retailer was more effective in advertising and protecting credence type green agricultural products than experience type green agricultural products. Third, when the types of agricultural products were different, the optimal decisions of supply chain members affected by the greenness reference effect were also different. The greenness of cooperative's products and the retailer's advertising and protection had an opposite correlation with the impact coefficient of reference greenness on consumer skepticism. Fourth, when the retailer's marginal profit was high, the cost sharing contract could improve the total profits of the supply chain. Fifth, the supply chain members' altruistic behaviors could effectively reduce consumers' skepticism on the greenness of agricultural products and improve the total profits of the supply chain.

Keyword: reference effect; consumer skepticism; agricultural product types; altruistic preference

Mathematics Subject Classification: Primary: 91A80, 90B06; Secondary: 91A10, 91A23

1. Introduction

For China, there are two important tasks to build a strong agricultural country. One is accelerating the comprehensive green transformation of agriculture, and the other is promoting rural ecological revitalization. In order to accelerate the realization of the above goals, the Ministry of Agriculture and Rural Affairs of the People's Republic of China issued the "Guiding Opinions of the Ministry of Agriculture and Rural Affairs on Accelerating the Comprehensive Green Transformation of Agricultural Development and Promoting Rural Ecological Revitalization" on December 24, 2024. The "Opinion" states that it is necessary to accelerate the green and low-carbon transformation of the industrial and supply chains, and to guide farmers, cooperatives, and other members to establish the concept of green development to increase investment in green technologies. Furthermore, it is important to develop a green and low-carbon agricultural industrial chain and accelerate the smooth circulation between agriculture and the secondary and tertiary industries. This can help form a modern composite circular economy industrial system featuring integrated production and sales, and the interconnection of three industries.

In response to the "Opinion", members of the agricultural supply chain have intensified investments in green technologies and product preservation to promote the production and sales of green and organic agricultural products. Tianchang Hehe Ecological Agriculture Professional Cooperative in Anhui Province has reduced the use of fertilizers, improving the greenness of agricultural products. Furthermore, this promoted the use of nano-scale pesticide products, innovated physical pest control technology, and installed moth-killing lamps to protect agricultural products. A total of 80% of the mango orchards in Huaping County Xinmin Mango Planting Professional Cooperative have achieved standardized organic cultivation. This improved mangoes' quality by reducing the use of fertilizers and pesticides and adopting ecological planting techniques. Through the establishment of many large-scale refrigerators, Yonghui Supermarket used advanced refrigeration technology and equipment to maintain a constant low-temperature environment. This helped it achieve the preservation of agricultural products. Moreover, Wal-Mart Supermarket used the modified atmosphere packaging (MAP) technology to control the growth of bacteria by adjusting the atmosphere content in the package. This behavior extended the fresh period of agricultural products. After purchasing agricultural products, Carrefour Supermarket would carry out pre-cooling treatment. Furthermore, they used packaging technologies as the MAP and the plastic wrap to extend the freshness period of agricultural products.

Although the green technology investment and protection by each member in the supply chain can enhance the greenness of agricultural products, consumers may raise skepticism about the greenness of agricultural products due to their changing cognition over time. Under the influence of the consumer reference greenness effect, when the actual greenness of the product purchased by consumers is higher than the reference greenness, there is a high possibility of repurchasing the product. On the contrary, consumers will reduce the demand for the product and shift toward purchasing its substitutes.

There are many types of green agricultural products, and consumers have varying levels of skepticism toward different types. Nelson [1] and Darby et al. [2] classified products into credence goods, experience goods, and search goods. Among them, credence goods refer to products that consumers cannot distinguish the quality and safety even after using them, such as non-Genetically Modified Organism (non-GMO) edible oils and non-GMO soybeans. The authenticity of such product advertising can be verified through some professional methods, but consumers do not have these abilities, and cannot identify them through observation and learning. Experience goods refer to

products that consumers can distinguish their quality after using them, such as fresh fruit and free-range eggs. For such products, consumers can judge the quality of the product by observing its appearance and learning identification methods. Compared to experience goods, consumers have a lower awareness of credence goods. Consumers' skepticism to credence goods will also be higher than that to experience goods.

In order to reduce consumer skepticism and increase supply chain profit, supply chain members need to improve the quality and reputation of green agricultural products. The cooperative needs to improve the quality of its green agricultural products, and the retailer needs to enhance the advertising and protection of its products to increase sales. However, the improvement of green agricultural products' quality often leads to an increase in cost. Compared to retailers, cooperatives need to invest a large amount of funds in land consolidation, infrastructure construction, and green technologies. These behaviors also make cooperatives face greater cost pressures. The Tiankai Rice Industry Professional Cooperative in Nankang District, Ganzhou City has invested in new types of agricultural products, pest control, and organic certification, which has resulted in higher production costs. Moreover, the Dingxi Qiaohua Agricultural Machinery Farmers Professional Cooperative provide multiple services, including agricultural machinery operation and technical guidance, which has led to an increase in labor and equipment costs and a relatively high production cost. Although the Xiangpeng Family Farm in Hushu Town, Jiangning District has achieved a high level of mechanization, it relies on manual operation in the rice transplanting process, resulting in high labor costs. It can be seen that cooperatives are facing a wide variety of cost pressures, and these cost pressures will dampen the enthusiasm of cooperatives to improve the greenness of agricultural products, leading to a decline in the greenness of agricultural products and an increase in consumer skepticism.

To advance rural revitalization, the Chinese government has implemented a paired assistance strategy targeting rural areas. In this background, many enterprises have also launched paired assistance and agricultural aid actions to help agricultural producers reduce production costs. Shanghai Hema Network Technology Co., Ltd. provided paired assistance to Daizhuang Village. It developed the "agriculture + digitalization" pattern to open the local sales channels for agricultural products. The "One Hundred Counties, One Hundred Products" project launched by Ant Group Co., Ltd. focuses on underdeveloped regions. It has assisted the sales of agricultural products in Yijun County, Qixian County and other areas. China Yizhong Group Co., Ltd. Provided paired assistance to Sixian County. It utilized its subsidiary agricultural machinery company to cooperate with Sixian County in the development of high-end agricultural machinery equipment. It also built an agricultural product sales network through e-commerce sales, internal subscriptions, and offline exhibitions. These paired assistance behaviors demonstrate an altruistic social preference. Enterprises will consider their own profits and others' profits.

Based on the above phenomena, we mostly address the following questions and issues: (1) How does the greenness reference effect affect consumer skepticism and supply chain profit? (2) Whether the retailer's advertising and protection strategies have differences when it faces different types of products like credence goods and experience goods. (3) Whether the cost sharing contract led by the retailer can improve supply chain profits and achieve Pareto improvement. (4) Whether altruistic behaviors of supply chain members can reduce consumer skepticism and improve supply chain profits. Therefore, we consider a two-echelon supply chain consisting of one cooperative and one retailer, incorporating the greenness reference effect, consumer skepticism, and two types of agricultural products. By constructing a differential game model between the cooperative and the retailer, we get the equilibrium strategies of the cooperative and the retailer under four different

supply chain modes: centralized mode (mode C), decentralized mode (mode N), cost sharing mode (mode Y), and altruistic preferences mode (mode A). We have found the following core findings: (1) The impact of greenness reference effect on supply chain decision-making varies by product type. This discovery reveals the interaction mechanism between reference effects and product types, which is an important supplement to Zhou and Duan [3] and He et al. [4]. (2) The Pareto improvement of the cost sharing contract needs to meet boundary conditions. This finding differs from the conclusions of Liu et al. [5] and Shen [6] that the cost sharing contract are always beneficial. (3) In the long term, altruistic preferences can increase supply chain profits, but the effect varies depending on the type of product. This finding extends the conclusion of Wang et al. [7] that altruistic preferences harm short-term profits. (4) Experience goods have better performances than credence goods in terms of consumer skepticism and supply chain profits. This finding extends the static classification of Nelson [1] and Darby and Karni [2] to a dynamic framework.

The rest of this paper is organized as follows: In Section 2, we review and analyze relevant literature. In Section 3, we describe the problem and hypothesis and construct profit functions of supply chain members under four modes. In Section 4, we compare and analyze the decision variables of supply chain members under four modes. In Section 5, we conduct numerical analysis. In Section 6, we draw research conclusions. In Section 7, we provide corresponding management measures.

2. Literature review

The green agricultural supply chain has always received attention and research from scholars. In terms of supply chain contracts, Ji et al. [8] incorporated the revenue sharing contract into a two-echelon supply chain composed of one manufacturer and one retailer, discussing the improvement of carbon emissions by members of the green agricultural supply chain through profit sharing contracts. Liu et al. [5] considered the improvement effects of the revenue sharing contract and the cost sharing contract on the green agricultural supply chain simultaneously. They found that under the cost sharing contract, increasing product green standards may reduce supply chain profits. To solve the issue of reduced profits, Shen [6] incorporated two cost sharing contracts into the green agricultural product supply chain. The result showed that although two cost sharing contracts cannot achieve a win-win situation, they can improve the greenness of products and the profitability of the supply chain. In terms of competition among supply chain members, Sharma and Jain [9] considered a green agricultural product supply chain dominated by a single agricultural manufacturer without competition. They studied whether the level of attention paid by supply chain members to fairness affected their own and the total profitability of the supply chain. Xi and Zhang [10] considered the scenario of two agricultural manufacturers competing with each other. The result showed that compared with adjusting fertilizer levels and emission reduction efforts, adjusting production has a more significant impact on expected returns. In terms of the supply chain members' rationality level, Cao et al. [11] assumed that members of the green agricultural supply chain made decisions in a rational manner. The study showed that when low green standards are found, the cooperative and enterprise will increase their green investment. Yan et al. [12] considered the irrational behavior of supply chain members and introduced fairness concern behavior into the green agricultural product supply chain. They found that the fairness concern behavior of supply chain members reduces the total efficiency of the supply chain. Jiang et al. [13] considered the fairness concern behavior of the supermarket and believed that fairness concern behavior changed the decision-making of all supply chain members and supermarket's choices to logistics modes.

In the operation of the green agricultural product supply chain, the transaction behavior between retailers and consumers is an important part of it. In this part, retailers will advertise their products, but the authenticity of the advertising can be recognized by only consumers. Due to changes in consumer perception of green agricultural products over time, consumers may have doubts about the retailer's advertising. In terms of the influencing factors of consumer skepticism, Thomas and Kureshi [14] analyzed the impact of marketing on consumer skepticism from the perspective of enterprises. Moreno and Kang [15] studied the impact of corporate social responsibility (CSR) activities in the marketing process on consumer skepticism. They found that the alignment between a company's core values and its CSR activities play an important role in alleviating consumer skepticism. Cho et al. [16] believed that the level of consumer skepticism to products can also be influenced by green product labels. Thus, they analyzed the level and reasons for these influences through field research and online experiments. The study revealed that consumers with high product skepticism are more influenced by green product labels. In terms of the sources of consumer skepticism, Farooq and Wicaksono [17] conducted a study on the factors that trigger consumer skepticism behavior. It was found that consumers' skepticism about the authenticity of green product advertising mainly come from the "greenwashing" incidents of enterprises. The negative information brought by "greenwashing" incidents will continue over time, affecting future consumer attitudes. Additionally, changes in enterprises' advertising strategy can lead to changes in consumer skepticism. Li and Ding [18] used game theory to study the risk of "greenwashing" in media disclosures. They discovered that media disclosure of "greenwashing" incidents by companies can lead to a decline in their profits. Liu and Shankar [19] studied the impact of product recalls on consumer brand preferences. The study showed that consumer skepticism of a brand has a temporal persistence and will dynamically change over time.

As the frequency of consumption increases, consumers will form reference values for products based on information such as enterprise's advertisement and past purchasing experiences. The research on reference effects mostly focuses on price reference effects and quality reference effects. In terms of price reference effect, Chen et al. [20] introduced the price reference effect into a dynamic pricing model within a finite time frame and derived the optimal pricing strategy for different scenarios. Wang [21] incorporated the price reference effect into the consumer choice model. He believed this method can significantly improve the match and prediction accuracy of consumer choice. Based on other studies, Den and Keskin [22] analyzed the dynamic pricing problem of merchants under demand learning and reference price effects. They analyzed the reference effect's impact on the complexity of dynamic pricing when the reference price was fixed. In terms of the quality reference effect, He et al. [4] integrated the reference quality effect into a dual channel supply chain and constructed a differential game model to obtain the equilibrium strategies of channel members. Qiu et al. [23] used the wholesale price contract and the cost sharing contract to coordinate dual channel supply chains based on other studies. They found that the cost sharing contract can improve supply chain efficiency. In addition, some scholars have considered other reference effects. Zhou and Duan [3] considered that consumers had greenness reference effects and environmental awareness. They studied the retailer's choices of sales modes. The research revealed that as consumers' greenness reference effect and environmental awareness increase, the retailer tends to be more inclined to agency sales. Compared to the price reference effect and quality reference effect, there is relatively less literature on the greenness reference effects.

Considering the complexity of the types of green agricultural products, consumers' level of skepticism to different product types may vary. Nelson [1] and Darby et al. [2] classified products into credence goods, experience goods, and search goods. The research on product types mainly

focused on credence goods, and the research content mainly included consumers' consumption choices when facing credence goods and discriminatory pricing behavior in the credence goods market. Costanigro and Onozaka [24] established a belief preference model for credence goods and experience goods. They believed this model can predict product quality to adjust consumer choices. Kerschbamer et al. [25] investigated whether consumers in the credence goods market can benefit themselves by searching for product information that meets their needs. The research revealed that consumers who excessively disclose their own needs pay higher average prices. Consumers reading online reviews can find sellers with more acceptable quality and price. Hall and Kerschbamer [26] studied discriminatory markups in the consumer market for credence goods. The result showed that minority groups pay discriminatory premiums for credence goods, while businesses use the characteristics of credence goods to cover up the increase of discriminatory markups.

In order to meet consumers' expectations for the quality of green agricultural products and reduce their skepticism about the products, supply chain members may show an altruistic social preference. Such preference is to simultaneously focus on profits and improve each other's production or advertising enthusiasm. In terms of the members that generate altruistic behavior, Wang et al. [27] considered a two-echelon supply chain consisting of one e-commerce platform with altruistic preferences and one manufacturer. They studied the impact of platform altruistic preferences on the supply chain members' decision-making. The research revealed that although altruistic behavior on the platform may harm its own profits, it can increase the profits of the manufacturer and the total profits of the supply chain. Wang et al. [7] considered a low-carbon supply chain consisting of one retailer and one small and medium-sized manufacturer, where the retailer has altruistic preferences. The retailer decides on the cost sharing ratio and unit profits at the same time as the leader. The research showed that altruistic behaviors of the retailer can help improve the profits and system efficiency of small and medium-sized manufacturer, but it can harm the retailer's profits. Wang et al. [28] considered the situation where the manufacturer and the retailer have altruistic preferences. They found that members' altruistic preferences enhance their abilities to adopt low-carbon technologies. Some scholars also considered the altruistic behavior of supply chain members and the coordinating role of supply chain contracts. Zhu et al. [29] used a Stackelberg game model to study the impact of altruistic preference behaviors on supply chain carbon reduction in e-commerce platforms. They also analyzed the improvement of the cost sharing contract on supply chain. They discovered that the cost sharing contract with altruistic preferences can improve the carbon reduction level of the supply chain. Yu et al. [30] considered the supply chain members' altruistic behaviors and the coordinating effect of the revenue sharing contract on the supply chain. It was found that when supply chain members exhibit altruistic behaviors, the revenue sharing contract has a coordinating and improving effect on the supply chain.

Through the organization and analysis of the above literature, it can be concluded that studies on the supply chain of green agricultural products mostly focus on the coordination and improvement effects of contracts such as cost sharing and revenue sharing on the supply chain. Few scholars considered the impact of consumer behavior and different types of agricultural products on supply chain members' decision-making and supply chain profits. There are researchers focusing on the factors influencing consumer skepticism, but there is limited literature on how consumer skepticism affects supply chain member decisions and supply chain profits. Moreover, researchers studying product types mainly focus on consumer choices and discriminatory pricing by enterprises in the credence goods market, and few studies entail the impact of different agricultural product types on supply chain members' decisions. In addition, the above literature did not involve the changes in

retailers' advertising strategies when facing consumer skepticism and different types of agricultural products.

Therefore, based on considering consumer skepticism, we incorporate the greenness reference effect and different types of agricultural products into the two-echelon supply chain composed of one cooperative and one retailer. We compare the decision-making and supply chain profits of supply chain members under several modes. Moreover, this study is a reference for the mode selection of supply chain members.

3. Model construction

3.1. Problem description and hypothesis

We take the two-echelon supply chain composed of one cooperative and one retailer as the research object. Among them, the cooperative produces green agricultural products, and the retailer purchases the green agricultural products from the cooperative and sells them to consumers. Consumers lack knowledge about agricultural products, so they may raise skepticism about the greenness of such products. Therefore, the retailer needs to advertise the knowledge of green agricultural products. During the sales period, the retailer also needs to provide good storage and preservation for agricultural products. These efforts will help reduce consumer skepticism and make consumers accept the products. Consumer skepticism is a dynamic element. It gradually changes with the retailer's advertising and consumers' consumption experience. The cooperative can improve the greenness of agricultural products by updating technology and changing production processes. The retailer can do some advertising explanations and protections for green agricultural products. These behaviors can reduce consumer skepticism. For the purpose of research, the following assumptions are made:

Assumption 1 According to the research by Farooq and Wicaksono [17], the level of consumer skepticism $z(t)$ at time t is a dynamic variable. It is influenced by the greenness of the cooperative's products, the level of the retailer's green advertising and protection, and the initial level of consumer skepticism. When the greenness of the cooperative's products, the level of the retailer's green advertising and protection become higher, the consumer skepticism decreases. We set $z(0) = z_0$, so the dynamic change model of $z(t)$ is shown in Equation (1).

$$\dot{z}(t) = (\alpha - \xi)z(t) - \gamma(g(t) - G(t)) - \beta s(t). \quad (1)$$

Among them, $\dot{z}(t)$ is the rate of change in consumer skepticism, and $\ddot{z}(t)$ denotes the instantaneous rate of change of consumer skepticism at time t . In the continuous-time framework, the evolution of skepticism is governed by this differential equation: The current level of skepticism adjusts continuously based on the gap between actual and reference greenness, the retailer's advertising effort, and the natural decay of skepticism. The trajectory $z(t)$ is obtained by integrating Equation (1) forward in time, reflecting the cumulative effect of past decisions and exogenous factors. $g(t)$ is the actual greenness of the product at time t , and $G(t)$ is the reference greenness. When $g(t) > G(t)$, the change rate of consumer skepticism decreases. Conversely, it increases. $s(t)$ is the retailer's efforts in green advertising and protection of the product at time t . α is the coefficient of consumer skepticism that already existed, β is the impact coefficient of the retailer's green advertising and protection efforts on consumer skepticism, ξ is the attenuation

coefficient of consumer skepticism with cognition, and γ is the impact coefficient of reference greenness on consumer skepticism. According to the research by Hellofs et al. [31], we assume that there is a correlation between the consumer reference greenness $G(t)$ and the retailer's efforts in green advertising and protection $s(t)$. According to the research by Sahni and Nair [32], advertising can significantly enhance consumers' expectations and evaluations of advertised products. Thus, we assume that when the retailer's efforts in advertising and protection become higher, consumers' psychological expectation to the greenness of products also become higher. We set $G(t) = \varphi s(t)$. φ is the correlation coefficient between the reference greenness and the efforts in green advertising and protection. Equation (1) can be expressed as follows:

$$\dot{z}(t) = (\alpha - \xi)z(t) - \gamma g(t) - \delta s(t). \quad (2)$$

We let the coefficient $\delta = \beta - \gamma\varphi$.

Assumption 2 The demand function is $D(t) = \theta(g(t) - G(t)) + \eta s(t) - \sigma z(t)$. Among them, θ is the impact coefficient of reference greenness on demand, σ is the impact coefficient of consumer skepticism on demand, and η is the impact coefficient of green advertising and protection on demand.

Assumption 3 When consumers can distinguish the authenticity of green products' advertising and are satisfied with the product quality, their skepticism will be a negative value. When consumer skepticism is a negative value, consumers will recommend the product to others. When the consumer skepticism is negative, it indicates that the consumer has developed trust in the advertising of products. The level of consumer skepticism characterizes only the level of trust consumers have with the product or its advertising and cannot reflect the level of consumer satisfaction with the product.

Assumption 4 Consumers have skepticism about products. When consumers' cognition of the product increases, the level of skepticism will decrease. In the credence goods market, consumers are unable to confirm the authenticity of the retailer's advertising of green products, and their skepticism will increase over time. We let $\alpha > \xi$ depict the credence goods market. In the experience goods market, consumers can identify the authenticity of green product advertising through learning and past purchasing experience. As such, consumer skepticism will decrease over time. We let $\alpha < \xi$ depict the experience goods market.

Assumption 5 The retailer's green advertising and protection cost are a positive growth function of advertising and protection. The second derivative is greater than 0, $C_R''(s) > 0$. Therefore, we assume the cost of green advertising and protection efforts is $C_R = \frac{1}{2}k_R s^2(t)$, where k_R is the retailer's cost coefficient of green advertising and protection efforts.

Assumption 6 The cooperative's cost of green agricultural products is $C_G = \frac{1}{2}k_M g^2(t)$, where k_M is the cooperative's green cost coefficient. The retailer shares some of the green agricultural products' costs for the cooperative, and the sharing ratio is $\psi(t)$. Thus, the cost of green agricultural products shared by the retailer is $C_{RG} = \frac{1}{2}\psi(t)k_M g^2(t)$. After the retailer shares some of the green agricultural products' costs, the cooperative's cost of green agricultural products is $C_{MG} = \frac{1}{2}[1 - \psi(t)]k_M g^2(t)$.

Assumption 7 The cooperative and the retailer have the same discount factor ρ and $\rho > 0$. Both pursue maximum self-profits within an infinite range.

Assumption 8 Let the cooperative's marginal profit be π_M , and the retailer's marginal profit be π_R .

3.2. Model construction and solution

3.2.1. Centralized mode (mode C)

Under centralized mode, we assume there are decision-makers with the goal of maximizing supply chain profits. Their decision variables are $g(t)$ and $s(t)$. The retailer increases the demand for agricultural products by increasing green advertising and protection efforts. The cooperative improves the greenness of agricultural products through technological or process transformation. They cooperate with each other and reduce consumers' skepticism to green supply chain and their agricultural products. Moreover, they pursue the maximization of total profits. The superscript C is used to represent the centralized mode. According to assumption 7, we use the discount factor ρ to discount the profits of the supply chain over infinite time zones. The total profit's function is continuously bounded and differentiable. The optimal control problem of the supply chain can be obtained as follows:

$$J_{MR}^C(z, t) = \max_{s, g} \int_0^{\infty} e^{-\rho t} \left\{ (\pi_M + \pi_R) [\theta(g - \varphi s) + \eta s - \sigma z] - \frac{1}{2} k_R s^2 - \frac{1}{2} k_M g^2 \right\} dt. \quad (3)$$

By solving the Hamilton-Jacobi-Bellman equation (HJB equation), the feedback equilibrium strategy of the problem can be obtained. Due to the complexity of solving dynamic parameters, it is assumed that all parameters in the model are constants and independent of time. For the convenience of writing, the following text will not list the time.

Proposition 1 The equilibrium results under the centralized mode are as follows:

(1) The optimal trajectory for consumer skepticism that changes over time is

$$z^{C^*}(t) = \left(z_0 - \frac{A^C + B^C}{\alpha - \xi} \right) e^{(\alpha - \xi)t} + \frac{A^C + B^C}{\alpha - \xi}. \quad (4)$$

When $\alpha < \xi$, the optimal trajectory for consumer skepticism tends to stabilize over time, reaching a steady state value $z_{\infty}^{C^*} = \frac{A^C + B^C}{\alpha - \xi}$.

We let

$$A^C = \frac{\gamma(\pi_M + \pi_R)[\theta(\alpha - \xi - \rho) - \gamma\sigma]}{k_M(\alpha - \xi - \rho)}, \quad B^C = \frac{\delta(\pi_M + \pi_R)[(\eta - \theta\varphi)(\alpha - \xi - \rho) - \delta\sigma]}{k_R(\alpha - \xi - \rho)}.$$

(2) The optimal equilibrium strategies for the cooperative's greenness of agricultural products and the retailer's green advertising and protection efforts in the supply chain are

$$g^{C^*} = \frac{(\pi_M + \pi_R)[\theta(\alpha - \xi - \rho) - \gamma\sigma]}{k_M(\alpha - \xi - \rho)}, \quad (5)$$

$$s^{C^*} = \frac{(\pi_M + \pi_R)[(\eta - \theta\varphi)(\alpha - \xi - \rho) - \delta\sigma]}{k_R(\alpha - \xi - \rho)}. \quad (6)$$

(3) The optimal function for the total profits of the supply chain is

$$V_{MR}^C(z) = f_1^* z + f_2^*. \quad (7)$$

We let

$$f_1^* = \frac{\sigma(\pi_M + \pi_R)}{\alpha - \xi - \rho}, \quad f_2^* = \frac{(\pi_M + \pi_R)^2 [k_M((\eta - \theta\varphi)(\alpha - \xi - \rho) - \delta\sigma)^2 + k_R(\theta(\alpha - \xi - \rho) - \gamma\sigma)^2]}{2(\alpha - \xi - \rho)^2 \rho k_M k_R}.$$

Proof about proposition 1 can be seen in the appendix.

Corollary 1 (1) When $\alpha < \xi$, there exists $\frac{\partial g^c}{\partial \gamma} > 0$, $\frac{\partial s^c}{\partial \gamma} < 0$. When $\xi < \alpha < \xi + \rho$, there exists $\frac{\partial g^c}{\partial \gamma} > 0$, $\frac{\partial s^c}{\partial \gamma} < 0$.

(2) When $\alpha > \xi + \rho$, there exists $\frac{\partial g^c}{\partial \gamma} < 0$, $\frac{\partial s^c}{\partial \gamma} > 0$.

When $\alpha < \xi$, it means in the experience goods market. As the coefficient γ increases, the actual greenness of the cooperative's agricultural products becomes higher, and the retailer's green advertising and protection efforts become lower. In order to meet consumers' expectations for its agricultural products, the cooperative will choose to increase its investment in green agricultural products and can improve the actual greenness of its products. Since consumers can identify the authenticity of the retailer's advertising for experience products, the retailer is unwilling to let consumers have high psychological expectations of the products. This leads to the retailer appropriately reducing its efforts in green advertising and protection.

When $\xi < \alpha < \xi + \rho$, it means the credence goods market. Due to the small gap between the consumer's own skepticism and the level of cognitive decline during this stage, it can be seen as a transitional stage. In the credence goods market at this stage, the impact of the greenness reference effect coefficient on the decision-making of supply chain members is consistent with that of the experience goods market. We define this type of credence goods as the first type of credence goods. In the subsequent corollary, we will analyze this type of credence goods with experience goods.

When $\alpha > \xi + \rho$, it means the credence goods market. As the coefficient γ increases, the actual greenness of the cooperative's agricultural products becomes lower, and the retailer's green advertising and protection efforts become higher. This result is contrary to the experience goods market. Consumers are unable to identify this type of products' green advertising through any means, so they always have skepticism about this type of product. Excessive consumer skepticism will restrain the cooperative's enthusiasm to improve the greenness of its products. Therefore, even if the reference greenness has a significant impact on consumer skepticism, the cooperative will not choose to increase the greenness of agricultural products. The retailer will take advantage of consumers' insufficient understanding of products to increase its advertising efforts to attract more consumers. We define this type of credence goods as the second type of credence goods.

Corollary 2 (1) When $\alpha < \xi + \rho$ and $\frac{\gamma(\pi_M + \pi_R)}{k_M} > \frac{\delta(\pi_M + \pi_R)\varphi}{k_R}$, there exists $\frac{\partial g^c}{\partial \theta} > 0$, $\frac{\partial s^c}{\partial \theta} < 0$, $\frac{\partial z_\infty^c}{\partial \theta} < 0$, $\frac{\partial D_\infty^c}{\partial \theta} > 0$.

(2) When $\alpha > \xi + \rho$ and $\frac{\gamma(\pi_M + \pi_R)}{k_M} < \frac{\delta(\pi_M + \pi_R)\varphi}{k_R}$, there exists $\frac{\partial g^c}{\partial \theta} > 0$, $\frac{\partial s^c}{\partial \theta} < 0$, $\frac{\partial z^c}{\partial \theta} > 0$, $\frac{\partial D^c}{\partial \theta} < 0$.

Corollary 2 indicates that, in the experience and first type credence goods market, as coefficient θ increases, the actual greenness of the cooperative's agricultural products becomes higher, and the retailer's green advertising and protection efforts become lower. The cooperative chooses to increase its investment in green agricultural products to ensure stable demand. This behavior will improve the actual greenness of agricultural products and reduce consumer skepticism. Consistent with Corollary 1, the retailer is unwilling to let consumers have excessively high psychological expectations of its products. Thus, it will appropriately reduce its efforts in green advertising and protection.

In the second type of credence goods market, as the coefficient θ increases, the actual greenness of the cooperative's agricultural products becomes higher, and the retailer's green advertising and protection efforts become lower. Changes in members' decisions are consistent with those in the experience goods market. However, due to the characteristic of credence goods, there has been an increase in consumer skepticism and a decrease in market demand.

Corollary 3 (1) When $\alpha < \xi + \rho$, there exists $\frac{\partial g^C}{\partial \varphi} = 0$, $\frac{\partial s^C}{\partial \varphi} < 0$.

(2) When $\alpha > \xi + \rho$ and $\frac{\gamma\sigma}{k_R(\alpha - \xi - \rho)} > \frac{\theta}{k_R}$, there exists $\frac{\partial g^C}{\partial \varphi} = 0$, $\frac{\partial s^C}{\partial \varphi} > 0$.

In the experience goods and first type credence goods market, as the correlation coefficient φ increases, the retailer's green advertising and protection efforts become lower. When the correlation between reference greenness and retailer's advertising is high, consumers' psychological expectations of products depend on the retailer's advertising level. In order to weaken expectations, the retailer will choose to reduce its efforts in green advertising and protection. The cooperative's green investment is not related to the correlation coefficient.

In the second type of credence goods market, as the correlation coefficient φ increases, the retailer's green advertising and protection efforts become higher. Due to the characteristic of credence goods, consumers are unable to distinguish the authenticity of the retailer's advertising. When the reference greenness is highly correlated with the retailer's advertising, it may take advantage of consumers' dependence on advertising. The retailer will improve its efforts in green advertising and protection to attract consumers. Consistent with the experience goods market, the cooperative's green investment is not related to the correlation coefficient.

3.2.2. Decentralized mode (mode N)

In this section, we use superscripts N to represent decentralized mode. The cooperative and the retailer are independent of each other. They have the same status, each choosing the decision that maximize their own interests. Under this mode, the optimal value of profits for each party is obtained. The supply chain members' profits functions satisfy all $z > 0$ and are continuously bounded and differentiable. In this scenario, the optimal control problems of the cooperative and the retailer are as follows:

$$J_M^N = \max_g \int_0^\infty e^{-\rho t} \left\{ \pi_M [\theta(g - \varphi s) + \eta s - \sigma z] - \frac{1}{2} k_M g^2 \right\} dt, \quad (8)$$

$$J_R^N = \max_s \int_0^\infty e^{-\rho t} \left\{ \pi_R [\theta(g - \varphi s) + \eta s - \sigma z] - \frac{1}{2} k_R s^2 \right\} dt. \quad (9)$$

To obtain feedback equilibrium strategies for the cooperative and the retailer, referring to centralized mode, the HJB equation is used to solve and obtain the equilibrium strategy under this decision, as shown in proposition 2.

Proposition 2 The equilibrium results under the decentralized mode are as follows:

(1) The optimal trajectory for consumer skepticism that changes over time is

$$z^{N*}(t) = \left(z_0 - \frac{A^N + B^N}{\alpha - \xi} \right) e^{(\alpha - \xi)t} + \frac{A^N + B^N}{\alpha - \xi}. \quad (10)$$

When $\alpha < \xi$, the optimal trajectory for consumer skepticism tends to stabilize over time,

reaching a steady state value $z_{\infty}^{N*} = \frac{A^N + B^N}{\alpha - \xi}$.

We let

$$A^N = \frac{\gamma\pi_M [\theta(\alpha - \xi - \rho) - \gamma\sigma]}{(\alpha - \xi - \rho)k_M}, \quad B^N = \frac{\delta\pi_R [(\eta - \theta\varphi)(\alpha - \xi - \rho) - \delta\sigma]}{(\alpha - \xi - \rho)k_R}.$$

(2) The optimal equilibrium strategies for the greenness of agricultural products and the retailer's green advertising and protection efforts in the supply chain are

$$g^{N*} = \frac{[\theta(\alpha - \xi - \rho) - \gamma\sigma]\pi_M}{(\alpha - \xi - \rho)k_M}, \quad (11)$$

$$s^{N*} = \frac{[(\eta - \theta\varphi)(\alpha - \xi - \rho) - \delta\sigma]\pi_R}{(\alpha - \xi - \rho)k_R}. \quad (12)$$

(3) The optimal profits functions for the cooperative and the retailer are

$$V_M^N = m_1^* z + n_1^*, \quad (13)$$

$$V_R^N = m_2^* z + n_2^*. \quad (14)$$

We let

$$m_1^* = \frac{\sigma\pi_M}{\alpha - \xi - \rho},$$

$$n_1^* = \frac{2k_M\pi_M\pi_R[(\eta - \theta\varphi)(\alpha - \xi - \rho) - \delta\sigma]^2 + k_R\pi_M^2[\theta(\alpha - \xi - \rho) - \gamma\sigma]^2}{2(\alpha - \xi - \rho)^2 k_M k_R},$$

$$m_2^* = \frac{\sigma\pi_R}{\alpha - \xi - \rho},$$

$$n_2^* = \frac{k_M\pi_R^2[(\eta - \theta\varphi)(\alpha - \xi - \rho) - \delta\sigma]^2 + 2k_R\pi_M\pi_R[\theta(\alpha - \xi - \rho) - \gamma\sigma]^2}{2(\alpha - \xi - \rho)^2 k_M k_R}.$$

Proof about proposition 2 can be seen in the appendix.

Corollary 4 (1) When $\alpha < \xi + \rho$ and $\frac{\gamma\pi_M}{k_M} > \frac{\delta\varphi\pi_R}{k_R}$, there exists $\frac{\partial g^N}{\partial \gamma} > 0$, $\frac{\partial s^N}{\partial \gamma} < 0$; $\frac{\partial g^N}{\partial \theta} > 0$, $\frac{\partial s^N}{\partial \theta} < 0$, $\frac{\partial z_{\infty}^N}{\partial \theta} < 0$, $\frac{\partial D_{\infty}^N}{\partial \theta} > 0$; $\frac{\partial g^N}{\partial \varphi} = 0$, $\frac{\partial s^N}{\partial \varphi} < 0$; $\frac{\partial g^N}{\partial \pi_M} > 0$, $\frac{\partial s^N}{\partial \pi_R} > 0$; $\frac{\partial g^N}{\partial k_M} < 0$, $\frac{\partial s^N}{\partial k_R} < 0$.

(2) When $\alpha > \xi + \rho$, $\frac{\gamma\pi_M}{k_M} < \frac{\delta\varphi\pi_R}{k_R}$ and $\frac{\gamma\sigma}{k_R(\alpha - \xi - \rho)} > \frac{\theta}{k_R}$, there exists $\frac{\partial g^N}{\partial \gamma} < 0$, $\frac{\partial s^N}{\partial \gamma} > 0$; $\frac{\partial g^N}{\partial \theta} > 0$, $\frac{\partial s^N}{\partial \theta} < 0$, $\frac{\partial z_{\infty}^N}{\partial \theta} > 0$, $\frac{\partial D_{\infty}^N}{\partial \theta} < 0$; $\frac{\partial g^N}{\partial \varphi} = 0$, $\frac{\partial s^N}{\partial \varphi} > 0$; $\frac{\partial g^N}{\partial \pi_M} > 0$, $\frac{\partial s^N}{\partial \pi_R} > 0$; $\frac{\partial g^N}{\partial k_M} < 0$, $\frac{\partial s^N}{\partial k_R} < 0$.

Corollary 4 indicates that, in the decentralized mode, the greenness reference effect has the same impact on the decision variables of supply chain members, consumer skepticism, and market demand as the centralized mode. Thus, it will not be further elaborated. The greenness of cooperative's products is positively correlated with the cooperative's marginal profits π_M , and negatively correlated with the green cost coefficient k_M . The retailer's green advertising and protection efforts is positively correlated with its marginal profits π_R , and negatively correlated with the cost coefficient of green advertising and protection efforts k_R . In this mode, supply chain members aim to maximize their own profits. This makes them neglect the total profits of the supply chain.

3.2.3. Decentralized mode with cost sharing led by the retailer (mode Y)

In this section, we explore the impact of cost sharing contract on the equilibrium solution and total profits of the supply chain, and study whether a cost sharing contract can achieve coordination or improve the profits of the supply chain. Under the decentralized mode with a cost sharing contract, the retailer shares a part of the cooperative's green agricultural products costs, which encourages the cooperative to increase its investment in agricultural products' greenness. We let $\psi(t)$ ($0 \leq \psi(t) < 1$) represent the proportion of green agricultural products cost shared by the retailer at time t . From the perspective of long-term and dynamic changes, the decision-making of the cooperative and the retailer forms a Stackelberg differential game model. Stackelberg game with a cost sharing contract is represented by the superscript Y . We assume that the cooperative and the retailer make decisions based on the principle of maximizing their own interests (refer to the decision sequence for the cost sharing mode of Wang et al. (2021)). First, the retailer determines its green advertising and protection efforts $s^Y(t)$ and the proportion of cost sharing $\psi(t)$. Second, the cooperative determines the greenness of its products $g^Y(t)$. In this scenario, the optimal control problems of the cooperative and the retailer are as follows:

$$J_M^Y(z, t) = \max_g \int_0^\infty e^{-\rho t} \left\{ \pi_M [\theta(g - \varphi s) + \eta s - \sigma z] - \frac{1}{2}(1 - \psi)k_M g^2 \right\} dt, \quad (15)$$

$$J_R^Y(z, t) = \max_s \int_0^\infty e^{-\rho t} \left\{ \pi_R [\theta(g - \varphi s) + \eta s - \sigma z] - \frac{1}{2}\psi k_M g^2 - \frac{1}{2}k_R s^2 \right\} dt. \quad (16)$$

To obtain feedback equilibrium strategies for the cooperative and the retailer, the HJB equation is used to solve for the equilibrium strategy under this decision, as shown in proposition 3.

Proposition 3 The equilibrium results under the cost sharing mode are as follows:

(1) The optimal trajectory for consumer skepticism that changes over time is

$$z^{Y*}(t) = \left(z_0 - \frac{A^Y + B^Y}{\alpha - \xi} \right) e^{(\alpha - \xi)t} + \frac{A^Y + B^Y}{\alpha - \xi}. \quad (17)$$

When $\alpha < \xi$, the optimal trajectory for consumer skepticism tends to stabilize over time, reaching a steady state value $z_\infty^{Y*} = \frac{A^Y + B^Y}{\alpha - \xi}$.

We let

$$A^Y = \frac{\gamma(\pi_M + 2\pi_R)[\theta(\alpha - \xi - \rho) - \gamma\sigma]}{2(\alpha - \xi - \rho)k_M}, \quad B^Y = \frac{\delta\pi_R[(\alpha - \xi - \rho)(\eta - \theta\varphi) - \delta\sigma]}{(\alpha - \xi - \rho)k_R}.$$

(2) The optimal equilibrium strategies for the greenness of agricultural products, the proportion of cost sharing, and the retailer's efforts in green advertising and protection are

$$g^{Y*} = \frac{(\pi_M + 2\pi_R)(\theta(\alpha - \xi - \rho) - \gamma\sigma)}{2(\alpha - \xi - \rho)k_M}, \quad (18)$$

$$\psi^* = \frac{2\pi_R - \pi_M}{\pi_M + 2\pi_R}, \quad (19)$$

$$s^{Y*} = \frac{\pi_R[(\alpha - \xi - \rho)(\eta - \theta\varphi) - \delta\sigma]}{(\alpha - \xi - \rho)k_R}. \quad (20)$$

(3) The optimal profits functions for the cooperative and the retailer are

$$V_M^Y = a_1^* z + b_1^*, \quad (21)$$

$$V_R^Y = a_2^* z + b_2^*. \quad (22)$$

We let

$$a_1^* = \frac{\sigma \pi_M}{\alpha - \xi - \rho},$$

$$b_1^* = \frac{k_M (\pi_M + \frac{\pi_R}{2})^2 [(\eta - \theta \varphi)(\alpha - \xi - \rho) - \delta \sigma]^2 + k_R [\pi_M (\theta(\alpha - \xi - \rho) - \gamma \sigma)]^2}{2(\alpha - \xi - \rho)^2 \rho k_M k_R},$$

$$a_2^* = \frac{\sigma \pi_R}{\alpha - \xi - \rho},$$

$$b_2^* = \frac{\pi_R [k_M (\pi_M + \frac{1}{2} \pi_R) ((\eta - \theta \varphi)(\alpha - \xi - \rho) - \delta \sigma)^2 + 2 \pi_M k_R (\theta(\alpha - \xi - \rho) - \gamma \sigma)^2]}{2 \rho (\alpha - \xi - \rho)^2 k_M k_R}.$$

Proof about proposition 3 can be seen in the appendix.

Corollary 5 (1) When $\pi_R > \frac{\pi_M}{2}$ and $\alpha < \xi + \rho$, there exists $\frac{\partial \psi}{\partial \pi_R} > 0$, $\frac{\partial g^Y}{\partial \pi_R} > 0$.

(2) When $\pi_R > \frac{\pi_M}{2}$, $\alpha > \xi + \rho$ and $\theta \gamma < \frac{\gamma \sigma}{k_M (\alpha - \xi - \rho)}$, there exists $\frac{\partial \psi}{\partial \pi_R} > 0$, $\frac{\partial g^Y}{\partial \pi_R} < 0$.

Under the cost sharing mode, in the experience goods and first type credence goods market, the retailer is willing to share only the cooperative's green agricultural products' costs when its marginal profits are large. The proportion of cost sharing is positively correlated with the retailer's marginal profits. When the proportion of cost sharing increases, the retailer shares more green agricultural products costs for the cooperative. This behavior will motivate the cooperative to increase its investment in product greenness. Furthermore, the retailer can indirectly benefit itself by increasing the profits of the cooperative.

In the second type of credence goods market, when the retailer's marginal profits are large, it is willing to share the cooperative's green agricultural products' cost. However, due to excessive consumer skepticism, the inhibitory effect on the cooperative's green investment is greater than the incentive effect brought by the retailer's cost sharing. At this time, the cooperative may reduce its green investment in agricultural products.

3.2.4. Decentralized mode considering altruistic behaviors (mode A)

Supply chain members may exhibit an altruistic social preference. This means supply chain members will not consider only their own profits, but also consider others. In this section, we study the decision-making of supply chain members who have altruistic preferences. We use superscripts A to represent a decentralized mode with altruistic preferences. The utility functions of supply chain members with altruistic preferences are as follows:

$$U_M^A = \pi_M + \phi_M(t) \pi_R, \quad (23)$$

$$U_R^A = \pi_R + \phi_R(t) \pi_M. \quad (24)$$

Among them, $\phi_M(t)$ is the level of the cooperative's altruistic preference, and $\phi_R(t)$ is the retailer's altruistic preference ($\phi_M(t), \phi_R(t) \geq 0$). In general, members' attention to each other's profits is not greater than that to their own profits. Thus, in this section, we assume the supply chain members' level of altruistic preference to be $\phi_i(t) \in (0, 1)$, $i = M, R$. In this scenario, the optimal

control problems of the cooperative and the retailer are as follows:

$$J_M^A = \max_g \int_0^\infty e^{-\rho t} \left\{ \pi_M [\theta(g - \varphi s) + \eta s - \sigma z] - \frac{1}{2} k_M g^2 + \phi_M (\pi_R [\theta(g - \varphi s) + \eta s - \sigma z] - \frac{1}{2} k_R s^2) \right\} dt, \quad (25)$$

$$J_R^A = \max_s \int_0^\infty e^{-\rho t} \left\{ \pi_R [\theta(g - \varphi s) + \eta s - \sigma z] - \frac{1}{2} k_R s^2 + \phi_R (\pi_M [\theta(g - \varphi s) + \eta s - \sigma z] - \frac{1}{2} k_M g^2) \right\} dt. \quad (26)$$

To obtain feedback equilibrium strategies for the cooperative and the retailer, the HJB equation is used to solve for the equilibrium strategy under this decision, as shown in proposition 4.

Proposition 4 The equilibrium results under the altruistic preference mode are as follows:

(1) The optimal trajectory for consumer skepticism that changes over time is

$$z^{A^*}(t) = (z_0 - \frac{A^A + B^A}{\alpha - \xi}) e^{(\alpha - \xi)t} + \frac{A^A + B^A}{\alpha - \xi}. \quad (27)$$

When $\alpha < \xi$, the optimal trajectory for consumer skepticism tends to stabilize over time, reaching a steady state value $z_\infty^{A^*} = \frac{A^A + B^A}{\alpha - \xi}$.

We let

$$A^A = \frac{\gamma(\pi_M + \phi_M \pi_R)[\theta(\alpha - \xi - \rho) - \gamma\sigma]}{(\alpha - \xi - \rho)k_M}, \quad B^A = \frac{\delta(\phi_R \pi_M + \pi_R)[(\eta - \theta\varphi)(\alpha - \xi - \rho) - \delta\sigma]}{(\alpha - \xi - \rho)k_R}.$$

(2) The optimal equilibrium strategies for the greenness of agricultural products and the retailer's efforts in green advertising and protection are

$$g^{A^*} = \frac{(\pi_M + \phi_M \pi_R)[\theta(\alpha - \xi - \rho) - \gamma\sigma]}{(\alpha - \xi - \rho)k_M}, \quad (28)$$

$$s^{A^*} = \frac{(\phi_R \pi_M + \pi_R)[(\eta - \theta\varphi)(\alpha - \xi - \rho) - \delta\sigma]}{(\alpha - \xi - \rho)k_R}. \quad (29)$$

(3) The optimal profits functions for the cooperative and the retailer are

$$V_M^A(z) = c_1^* z + d_1^*, \quad (30)$$

$$V_R^A(z) = c_2^* z + d_2^*. \quad (31)$$

We let

$$c_1^* = \frac{\sigma(\pi_M + \phi_M \pi_R)}{\alpha - \xi - \rho},$$

$$d_1^* = \frac{k_M(\phi_R \pi_M + \pi_R)((2 - \phi_M \phi_R)\pi_M + \phi_M \pi_R)[(\eta - \theta\varphi)(\alpha - \xi - \rho) - \delta\sigma]^2}{2(\alpha - \xi - \rho)^2 \rho k_M k_R}$$

$$+ \frac{k_R[(\pi_M + \phi_M \pi_R)(\theta(\alpha - \xi - \rho) - \gamma\sigma)]^2}{2(\alpha - \xi - \rho)^2 \rho k_M k_R},$$

$$c_2^* = \frac{\sigma(\phi_R \pi_M + \pi_R)}{\alpha - \xi - \rho},$$

$$d_2^* = \frac{k_M [(\theta\varphi - \eta)(\phi_R \pi_M + \pi_R) - \delta c_2^*]^2 - k_R (\gamma c_1^* - \theta \pi_M) [\theta(\phi_R \pi_M + \pi_R) + \gamma(\phi_R c_1^* - 2c_2^*)]}{2\rho k_M k_R}$$

Proof for proposition 4 can be seen in the appendix.

Corollary 6 (1) When $\alpha < \xi + \rho$ and $\eta - \theta\varphi > 0$, there exists $\frac{\partial g^A}{\partial \phi_M} > 0$, $\frac{\partial z_\infty^{A^*}}{\partial \phi_M} < 0$, $\frac{\partial D_\infty^A}{\partial \phi_M} > 0$;

$$\frac{\partial s^A}{\partial \phi_R} > 0, \quad \frac{\partial z_\infty^A}{\partial \phi_R} < 0, \quad \frac{\partial D_\infty^A}{\partial \phi_R} > 0.$$

$$(2) \text{ When } \alpha > \xi + \rho, \quad \frac{\gamma\theta\pi_R}{k_M} < \frac{\gamma\sigma}{k_M(\alpha - \xi - \rho)} \text{ and } \frac{\delta\pi_M(\eta - \theta\varphi)}{k_R} < \frac{\delta\sigma}{k_R(\alpha - \xi - \rho)}, \text{ there exists } \frac{\partial g^A}{\partial \phi_M} > 0, \\ \frac{\partial z^A}{\partial \phi_M} > 0, \quad \frac{\partial D^A}{\partial \phi_M} < 0; \quad \frac{\partial s^A}{\partial \phi_R} > 0, \quad \frac{\partial z^A}{\partial \phi_R} > 0, \quad \frac{\partial D^A}{\partial \phi_R} < 0.$$

In the experience goods and first type credence goods market, the supply chain members' decision variables under the altruistic preference mode are positively correlated with their own altruistic preference level. The consumer skepticism decreases as the members' altruistic preference coefficient increases, leading to an increase in market demand. In the experience goods market, consumers can distinguish the authenticity of the retailer's advertising through learning and other means. The cooperative must ensure the greenness of its products, and the retailer must strengthen the advertising and protection of its products at the same time. The altruistic behavior of the cooperative and the retailer can stimulate each other's enthusiasm to improve product greenness and advertise protection. This will meet consumer demands for products, reduce consumer skepticism, and increase market demand. In this situation, the cooperative and the retailer should adopt some altruistic behaviors. These behaviors can strengthen cooperation between each other and increase the total profits of the supply chain.

In the second type of credence goods market, the supply chain members' decision variables under the altruistic preference mode are positively correlated with their own altruistic preference level. However, consumer skepticism becomes higher with the increase of members' altruistic preference coefficient, leading to a decrease in market demand. In the second type of credence goods market, the supply chain members' altruistic behaviors can stimulate each other's enthusiasm to improve product greenness and efforts in advertising and protection. However, consumers lack the ability to distinguish such products' quality and advertising. They may always raise skepticism to the greenness and advertising of such products. This affects the market demand for such products.

4. Comparative Analysis

In this section, we compare equilibrium solutions for supply chain members' decision variables under four supply chain modes. The equilibrium solutions of each decision variable under the four modes are shown in Table 1.

Table 1. Comparison of decision variables in different modes.

variable	Mode C	Mode N	Mode Y	Mode A
g	$\frac{(\pi_M + \pi_R)[\theta(\alpha - \xi - \rho) - \gamma\sigma]}{k_M(\alpha - \xi - \rho)}$	$\frac{[\theta(\alpha - \xi - \rho) - \gamma\sigma]\pi_M}{(\alpha - \xi - \rho)k_M}$	$\frac{(\pi_M + 2\pi_R)(\theta(\alpha - \xi - \rho) - \gamma\sigma)}{2(\alpha - \xi - \rho)k_M}$	$\frac{(\pi_M + \phi_M\pi_R)[\theta(\alpha - \xi - \rho) - \gamma\sigma]}{(\alpha - \xi - \rho)k_M}$
s	$\frac{(\pi_M + \pi_R)[(\eta - \theta\varphi)(\alpha - \xi - \rho) - \delta\sigma]}{k_R(\alpha - \xi - \rho)}$	$\frac{[(\eta - \theta\varphi)(\alpha - \xi - \rho) - \delta\sigma]\pi_R}{(\alpha - \xi - \rho)k_R}$	$\frac{\pi_R[(\eta - \theta\varphi)(\alpha - \xi - \rho) - \delta\sigma]}{(\alpha - \xi - \rho)k_R}$	$\frac{(\phi_R\pi_M + \pi_R)[(\eta - \theta\varphi)(\alpha - \xi - \rho) - \delta\sigma]}{(\alpha - \xi - \rho)k_R}$

Proposition 5 The relationship between the green advertising and protection efforts under four supply chain modes is $s^C > s^A > s^N = s^Y$.

Proposition 5 indicates that the altruistic behaviors of the supply chain members can stimulate the retailer's enthusiasm to improve the green advertising and protection efforts. When the cooperative is fully altruistic ($\phi_M = 1$), the green advertising and protection efforts under the altruistic

preferences mode will reach the value of the centralized mode. Because the cost sharing contract indirectly increases retailer's profits by assisting the cooperative, it does not directly affect retailer's efforts in green advertising and protection. Therefore, the advertising and protection efforts under the cost sharing mode and the decentralized mode are lower compared to the value of the centralized mode and the altruistic preferences mode.

Proposition 6 The relationship between the product greenness under three supply chain modes is $g^C \geq g^A \geq g^N$.

Proposition 6 indicates that the supply chain members' altruistic behaviors can stimulate the cooperative's enthusiasm to improve the product greenness. Similar to proposition 5, when the retailer is fully altruistic ($\phi_R = 1$), cooperative's products greenness under the altruistic preferences mode will reach the value of the centralized mode. The level of the cooperative's products greenness under the cost sharing mode needs further discussion, as stated in proposition 7.

Proposition 7 When $\phi_R \in (0,1)$ and $\pi_R < \frac{\pi_M}{2}$, there exists $g^C > g^A > g^N > g^Y$. When $\phi_R \in (0,1)$ and $\frac{\pi_M}{2} < \pi_R < \frac{\pi_M}{2(1-\phi_M)}$, there exists $g^C > g^A > g^Y > g^N$. When $\phi_R \in (0,1)$ and $\pi_R > \frac{\pi_M}{2(1-\phi_M)}$, there exists $g^C > g^Y > g^A > g^N$.

Proposition 7 indicates that under the cost sharing mode, the retailer's willingness to share the cooperative's green agricultural products costs is contingent upon its marginal profit being sufficiently high. The retailer's marginal profit is positively correlated with the proportion of cost sharing. When $\pi_R > \frac{\pi_M}{2(1-\phi_M)}$, the cooperative's greenness of agricultural products under the cost sharing mode is just lower than that under the centralized mode. When the retailer's marginal profit is low, it will not choose to share the cooperative's cost. At this time, the cooperative's greenness of agricultural products under the cost sharing mode is lower than that under the decentralized mode.

5. Numerical analysis

To further reveal the dynamic characteristics of consumer skepticism and the impact of the reference effect and altruistic preferences on the supply chain members' profits, we compare the impact of reference effects and altruistic preferences on consumer skepticism and supply chain member profits under four supply chain modes. As inferred from the previous text, the characteristics of the first type of credence goods are similar to those of experience goods. Therefore, in this section, we mainly discuss the differences between the second type of credence goods and experience goods. When studying the change of decision variables and profits over time, we also focus on two products; the second type of credence goods ($\alpha > \xi + \rho$) and the experience goods ($\alpha < \xi$). When studying the change of decision variables and profits with other parameters, we mainly focus on experience goods ($\alpha < \xi$), and take the steady-state values of each variable for research. Based on previous research results, the parameters set in this section are $k_M = 2.0$, $k_R = 3.0$, $z_0 = 70.0$, $\alpha = 0.05$ (experience goods), $\alpha = 0.12$ (second type of credence goods), $\sigma = 0.04$, $\xi = 0.07$, $\beta = 0.35$, $\gamma = 1.0$, $\varphi = 0.05$, $\delta = \beta - \gamma\varphi = 0.3$, $\eta = 1.0$, $\theta = 1.0$, $\pi_M = 3.0$, $\pi_R = 2.0$, $\rho = 0.03$, $\phi_M = 0.5$, and $\phi_R = 0.5$.

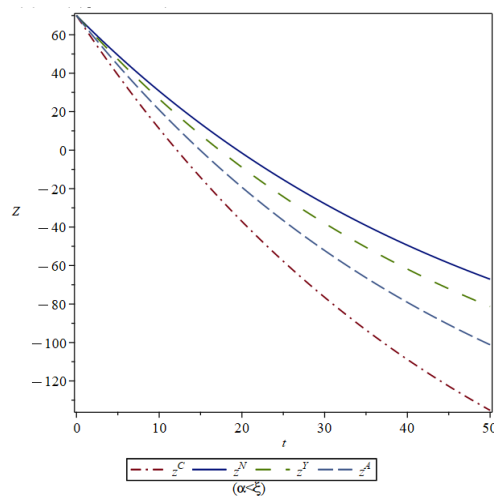


Figure 1. The variation of z with respect to t (experience goods).

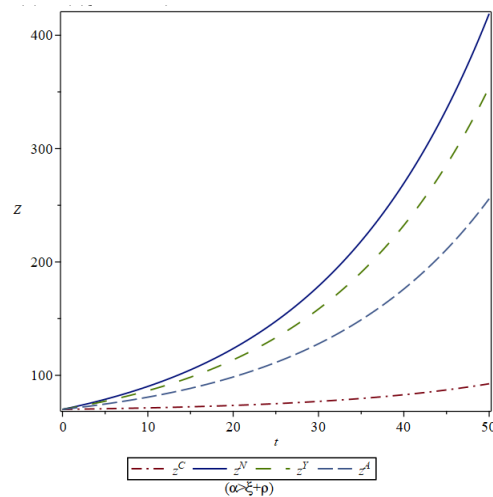


Figure 2. The variation of z with respect to t (second type of credence goods).

Figures 1 and 2 depict the changes of consumer skepticism over time for different types of products. As shown in Figure 1, for experience goods, in the early stage of product sales, consumers' cognition of the product is insufficient. Thus, the consumer skepticism curve is above the coordinate axis (greater than 0). However, in the middle and later stages of product sales, as consumers' cognition of the product continues to increase, the consumer skepticism curve shows a continuous downward trend and decreases to below the coordinate axis (less than 0). This can be understood as consumers having a certain level of cognition and satisfaction with the products. This makes them willing to recommend such products to others. As shown in Figure 2, for the second type of credence goods, consumers are unable to correctly recognize this product, and the consumer skepticism curve continues to rise and remains positive. It should be noted that the consumer skepticism defined in this paper does not depict the level of consumer satisfaction with the products, but the level of consumer perception of the products.

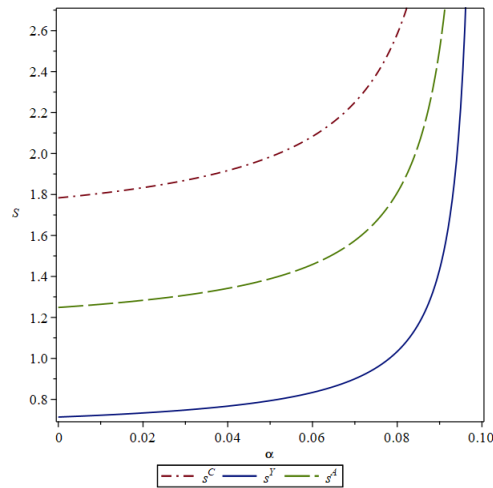


Figure 3. The differences in advertising and protection of the retailer under different product types.

Figure 3 depicts the differences in advertising and protection of the retailer when facing two products. According to proposition 5, the retailer's efforts in advertising and protection under the cost sharing mode is consistent with the decentralized mode. Therefore, Figure 3 shows only the changes under the cost sharing mode. We set $\xi = 0.07$ in this paper. As shown in Figure 3, when $\alpha < 0.07$, that is, when the product is an experience good. The retailer's efforts in advertising and protection slowly increase with the increase of α . When $\alpha > 0.07$, the product is a credence good. The retailer's efforts in advertising and protection increase sharply with the increase of α . This indicates that in the credence goods market, the retailer makes much greater efforts in green advertising and protection than in the experience goods market.

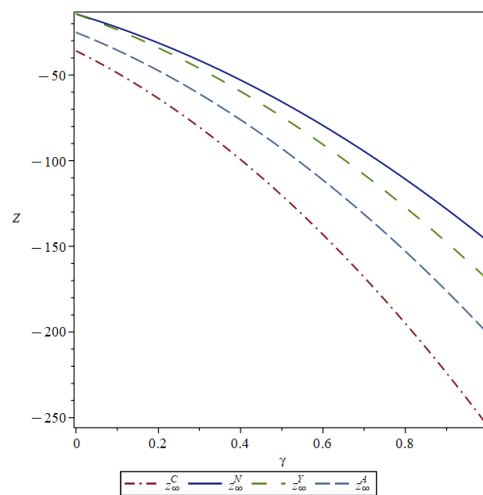


Figure 4. The variation of z_{∞} with respect to γ (experience goods).

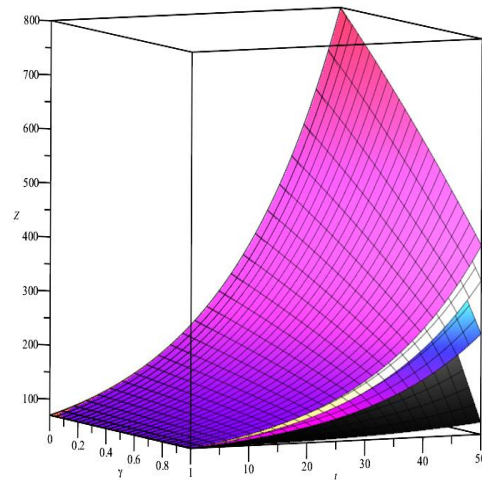


Figure 5. The variation of z with respect to t and γ (second type of credence goods).

Figure 4 depicts the impact of the coefficient γ on steady-state values z_∞ in the experience goods market. According to corollary 1, in the experience goods market, as the coefficient γ increases, the cooperative increases its investment in green products. Therefore, the steady-state values z_∞ in all four supply chain modes show a downward trend. The steady-state values z_∞ under the centralized mode is lower than that under the cost sharing mode, and both are lower than that under the decentralized mode. For the steady-state values z_∞ under the cost sharing mode, when the coefficient γ is low, the steady-state values z_∞ under this mode is higher than that under the decentralized mode. With the γ continuous increases, the steady-state values z_∞ under the cost sharing mode lies between that under the altruistic preferences mode and the decentralized mode.

Figure 5 depicts the changes in consumer skepticism when the coefficient γ and time change simultaneously in the second type of credence goods market. According to corollary 1, in the second type of credence goods market, as the coefficient γ increases, the cooperative reduces its investment in green products. Therefore, consumer skepticism is on the rise.

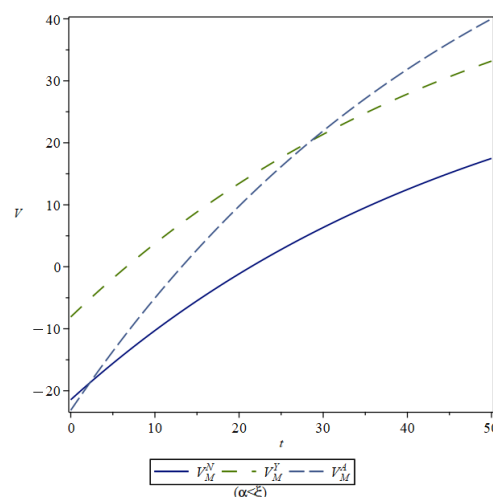


Figure 6. The variation of V_M with respect to t (experience goods).

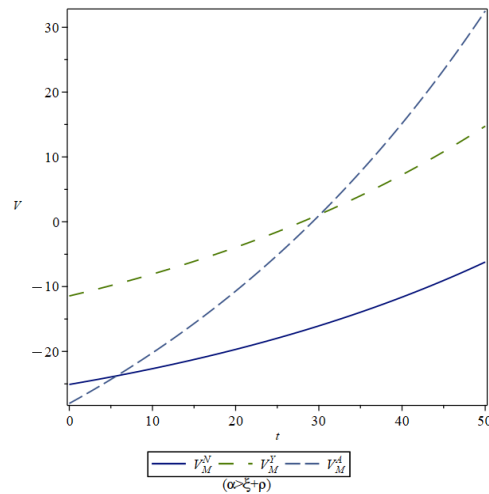


Figure 7. The variation of V_M with respect to t (second type of credence goods).

Figures 6 and 7 depict the variation of cooperative's profits over time when there are two types of products. From Figures 6 and 7, it can be seen that in the initial stage of product sales, the efficiency curve of the cooperative is below 0. This is due to the consumer skepticism initial value. In the early stage of sales, consumers have certain skepticism about any types of product, resulting in a negative profits curve for a certain period of time, and, at this time, the cooperative's profits under altruistic preference are lower than the other two situations. In the middle and later stages of sales, the profits curve of the cooperative shows an upward trend, and the profits of the cooperative under the altruistic preferences mode is higher than that under the decentralized mode and the cost sharing mode. This indicates that for the cooperative, when it has a certain level of altruistic preference, it needs to consider long-term profits regardless of the product they are facing. For product types, as consumer skepticism toward experience goods decreases over time, and while consumer skepticism toward second type credence goods increases, the profits brought by experience goods are higher for the cooperative than those of second type credence goods.

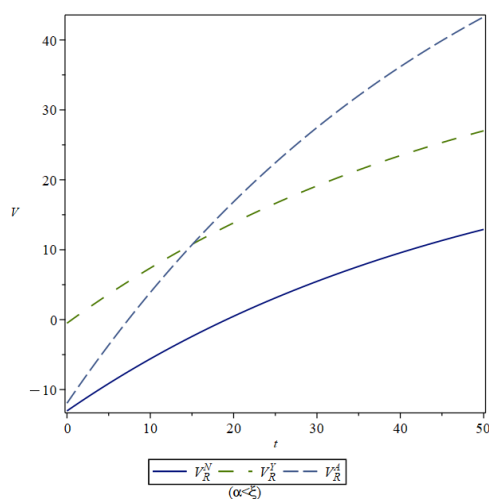


Figure 8. The variation of V_R with respect to t (experience goods).

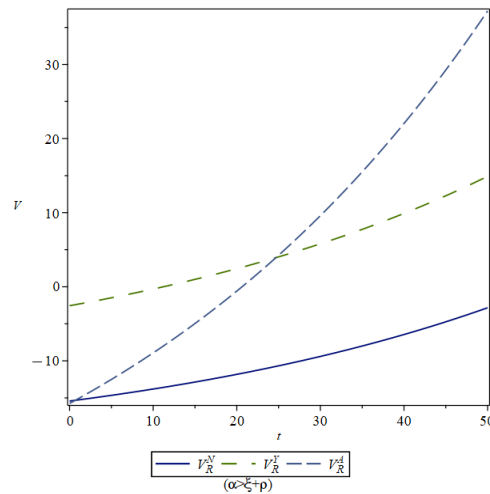


Figure 9. The variation of V_R with respect to t (second type of credence goods).

Figures 8 and 9 depict the changes in retailer's profits over time when there are two types of products. From Figures 8 and 9, it can be seen that in the early stage of product sales, the retailer's profits of the second type of credence goods under the altruistic preferences mode are lower than those under the decentralized mode and the cost sharing mode. While in the middle and later stages, the retailer's profits of the second type of credence goods under the altruistic preferences mode gradually exceed the other two modes. This indicates that during a certain period of time, the retailer's altruistic behaviors may harm its profits. However, over time, these behaviors will also benefit the retailer. Therefore, when facing the second type of credence goods, the retailer needs to pay more attention to long-term profits rather than short-term profits.

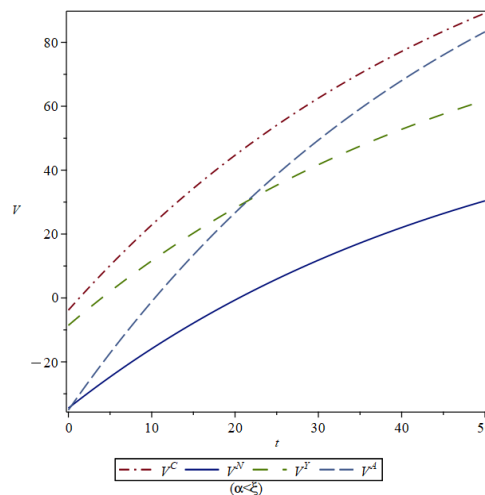


Figure 10. The variation of V with respect to t (experience goods).

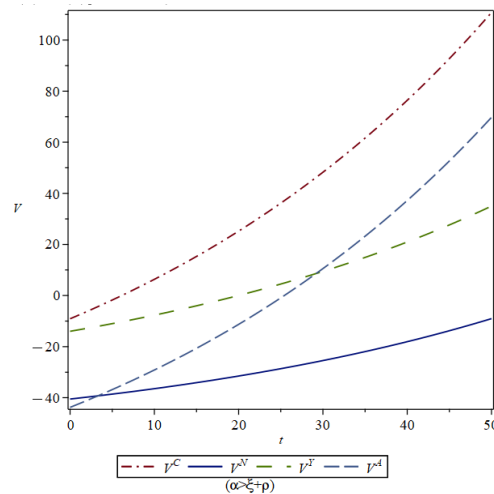


Figure 11. The variation of V with respect to t (second type of credence goods).

Figures 10 and 11 depict the variation of the total supply chain profits over time when there are two types of products. It can be seen from Figure 10 that the total profits of experience goods increase over time. At the initial stage of product sales, the total profits under the altruistic preferences mode are lower than that under the other three modes. At the later stage of product sales, the total profits under the altruistic preferences mode are higher than that under the cost sharing mode and the decentralized mode. This indicates that altruistic behaviors of supply chain members can improve supply chain efficiency, and supply chain members need to pay attention to the long-term profits of the supply chain system.

It can be seen from Figure 11 that the total profits of the second type of credence goods also increases over time. At the initial stage of product sales, the total profits under the altruistic preferences mode are lower than that of the other three modes. This differs from that shown in Figure 10, as in the later stage of product sales, the total profits under the altruistic preferences mode exceeds that under the cost sharing mode and the decentralized mode. Moreover, there is a certain gap between the total profits under the altruistic preferences mode and the centralized mode. This indicates that compared to the second type of credence goods, the supply chain members' altruistic behaviors are more beneficial to experience goods.

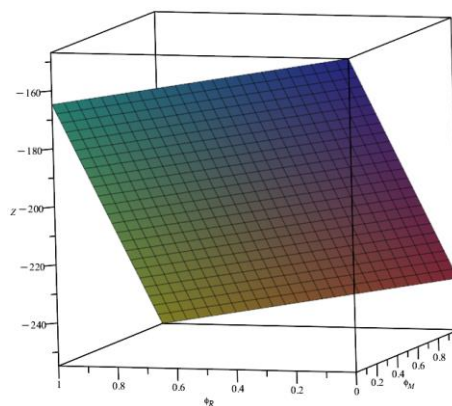


Figure 12. The influence of the supply chain members' altruistic preferences on z .

Figure 12 depicts the changes in consumer skepticism as the supply chain members' altruistic preferences change. From Figure 12, it can be seen that the cooperative and retailer's altruistic behaviors can reduce consumer skepticism. The retailer's altruistic behaviors reduce more consumer skepticism than the cooperative's altruistic behaviors.

6. Conclusion

In this paper, we consider consumers' reference expectations for the greenness of green products before purchasing them and incorporate consumer skepticism and two product types into the two-echelon supply chain composed of one cooperative and one retailer. Based on these, we analyze the centralized mode, decentralized mode, cost sharing mode, and altruistic preference mode. Thereafter, we obtain the equilibrium strategies of the cooperative and the retailer under each mode through the HJB equation. We use centralized and decentralized mode as benchmark modes, and discuss the impact of cost sharing contract and altruistic preference behaviors on the supply chain members' decision-making. Based on mathematical and numerical analysis, the following conclusions are drawn:

(1) Under the four supply chain modes, the greenness reference effect has an impact on consumer skepticism, market demand, and retailer's green advertising and protection efforts. Regardless of the supply chain mode, when the correlation between reference greenness effect and retailer advertising is too high, it will increase consumer skepticism. When the reference greenness has a significant impact on demand, it will damage the enthusiasm of retailer's green advertising and protection efforts, and increase the cooperative's investment of actual product greenness. In addition, the retailer tends to invest more efforts in green advertising and protection for credence goods than for experience goods. Zhou and Duan [3] discussed only the sales model selection of retailers under the greenness reference effect without considering the impact of reference effect on members' decision-making.

(2) The implementation of Pareto improvement in cost sharing contract requires certain conditions to be met. The proportion of cost sharing depends on the marginal profits of the cooperative and the retailer, so the retailer will not choose to share the cooperative's costs when its marginal profit is low. At this time, the cooperative's greenness of agricultural products under the cost sharing mode is lower than that of decentralized mode. On the contrary, when the retailer's marginal profit is high, it is willing to share the cooperative's costs. At this time, the cooperative's profits and the total profits of the supply chain under the cost sharing mode are between the centralized mode and decentralized mode, which can achieve Pareto improvement. Thus, when the retailer's marginal profit is high, introducing cost sharing contract in the supply chain can improve supply chain performance. Liu et al. [5] and Shen [6] did not discuss the effective conditions for cost sharing, as they believe that cost sharing is always beneficial.

(3) From a long-term perspective, altruistic preference can increase supply chain profits. Altruistic behaviors of supply chain members can stimulate the cooperative's enthusiasm to improve the greenness of its products. As the level of altruistic preference among supply chain members increases, the consumer skepticism shows a downward trend. However, market demand and retailer's efforts in green advertising and protection show an upward trend. When supply chain members adopt altruistic behaviors, each member's profit and the total profits are higher than those of the decentralized mode. This indicates that the altruistic preference mode can perform Pareto improvement on the supply chain profits. For different product types, the total supply chain profits of experience goods under the altruistic mode are closer to the centralized mode in the later stage of

product sales. There is a certain gap between the total profits of the second type credence goods under the altruistic mode and the centralized mode. Wang et al. [7] found only that, in the short term, the retailer's altruistic behavior would cause adverse effects on its own profits, without analyzing the long-term impact of altruistic behavior. Zhu et al. [29] did not consider that the effect of altruistic preferences varies by product type.

(4) Except for the centralized mode, experience goods perform better than credence goods in terms of consumer skepticism and supply chain profits. Under the four supply chain modes, the experience goods' consumer skepticism shows a downward trend over time and will become negative after a certain point in time. At this point, consumers will recommend this type of product to others. Moreover, the credence goods' consumer skepticism is on the rise. In addition, credence goods can be further divided into two types, and the differences in product types can cause changes in the impact of the greenness reference effect coefficient on supply chain members' decision-making. In the second type of credence goods market, when the impact of greenness reference effect on consumer skepticism increases, it will restrain the cooperative's green investment in products. In the experience goods and first type credence goods market, when the impact of greenness reference effect on consumer skepticism increases, it will increase the cooperative's green investment in products. For the retailer, the opposite is true. This finding extends the static classification of Nelson [1] and Darby and Karni [2] to a dynamic framework.

7. Management measures

(1) For cooperatives, when consumers have a green reference effect, they should increase the investment in green innovation and improve product greenness. This behavior can reduce consumer skepticism and meet consumers' demand for green products. For retailers, when the greenness reference effect has a significant impact on demand, it is necessary to appropriately control the efforts in green advertising and protection. This behavior can lower consumers' psychological expectations of the product and reduce consumer skepticism.

(2) When the retailers' marginal profits are high, retailers can share cooperatives' green investment cost. It can stimulate cooperatives' enthusiasm to improve the greenness of agricultural products. Furthermore, it can improve product quality, reduce consumer skepticism, and improve total supply chain profits. When the retailers' marginal profits are low, they will not choose to share the cooperatives' costs, but to ensure their own profits.

(3) Cooperatives and retailers need to create an environment that can foster altruistic preferences, such as mutual cooperation or shareholding. In this environment, they can utilize each other's altruistic behaviors to stimulate their production and advertising enthusiasm. This can improve the total profits of the supply chain. Compared to retailers, cooperatives need to have a longer-term perspective when facing different product types and trading short-term losses for the long-term development of the supply chain.

(4) For credence goods, unilateral product advertising by retailers cannot increase the sales of such products. Therefore, cooperatives need to improve the greenness of agricultural products, and retailers need to increase their efforts in advertising and protection. Thus, they need to take the above actions to maintain stable sales of this type of green agricultural products. In addition, as credence goods can be further classified, supply chain members need to consider the stage characteristics of such products to flexibly adjust their own decisions. For experience goods, cooperatives need to ensure the greenness of products and meet the needs of consumers. Retailers need to increase their advertising and protection efforts to reduce consumer skepticism.

By introducing the consumer skepticism, greenness reference effect, and different types of agricultural products, we discuss the decision-making of the cooperative and the retailer under different supply chain modes, and make corresponding management strategies. We mainly study supply chain members' mode selection and the impact of the consumer skepticism and greenness reference effect on supply chain members' decision-making, and obtain some research results. However, there are many problems that can be further studied, including the following aspects:

(1) In this paper, the altruistic preferences in the model are given in the form of constants. However, in the actual decision-making process, the altruistic preferences of decision-makers will be affected by the external environment, such as their own financial situation and the supply chain members' relationship. Therefore, it is worthwhile to study the green agricultural product supply chain decision-making under different altruistic preference levels.

(2) In this paper, we consider only a supply chain with one cooperative and one retailer. Thus, the situation where multiple cooperatives or multiple retailers compete with each other is not taken into consideration. Therefore, future research can incorporate competitive factors.

(3) We consider the cost-sharing mode and the altruistic preference mode as two separate modes. Thus, we do not take into account the situation where supply chain members introduce a cost-sharing contract or other contracts while having altruistic preferences. Thus, the impact of different supply chain contracts to supply chain members under altruistic preferences can be studied in the future.

Use of Generative-AI tools declaration

During the preparation of this manuscript, the authors used ChatGPT for language polishing and expression improvement. All AI-assisted content was critically reviewed and revised by the authors, who take full responsibility for the final published version.

Author contributions

In this study, the contributions of each author are as follows:

Weifan Jiang designed the overall research, including the framework and core differential game model integrating greenness reference effect, consumer skepticism and agricultural product types. He supervised the research process and result analysis to ensure accuracy, and contributed to manuscript writing and revision with valuable insights.

Siyu Wu constructed the two-echelon supply chain model and clarified how consumer skepticism affects purchase willingness. His work ensured model rationality and research progress; he also drafted the initial manuscript and provided content feedback. Additionally, he studied the retailer-led cost-sharing contract's optimization effect, and analyzed altruistic behaviors' role in reducing skepticism and improving supply chain profit, sorting out research implications and refining altruistic preference analysis.

Chengxiang Wu classified green agricultural products into credence and experience types, and analyzed supply chain members' decision differences. He refined the correlation between reference greenness impact coefficient and supply chain efforts, and revised the manuscript to clarify related analysis and conclusions.

Jinli Zhang specialized in data analysis and interpretation, using appropriate statistical methods to analyze research data and extract meaningful results. She created figures and tables to effectively present research findings, and refined the data analysis section during manuscript revision to ensure the clarity and completeness of the results.

Qin Li focused on data validation and result interpretation, cross-checking analyzed data to confirm its accuracy and consistency. She assisted in organizing data results, optimized the presentation logic of the data section, and reviewed the manuscript to provide valuable comments on the rationality of research methodology and conclusions.

In summary, this study was a collaborative effort of all authors, with each contributing their unique expertise and skills to ensure the success of the research.

Conflict of interest

The authors declare that there are no conflict of interests.

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Data availability statement

Some or all data, models, or code generated or used during the study are available from the corresponding author by request.

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