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Government Subsidy Strategies Considering Greenness on Agricultural Product E-Commerce Supply Chain

Fangfang Guo [1,2], Tao Zhang [2], Xiuquan Huang [2] and Yaoguang Zhong [3,*]

1 School of Economics and Management, Dongguan University of Technology, Dongguan 523808, China
2 Faculty of Humanities and Social Sciences, Macao Polytechnic University, Macau 999078, China
3 School of Business, Dongguan Polytechnic, Dongguan 523808, China
* Correspondence: zhongyg@dgpt.edu.cn

Abstract: Based on the Stackelberg game theory, this paper explores the incentive effects of five government subsidy strategies on agricultural products in e-commerce. A two-tier e-commerce supply chain of one farmer and one e-commerce platform is constructed to examine the impact of five different government subsidy strategies on the greenness of an agricultural product, the wholesale price, the selling price, and the profit of the supply chain. The results show that the effect of offering government subsidies is significant. Also, the direct subsidization from the government to a farmer has the maximum effect on the sales and greenness of the agricultural product. The results of this study provide policy implications for governments in establishing a sustainable mechanism through direct subsidization.

Keywords: Stackelberg game; government subsidies; agricultural products supply chain; greenness

MSC: 90B06

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1. Introduction

In China, e-commerce has been an important tool to help increase farmers' income. In the first half of 2020, online retail sales in 832 nationally poverty-stricken counties in China reached 68.48 billion yuan [1]. However, there is a widespread problem of low quality and serious homogenization of agricultural products, resulting in low sales prices, which affects farmers' enthusiasm for planting [2]. Government subsidies for agricultural products are a support policy commonly implemented by countries worldwide [3]. Because agricultural products are essential for people's lives in various countries, the government supports planting agricultural products, and improving the enthusiasm and quality of farmers in planting agricultural products is an important measure to ensure the primary livelihood of the people.

However, with the advancement of science and technology and economic development, resources on the planet are increasingly scarce, and more specifically, environmental pollution is exacerbated. In this context, the development of green technology and green products has become particularly important [4]. To promote the green development of agriculture, the central government in China has created a set of policies, including subsidization of green and organic agricultural products. In addition, the central government is still looking for a better way to help farmers sell green agricultural products through e-commerce platforms.

Given this, this paper aims to improve the greenness of agricultural products through government subsidies, increase the sales of green agricultural products and farmers' income, and finally achieve the goal of shared prosperity. So then, in the agricultural product e-commerce supply chain, what kind of subsidy strategies should the government implement to promote agricultural product e-commerce sales? How do different government subsidy strategies affect the greenness of agricultural products? Does it affect consumer behaviour?

Based on the Stackelberg game theory [5], this paper examines the impact of government subsidies on the supply chain and profits. First, this paper introduces greenness by analysing the effects of different government subsidies. Then, it proposes strategies to improve the greenness of agricultural products through green planting, which is in line with government policy guidance and consumer demand. Finally, this paper provides a decision-making reference to government subsidies by comparing the impact of different government subsidies on decision-making variables, decision-maker profits, the greenness of agricultural products, and consumer behaviour.

This study is organized as follows: Section 2 presents the literature review. In Section 3, we make basic assumptions and notations. In Section 4, based on the Stackelberg game model, we construct the non-government subsidy and five government subsidy strategy models. In Section 5, we compare the impacts of different government subsidy strategies on decision variables, profits, and the green degree of agricultural products. Section 6 presents the numerical examples. Finally, we conclude this study in Section 7.

2. Literature Review

2.1. Agricultural Product Supply Chain

The research on agricultural product supply chain mainly focuses on the coordination of agricultural product supply chain, risk management of agricultural product supply chain [6,7], agricultural product brand [8–10], bargaining power [8,11,12], etc. Researchers also considered the impact of government subsidies on the supply chain of agricultural products [13,14]. In the research on agricultural product supply chain coordination, they have studied the impact on agricultural product supply chain coordination from consumer preference [15–17] and logistics [17–20]. Researchers also studied from the perspective of brand promotion [21] and the participation of farmers' cooperatives [9]. Most scholars believe that the role of agricultural product brands in the sales of agricultural products is becoming increasingly important. It is the fundamental way to improve the circulation efficiency of agricultural products and has become a critical factor in enhancing the industry's competitiveness. In addition, most scholars believe that farmers' cooperatives can improve the bargaining power of agricultural products and increase farmers' income.

2.2. Consumers' Green Preferences

Researchers have studied supply chain decision-making from the perspectives of consumers' green preference, energy conservation, low carbon and environmental protection, and risk preference. Peng [22] considered market demand a function of time and studied how the government subsidizes consumers' purchase of green products. Hafezalkotob [23] assumed that green and ordinary products coexist in a market. He studied and analyzed the impact of government financial intervention on the green supply chain. Yu et al. [24] established an optimization model under oligopoly competition considering green preference and government subsidies, intending to maximize the manufacturer's profit. Madani and Rasti-Barzoki [25] took green and non-green competitive supply chains as research objects, constructed a game model considering consumers' green subsidies and non-green consumption taxation, and analyzed the impact of government fiscal and tax policies on the optimal decision-making of supply chain under centralized and decentralized decision-making. Under fuzzy uncertainty, Yang and Xiao [26] constructed a game model between manufacturers and retailers in a green supply chain, considering government subsidies and consumers' green preferences. The equilibrium price and greenness under three power structures of manufacturer-led, retailer-led, and Nash game are determined, respectively. The results of the three models are compared and analyzed. The research of Hong and Guo [27] also considered the impact of wholesale price contracts, cost-sharing contracts, and two tariff contracts on the optimal decision-making of the green supply chain under the green efforts of manufacturers and retailers. Conrad [28] and Liu et al. [29] have established a green supply chain decision-making model based on consumers' environmental awareness. Xue et al. [30] and Huang et al. [31] have constructed government-subsidized green supply chain decision-making models for energy-saving products to study the impact of government subsidies on supply chain decision-making. Gao et al. [32] studied the impact of risk aversion and free riding on supply chain decision-making. Previous studies on consumers' green preferences mainly focused on energy conservation, emission reduction, low-carbon environmental protection, etc. However seldom conducted from the perspective of agricultural product quality.

2.3. Supply Chain Decision under Different Government Subsidies

As an important factor in supply chain decision-making, government subsidy has an essential impact on the operations of supply chains. In recent years, researchers have conducted in-depth and extensive research on the effects of government subsidies on the decision-making of green supply chains.

From the government subsidy model perspective, Ma et al. [33] studied retailer subsidy strategies and found that this subsidy strategy benefits both manufacturers and retailers. When studying the manufacturer's subsidy strategy, Zhao et al. [34] considered the green production decision of sharing part of the subsidy to consumers. Huang and Fu [35] constructed a Stackelberg game model with pharmaceutical logistics suppliers as the leading and manufacturers as the followers. They compared the effects of different subsidy strategies on green investment and the strategy selection of logistics suppliers and manufacturers. Based on dynamic game theory and principal-agent theory, Yuan et al. [36] studied the influence of different government subsidy strategies on wholesale price, product greenness level, retail price, sales effort level, manufacturer's profit, and retailer's profit in green supply chain management. Considering the complexity of consumer groups, Meng et al. [4] constructed a two-stage price decision model of a green supply chain composed of manufacturers and retailers. They analyzed the impact of government subsidies on the price decision of green supply chain members. Wu et al. [37] studied the cost-sharing strategy of retailers and manufacturers in the Nash game, considering government subsidies and consumer green preferences. And retailer sales efforts.

From the effect of government subsidies, Shi and Min [38] studied two manufacturers' subsidy models, unit product subsidies and one-time subsidies. In comparison, unit subsidies are more effective. Cohen et al. [39] studied the consumer subsidy strategy and found that the subsidy strategy can coordinate the production quantity and sales price of products. Su et al. [40] discussed a green supply chain composed of manufacturers and retailers, considering consumers' green preferences. They established a pricing decision model of a green supply chain under different power structures. The government subsidizes the manufacturers of green products and consumers who buy green products. Li et al. [41] considered government subsidies, consumers' preference for energy-saving products, and random demand and established a four-stage Stackelberg game model to study retailer information investment and sharing and manufacturers' optimal strategies for energy-saving research and development. Wang et al. [42] discussed the impact of government subsidies on members' profits, social responsibility efforts, and social welfare. They established the decision-making models of the government, manufacturers, and retailers under different subsidy policies.

To summarize, the above literature mainly studied the issue of government subsidies in supply chains composed of manufacturers and retailers. Few studies put their research perspective on the government subsidy decision-making of the supply chain composed of farmers and e-commerce platforms. At the same time, subsidy policies are primarily aimed at manufacturers, retailers, and consumers, with little consideration for simultaneous subsidies. Furthermore, researchers consider greenness mainly to reduce link pollution or carbon emissions in processing or transportation. However, few studies considered the greenness of agricultural product cultivation. For example, this paper constructs an agricultural product's two-level supply chain decision-making model composed of an E-commerce platform and a farmer under government subsidies.

3. Model Description and Assumptions

3.1. Model Description

This research uses an agricultural product as an example to study the decision-making model of two main bodies composed of a farmer f and an E-commerce platform l. Assuming that the farmer only sells one kind of agricultural product [43], the E-commerce platform l purchases this kind of agricultural product from the farmer f and sells them online to consumers. The E-commerce platform only sells one type of agricultural product. Consumer behaviour is affected by both the agricultural product's price and the agricultural product's greenness. However, the sensitivity to agricultural prices is higher than the sensitivity to greenness.

3.2. Model Symbol Description

The descriptions of symbols involved in the model of this research are shown in Table 1.

Table 1. Research model symbols and descriptions.

Symbol	Meaning	Symbol	Meaning
D	Market demand for product	C_l	The unit cost of procurement and operation for an E-commerce product
D_0	Market base demand for product	C_f	Planting cost of the agricultural product
a	The elasticity coefficient of market demand to price	$g(s)$	The cost function of improving the greenness of the agricultural product
b	The elasticity coefficient of market demand to greenness	k	Sensitivity coefficient of farmers to improve the greenness of the agricultural product
p	The selling price of an E-commerce product	W	The wholesale price of the agricultural product
s	Greenness of the agricultural product	d	Government unit subsidy price
q	Order quantity of E-commerce platform	ρ	Government subsidy ratio
p_l	Actual sales unit price of e-commerce platform	W_f	The actual wholesale price of the agricultural product
p_c	Actual purchase price of consumers	π_l	Profit of e-commerce platform
π_f	Profit of the farmer	π	The overall profit of the agricultural product supply chain

3.3. Research Assumptions

(1) Using the functional form used by Ghosh and Shah [44] and Zhao and Wei [45], the relationship between cost and greenness is quadratic. The cost function of farmers to improve the greenness of the agricultural product is $g(s) = \frac{1}{2}ks^2 (k > 0)$. It represents the cost that farmers pay to bring satisfaction to customers by enhancing the greenness of the agricultural product. k indicates the sensitivity coefficient of farmers to improve the greenness of the agricultural product.

(2) Δp represents the marginal profit of the E-commerce platform. To ensure the profitability of the E-commerce platform, Δp > 0.

This study includes a farmer f and an E-commerce platform l, which plays a leading role in the supply chain. Based on Liu et al. [29] and Ghosh and Shah [44] 's linear demand functions, the market demand D is affected by the price p and the greenness of the agricultural product s, which decreases with the price increase and increases with the greenness of the agricultural product. Suppose the relationship among the three is $D = D_0 - ap + bs$, and $D_0 > 0, a > 0, b > 0$. Then, according to the market demand, the suppliers decide the order quantity and assume there is no shortage. That is $q = D$.

The farmer determines the greenness s and wholesale price W of the agricultural product, whose unit operating cost is C_f. The E-commerce platform determines the sales price of the agricultural product p, whose unit operating cost is C_l. To ensure the decision variables p, W, and s are positive, the relationship between the parameters should be satisfied $D_0 - a\left(C_f + C_l\right) > 0$.

To encourage the farmer to improve the greenness of the agricultural product, the E-commerce platform sells the green agricultural product. It enhances the enthusiasm and confidence of consumers to buy that green product. The government guides the behaviour of the supply chain and consumers through price subsidies to the supply chain and consumers. The main strategies include: First, subsidize the supply chain composed of a farmer and an E-commerce platform. There are three strategies: separate subsidies for the farmer, separate subsidies for the E-commerce platform, and subsidies for the "farmer + E-commerce platform". The second is to subsidize consumers, including two strategies of subsidizing consumers alone and subsidizing "consumers + farmer". To analyse the impact of government subsidies on agricultural green planting behaviour, a supply chain decision model without government subsidies as a benchmark model was established. The optimal green decision-making of the supply chain includes the farmer's decision-making on the optimal wholesale price and greenness of the agricultural product and the E-commerce platform's decision-making on the optimal sales price of the agricultural product. Then, the supply chain decision-making models are established under five strategies: government subsidies to the farmer, government subsidies to the E-commerce platform, government subsidies to "farmer + E-commerce platform", government subsidies to consumers, and government subsidies to "farmer + consumers". Analysing the optimal decisions under different subsidy strategies and comparing the effects of different subsidy schemes can provide a reference for the government to design appropriate subsidy decisions.

4. Government Price Subsidy Strategy

4.1. No Subsidy Strategy

Under the non-subsidy strategy, the market demand function of the agricultural product, the profit of the E-commerce platform, the profit of the farmer, and the total profit of the system are expressed as follows:

The market demand for the product is $q = D = D_0 - ap + bs$

The profit of the farmer is $\pi_f = \left(W - C_f\right)q - g(s) = \left(W - C_f\right)q - \frac{1}{2}ks^2$

The profit of the E-commerce platform is $\pi_l = (p - C_l - W)q$

The system profit is $\pi = \pi_f + \pi_l = \left(p - C_f - C_l\right)q - g(s) = \left(p - C_f - C_l\right)q - \frac{1}{2}ks^2$

In the above model, the E-commerce platform is the decision maker, and the farmer is the follower. The E-commerce platform determines the sales price p of the agricultural product to meet the market demand. The farmer determines the wholesale price W and greenness s of the agricultural product. According to the inverse solution method, Lemma 1 can be obtained.

Lemma 1. *Under the no subsidy policy, the optimal decision of the supply chain is*

$$p_1{}^* = \frac{\left(3ak - b^2\right)D_0 + a\left(ak - b^2\right)\left(C_f + C_l\right)}{2a\left(2ak - b^2\right)} \tag{1}$$

$$W_1{}^* = \frac{k(D_0 - aC_l) + \left(3ak - 2b^2\right)C_f}{2\left(2ak - b^2\right)} \tag{2}$$

$$s_1{}^* = \frac{b\left[D_0 - a\left(C_f + C_l\right)\right]}{2\left(2ak - b^2\right)} \tag{3}$$

then,

$$q_1{}^* = \frac{ak\left[D_0 - a\left(C_f + C_l\right)\right]}{2(2ak - b^2)} \tag{4}$$

The optimal profits of the E-commerce platform and the farmer and the overall system are further obtained:

$$\pi_{l1}{}^* = \frac{k\left[D_0 - a\left(C_f + C_l\right)\right]^2}{4(2ak - b^2)} \tag{5}$$

$$\pi_{f1}{}^* = \frac{k\left[D_0 - a\left(C_f + C_l\right)\right]^2}{8(2ak - b^2)} \tag{6}$$

$$\pi_1{}^* = \frac{3k\left[D_0 - a\left(C_f + C_l\right)\right]^2}{8(2ak - b^2)} \tag{7}$$

From the optimal decision when the government does not subsidize, the optimal decision of the supply chain is related to the sensitivity of the farmer to improve the greenness of the agricultural product k, the sensitivity coefficient of consumers to the price a, and the sensitivity coefficient of consumers to the greenness of the agricultural product b.

4.2. Subsidizing the Farmer

Suppose that the unit price of government subsidies to farmers is d, then

The profit of the farmer is $\pi_f = \left(W + d - C_f\right)q - \frac{1}{2}ks^2$

The profit of the E-commerce platform is $\pi_l = (p - C_l - W)q$

The system profit is $\pi = \pi_f + \pi_l = \left(p + d - C_f - C_l\right)q - \frac{1}{2}ks^2$

The optimal green decision of the supply chain can be obtained, and the result is shown in Lemma 2.

Lemma 2. *Under the strategy of government subsidizing the farmer, the optimal decisions of the supply chain are as follows:*

$$s_2{}^* = \frac{b\left[D_0 - a\left(C_f + C_l - d\right)\right]}{2(2ak - b^2)} \tag{8}$$

$$W_2{}^* = \frac{k(D_0 - aC_l) + (3ak - 2b^2)\left(C_f - d\right)}{2(2ak - b^2)} \tag{9}$$

$$p_2{}^* = \frac{(3ak - b^2)D_0 + a(ak - b^2)\left(C_f + C_l - d\right)}{2a(2ak - b^2)} \tag{10}$$

then,

$$q_2{}^* = \frac{ak\left[D_0 - a\left(C_f + C_l - d\right)\right]}{2(2ak - b^2)} \tag{11}$$

The optimal profits of the E-commerce platform and the farmer and the overall system are further obtained:

$$\pi_{l2}{}^* = \frac{k\left[D_0 - a\left(C_f + C_l - d\right)\right]^2}{4(2ak - b^2)} \tag{12}$$

$$\pi_{f2}{}^{*} = \frac{k\left[D_0 - a\left(C_f + C_l - d\right)\right]^2}{8(2ak - b^2)} \tag{13}$$

$$\pi_2{}^{*} = \frac{3k\left[D_0 - a\left(C_f + C_l - d\right)\right]^2}{8(2ak - b^2)} \tag{14}$$

It can be seen from the optimal decision that the strategy of subsidizing the farmer impacts the greenness and wholesale price of the agricultural product, which also impacts the sales price of the E-commerce platform. The supply chain decisions composed of the farmer and the E-commerce platform are not only affected by the farmer's sensitivity to the agricultural product's greenness k, consumers' sensitivity to the price a, and consumers' sensitivity to the agricultural product's greenness b, but also by the government the subsidized price d. We further analyze the influence of optimal green effort and subsidy in the supply chain, and the result is shown in Corollary 1.

Corollary 1. $\frac{\partial s_2{}^{*}}{\partial d} = \frac{ab}{2(2ak - b^2)} > 0$

From Corollary 1, it can be seen that under the strategy of subsidizing the farmer, government subsidies positively impact the farmer's greenness of the agricultural product. The greater the government subsidies, the more the farmer is willing to improve the greenness of the agricultural product. Government subsidies have an incentive effect on the green development of the supply chain. Therefore, the government can improve the green quality of agricultural products through subsidy strategies.

Corollary 2. $W_{f2} > W_1{}^{*},\ p_{c2} < p_1{}^{*}$

Proof. The actual wholesale price of the agricultural product is

$$W_{f2} = W_2{}^{*} + d = \frac{k[D_0 - a(C_l - d)] + \left(3ak - 2b^2\right)C_f}{2(2ak - b^2)}$$

$$W_{f2} - W_1{}^{*} = \frac{kad}{2(2ak - b^2)}, \text{ so } W_{f2} > W_1{}^{*}$$

The actual purchase price of consumers is

$$p_{c2} = p_2{}^{*} = \frac{\left(3ak - b^2\right)D_0 + a\left(ak - b^2\right)\left(C_f + C_l - d\right)}{2a(2ak - b^2)}$$

$$p_{c2} - p_1{}^{*} = \frac{-ad\left(ak - b^2\right)}{2a(2ak - b^2)}, \text{ so } p_{c2} < p_1{}^{*}$$

Corollary 2 shows that under the government's strategy of subsidizing the farmer, the actual wholesale price of the agricultural product is higher than that without subsidies, and the cost of consumers buying the agricultural product will decrease instead. That is, both the farmer and consumers benefit. □

Corollary 3. $\frac{\partial W_{f2}}{\partial d} > 0$, $\frac{\partial p_{l2}}{\partial d} < 0$, $\frac{\partial W_{f2}}{\partial d} > \left|\frac{\partial p_{l2}}{\partial d}\right|$.

Proof. $\frac{\partial W_{f2}}{\partial d} = \frac{ak}{2(2ak - b^2)} > 0$, $\frac{\partial p_2{}^{*}}{\partial d} = \frac{\partial p_{l2}}{\partial d} = -\frac{ak - b^2}{2(2ak - b^2)}$

When $ak - b^2 > 0$, $\frac{\partial p_{l2}}{\partial d} < 0$, then $\frac{\partial W_{f2}}{\partial d} - \left|\frac{\partial p_{l2}}{\partial d}\right| = \frac{b^2}{2(2ak - b^2)} > 0$.

When $ak - b^2 < 0$, $\frac{\partial p_{l2}}{\partial d} > 0$, then $\frac{\partial W_{f2}}{\partial d} - \frac{\partial p_{l2}}{\partial d} = \frac{1}{2} > 0$

So $\frac{\partial W_{f2}}{\partial d} > \left|\frac{\partial p_{l2}}{\partial d}\right|$

Corollary 3 shows that under the strategy of government subsidizing the farmer, the actual wholesale price of the farmer increases has a more significant change than the price of e-commerce platforms. □

4.3. Subsidizing the E-Commerce Platform

Suppose that the unit price of the E-commerce platform subsidized by the government is d, then:

The profit of the farmer is $\pi_f = \left(W - C_f\right)q - \frac{1}{2}ks^2$

The profit of the E-commerce platform is $\pi_l = (p + d - C_l - W)q$

The system profit is $\pi = \pi_f + \pi_l = \left(p + d - C_f - C_l\right)q - \frac{1}{2}ks^2$

The optimal green decision of the supply chain can be obtained, and the result is shown in Lemma 3.

Lemma 3. *Under the strategy of government subsidizing the E-commerce platform, the optimal decisions of the supply chain are as follows:*

$$W_3{}^* = \frac{k[D_0 - a(C_l - d)] + \left(3ak - 2b^2\right)C_f}{2(2ak - b^2)},\ s_3{}^* = \frac{b\left[D_0 - a\left(C_f + C_l - d\right)\right]}{2(2ak - b^2)}$$

$p_3{}^* = \frac{\left(3ak-b^2\right)D_0 + a\left(ak-b^2\right)\left(C_f+C_l-d\right)}{2a(2ak-b^2)}$, *then*, $q_2{}^* = \frac{ak\left[D_0-a\left(C_f+C_l-d\right)\right]}{2(2ak-b^2)}$

The optimal profits of the E-commerce platform, the farmer and the overall system are further obtained:

$$\pi_{l3}{}^* = \frac{k\left[D_0 - a\left(C_f + C_l - d\right)\right]^2}{4(2ak - b^2)}, \pi_{f3}{}^* = \frac{k\left[D_0 - a\left(C_f + C_l - d\right)\right]^2}{8(2ak - b^2)},\ \pi_3{}^* = \frac{3k\left[D_0 - a\left(C_f + C_l - d\right)\right]^2}{8(2ak - b^2)}$$

Similarly, it can be seen from the optimal decision that the government's strategy of subsidizing the E-commerce platform alone has an impact on the greenness and wholesale price of the agricultural product, which also has an impact on the sales price of the E-commerce platform. The supply chain decisions composed of the farmer and the E-commerce platform are not only affected by farmers' sensitivity to the agricultural product's greenness k, consumers' sensitivity to the price a, and consumers' sensitivity to the agricultural product's greenness b, but also by the government the subsidized price d. We further analyze the influence of optimal green effort and subsidy in the supply chain, and the result is shown in Corollary 4.

Corollary 4. $\frac{\partial s_2{}^*}{\partial d} = \frac{\partial s_3{}^*}{\partial d} > 0$

Proof. $\frac{\partial s_2{}^*}{\partial d} = \frac{\partial s_3{}^*}{\partial d} = \frac{ab}{2(2ak-b^2)} > 0$

Corollary 4 shows that the strategy of subsidizing the E-commerce platform has a positive effect on the improvement of the greenness of the agricultural product. The impact of subsidies on greenness has the same effect as the government subsidizing the farmer separately. □

Corollary 5. $W_{f3} > W_1{}^*$, $p_{c3} < p_1{}^*$.

Proof. The actual wholesale price of the agricultural product is

$$W_{f3} = W_3{}^* = \frac{k[D_0 - a(C_l - d)] + \left(3ak - 2b^2\right)C_f}{2(2ak - b^2)} = W_{f2} > W_1{}^*$$

The actual purchase price of consumers is

$$p_{c3} = p_3{}^* = \frac{(3ak - b^2)D_0 + a(ak - b^2)\left(C_f + C_l - d\right)}{2a(2ak - b^2)} = p_{c2} < p_1{}^*$$

Corollary 5 shows that under the government's strategy of subsidizing the E-commerce platform, the wholesale price of the agricultural product is higher than that without subsidies, and the cost of consumers buying the agricultural product is lower. That is, both the farmer and consumers benefit. □

Corollary 6. $\frac{\partial W_{f3}}{\partial d} > 0$, $\frac{\partial p_{l3}}{\partial d} < 0$, $\frac{\partial W_{f3}}{\partial d} < \left|\frac{\partial p_{l3}}{\partial d}\right|$.

Proof. The actual selling price of the e-commerce platform is

$$p_{l3} = p_3{}^* + d = \frac{(3ak - b^2)(D_0 - ad) + a(ak - b^2)\left(C_f + C_l\right)}{2a(2ak - b^2)}$$

$$\frac{\partial W_{f3}}{\partial d} = \frac{\partial W_3{}^*}{\partial d} = \frac{ak}{2(2ak - b^2)} > 0,\ \frac{\partial p_{l3}}{\partial d} = -\frac{3ak - b^2}{2(2ak - b^2)} < 0$$

$$\frac{\partial W_{f3}}{\partial d} - \left|\frac{\partial p_{l3}}{\partial d}\right| = -\frac{1}{2} < 0$$

Under the government's strategy of separately subsidizing the E-commerce platform, the actual wholesale price of the agricultural product increase while the sale price of the E-commerce platform declines and the impact on the actual sale price of the E-commerce platform is greater than the impact on the wholesale price of the agricultural product. □

4.4. Subsidizing "Farmer + E-Commerce Platform"

Assuming that the unit price of government subsidies is d, and the proportion of subsidized the E-commerce platform is ρ, $0 < \rho < 1$, then the subsidy price of the E-commerce platform is ρd, and the subsidy price of the farmer is $(1 - \rho)d$. Now

The profit of the farmer is $\pi_f = \left[W + (1 - \rho)d - C_f\right]q - \frac{1}{2}ks^2$

The profit of the E-commerce platform is $\pi_l = (p + \rho d - C_l - W)q$

The system profit is $\pi = \pi_f + \pi_l = \left(p + d - C_f - C_l\right)q - \frac{1}{2}ks^2$

The optimal green decision of the supply chain can be obtained, and the result is shown in Lemma 4.

Lemma 4. *Under the strategy of government subsidies "farmer + E-commerce platform", the optimal decisions of the supply chain are:*

$$W_4{}^* = \frac{k(D_0 - aC_l) + (3ak - 2b^2)C_f + \left[2b^2(1 - \rho) - ak(3 - 4\rho)\right]d}{2(2ak - b^2)}, s_4{}^* = \frac{b\left[D_0 - a\left(C_f + C_l - d\right)\right]}{2(2ak - b^2)}$$

$$p_4{}^* = \frac{(3ak - b^2)D_0 + a(ak - b^2)(C_f + C_l - d)}{2a(2ak - b^2)},\ \textit{then},\ q_4{}^* = \frac{ak\left[D_0 - a\left(C_f + C_l - d\right)\right]}{2(2ak - b^2)}$$

According to Proposition 4, the optimal profits of the E-commerce platform and the farmer and the overall system are further obtained:

$$\pi_{l4}{}^* = \frac{k\left[D_0 - a\left(C_f + C_l - d\right)\right]^2}{4(2ak - b^2)},\ \pi_{f4}{}^* = \frac{k\left[D_0 - a\left(C_f + C_l - d\right)\right]^2}{8(2ak - b^2)} \pi_4{}^* = \frac{3k\left[D_0 - a\left(C_f + C_l - d\right)\right]^2}{8(2ak - b^2)}$$

We further analyze the influence of optimal green effort and subsidy in the supply chain, and the result is shown in Corollary 7.

Corollary 7. $\frac{\partial s_2{}^*}{\partial d} = \frac{\partial s_3{}^*}{\partial d} = \frac{\partial s_4{}^*}{\partial d}$

$$\frac{\partial s_2{}^*}{\partial d} = \frac{\partial s_3{}^*}{\partial d} = \frac{\partial s_4{}^*}{\partial d} = \frac{ab}{2(2ak - b^2)}$$

The three strategies of government subsidies for the supply chain have the same impact on greenness.

Corollary 8. $W_{f4} > W_1{}^*$, $p_{c4} < p_1{}^*$.

Proof. The actual wholesale price of the agricultural product is

$$W_{f4} = W_4{}^* + (1-\rho)d = \frac{k[D_0 - a(C_l - d)] + \left(3ak - 2b^2\right)C_f}{2(2ak - b^2)} = W_{f2} = W_{f3} > W_1{}^*$$

The actual purchase price of consumers is

$$p_{c4} = p_4{}^* = \frac{\left(3ak - b^2\right)D_0 + a\left(ak - b^2\right)\left(C_f + C_l - d\right)}{2a(2ak - b^2)} = p_{c2} = p_{c3} < p_1{}^*$$

Under the government's strategy of subsidizing "farmer + E-commerce platform", the wholesale price of the agricultural product is higher than that without subsidies, and the cost of consumers to buy the agricultural product is lower. That is, both the farmer and consumers benefit. □

Corollary 9. *When* $0 < \rho < \frac{1}{2}$, $\frac{\partial W_{f4}}{\partial d} > \left|\frac{\partial p_{l4}}{\partial d}\right| > 0$. *When* $\frac{1}{2} < \rho < 1$, $\frac{\partial p_{l4}}{\partial d} > \frac{\partial W_{f4}}{\partial d} > 0$

Proof. The actual sales price of the E-commerce platform is

$$p_{l4} = p_4{}^* + \rho d = \frac{\left(3ak - b^2\right)D_0 + a\left(ak - b^2\right)\left(C_f + C_l\right) + a\left[2\rho\left(2ak - b^2\right) - \left(ak - b^2\right)\right]d}{2a(2ak - b^2)}$$

The actual wholesale price of the agricultural product is

$$W_{f4} = W_4{}^* + (1-\rho)d = \frac{k[D_0 - a(C_l - d)] + \left(3ak - 2b^2\right)C_f}{2(2ak - b^2)}$$

Then $\frac{\partial W_{f4}}{\partial d} = \frac{ak}{2(2ak - b^2)} > 0$ and $\frac{\partial p_{l4}}{\partial d} = \frac{2\rho\left(2ak - b^2\right) - \left(ak - b^2\right)}{2(2ak - b^2)}$.
Case 1: $ak - b^2 < 0$
Then $\frac{\partial p_{l4}}{\partial d} > 0$ and $\frac{\partial W_{f4}}{\partial d} - \frac{\partial p_{l4}}{\partial d} = \frac{1-2\rho}{2}$.
When $0 < \rho < \frac{1}{2}$, $\frac{\partial W_{f4}}{\partial d} > \frac{\partial p_{l4}}{\partial d}$; when $\frac{1}{2} < \rho < 1$, $\frac{\partial W_{f4}}{\partial d} < \frac{\partial p_{l4}}{\partial d}$.
Case 2: $ak - b^2 > 0$
When $0 < \rho < \frac{ak - b^2}{2(2ak - b^2)}$, $\frac{\partial p_{l4}}{\partial d} < 0$; When $\frac{ak - b^2}{2(2ak - b^2)} < \rho < 1$, $\frac{\partial p_{l4}}{\partial d} > 0$.
When $0 < \rho < \frac{ak - b^2}{2(2ak - b^2)}$, $\frac{\partial W_{f4}}{\partial d} - \left|\frac{\partial p_{l4}}{\partial d}\right| = \frac{b^2 + 2\rho\left(2ak - b^2\right)}{2(2ak - b^2)} > 0$, then $\frac{\partial W_{f4}}{\partial d} > \left|\frac{\partial p_{l4}}{\partial d}\right|$.
When $\frac{ak - b^2}{2(2ak - b^2)} < \rho < 1$, then $\frac{\partial W_{f4}}{\partial d} - \frac{\partial p_{l4}}{\partial d} = \frac{1-2\rho}{2}$.
So when $\frac{1}{2} < \rho < 1$, $\frac{\partial W_{f4}}{\partial d} < \frac{\partial p_{l4}}{\partial d}$; when $\frac{ak - b^2}{2(2ak - b^2)} < \rho < \frac{1}{2}$, $\frac{\partial W_{f4}}{\partial d} > \frac{\partial p_{l4}}{\partial d}$.

Then $0 < \rho < \frac{ak-b^2}{2(2ak-b^2)}$, $\frac{\partial W_{f4}}{\partial d} > \left|\frac{\partial p_{l4}}{\partial d}\right|$; $\frac{ak-b^2}{2(2ak-b^2)} < \rho < \frac{1}{2}$, $\frac{\partial W_{f4}}{\partial d} > \frac{\partial p_{l4}}{\partial d}$; $\frac{1}{2} < \rho < 1$, $\frac{\partial W_{f4}}{\partial d} < \frac{\partial p_{l4}}{\partial d}$. That is: when $0 < \rho < \frac{1}{2}$, $\frac{\partial W_{f4}}{\partial d} > \left|\frac{\partial p_{l4}}{\partial d}\right|$; when $\frac{1}{2} < \rho < 1$, $\frac{\partial W_{f4}}{\partial d} < \frac{\partial p_{l4}}{\partial d}$.

So whether $ak - b^2$ is greater than 0 or not, the following relationship exists: when $0 < \rho < \frac{1}{2}$, $\frac{\partial W_{f4}}{\partial d} > \left|\frac{\partial p_{l4}}{\partial d}\right|$; when $\frac{1}{2} < \rho < 1$, $\frac{\partial W_{f4}}{\partial d} < \frac{\partial p_{l4}}{\partial d}$.

According to comprehensive inferences 3, 6, and 9, if the government subsidizes a supply chain consisting of farmers and e-commerce platforms, when government subsidies are skewed towards farmers, the actual wholesale price of agricultural products changes more significantly than e-commerce platforms. At the same time, when government subsidies are skewed towards e-commerce platforms, the actual selling price of e-commerce platforms will fluctuate more than agricultural products. □

4.5. Subsidizing Consumers

Suppose the unit price of government subsidies is d, using the practice of Tan et al. [43] for reference, the market demand for the agricultural product $q = D = D_0 - ap + bs + \sigma d$. σ is the sensitivity coefficient of consumers to government price subsidy. Consumers' sensitivity to the agricultural product price is higher than their sensitivity to government price subsidies. That is $a > \sigma$.

The profit of the farmer is $\pi_f = \left(W - C_f\right)q - \frac{1}{2}ks^2$

The profit of the E-commerce platform is $\pi_l = (p - C_l - W)q$

The system profit is $\pi = \pi_f + \pi_l = \left(p - C_f - C_l\right)q - \frac{1}{2}ks^2$

The optimal green decision of the supply chain can be obtained, and the result is shown in Lemma 5.

Lemma 5. *Under the strategy of government subsidies to consumers, the optimal decisions of the supply chain are:*

$$W_5{}^* = \frac{k(D_0 - aC_l + \sigma d) + (3ak - 2b^2)C_f}{2(2ak - b^2)} > W_1{}^* \tag{15}$$

$$s_5{}^* = \frac{b\left[D_0 + \sigma d - a\left(C_f + C_l\right)\right]}{2(2ak - b^2)} \tag{16}$$

$$p_5{}^* = \frac{(3ak - b^2)(D_0 + \sigma d) + a(ak - b^2)\left(C_f + C_l\right)}{2a(2ak - b^2)} \tag{17}$$

then,

$$q_5{}^* = \frac{ak\left[D_0 + \sigma d - a\left(C_f + C_l\right)\right]}{2(2ak - b^2)} \tag{18}$$

According to Lemma 5, the optimal profits of the E-commerce platform and the farmer and the overall system are further obtained:

$$\pi_{l5}{}^* = \frac{k\left[D_0 + \sigma d - a\left(C_f + C_l\right)\right]^2}{4(2ak - b^2)} \tag{19}$$

$$\pi_{f5}{}^* = \frac{k\left[D_0 + \sigma d - a\left(C_f + C_l\right)\right]^2}{8(2ak - b^2)} \tag{20}$$

$$\pi_5{}^* = \frac{3k\left[D_0 + \sigma d - a\left(C_f + C_l\right)\right]^2}{8(2ak - b^2)} \tag{21}$$

It can be seen from the optimal decision that the government's strategy of subsidizing consumers alone impacts the greenness and wholesale price of the agricultural product, which also impacts the sales price of the E-commerce platform. The supply chain decisions composed of the farmer and the E-commerce platform are not only affected by the farmer's sensitivity to the agricultural product's greenness k, consumers' sensitivity to the price a, and consumers' sensitivity to the agricultural product's greenness b, but also by the government the subsidized price d and the sensitivity coefficient of consumers to government price subsidy σ. We further analyze the influence of optimal green effort and subsidy in the supply chain, and the result is shown in Corollary 10.

Corollary 10. $\frac{\partial s_2{}^*}{\partial d} > \frac{\partial s_5{}^*}{\partial d} > 0$

Proof. $\frac{\partial s_5{}^*}{\partial d} = \frac{\sigma b}{2(2ak-b^2)} > 0$, $\frac{\partial s_5{}^*}{\partial d} - \frac{\partial s_2{}^*}{\partial d} = \frac{(\sigma-a)b}{2(2ak-b^2)} < 0$

Corollary 10 shows that under the strategy of government subsidizing consumers alone, the impact of subsidies on green efforts is positive. But the effect is lower than that of the government-subsidized supply chain. □

Corollary 11. $W_{f5} > W_1{}^*$, $p_{c5} < p_1{}^*$

Proof. The actual wholesale price of the agricultural product is

$W_{f5} = W_5{}^* = \frac{k(D_0 - aC_l + \sigma d) + (3ak - 2b^2)C_f}{2(2ak-b^2)}$, then $W_{f5} - W_1{}^* = \frac{k\sigma d}{2(2ak-b^2)}$, so $W_{f5} > W_1{}^*$

The actual purchase price of consumers is

$$p_{c5} = p_5{}^* - d = \frac{(3ak - b^2)(D_0 + \sigma d) - 2a(2ak - b^2)d + a(ak - b^2)\left(C_f + C_l\right)}{2a(2ak - b^2)}$$

Then $p_{c5} - p_2{}^* = \frac{(3ak-b^2)(\sigma-a)b}{2a(2ak-b^2)}$.

Because of $a > \sigma$, so $p_{c5} < p_2{}^*$. While $p_2{}^* < p_1{}^*$, so $p_{c5} < p_1{}^*$.

Corollary 11 shows that under the government's strategy of subsidizing consumers, the actual wholesale price of the agricultural product is higher than that without subsidies. The cost of consumers buying agricultural products has fallen due to subsidies. That is, both the farmer and consumers benefit. □

Corollary 12. $\frac{\partial W_{f5}}{\partial d} > 0$, $\frac{\partial p_{l5}}{\partial d} > 0$ *and* $\frac{\partial W_{f5}}{\partial d} < \frac{\partial p_{l5}}{\partial d}$.

$$\frac{\partial W_{f5}}{\partial d} = \frac{\partial W_5{}^*}{\partial d} = \frac{\sigma k}{2(2ak - b^2)} > 0, \ \frac{\partial p_{l5}}{\partial d} = \frac{\partial p_5{}^*}{\partial d} = \frac{(3ak - b^2)\sigma}{2a(2ak - b^2)} > 0$$

$$\frac{\partial W_{f5}}{\partial d} - \frac{\partial p_{l5}}{\partial d} = \frac{\sigma k}{2(2ak - b^2)} - \frac{(3ak - b^2)\sigma}{2a(2ak - b^2)} = -\frac{\sigma}{2a} < 0$$

Corollary 12 shows that under the government's strategy of separately subsidizing the E-commerce platform, every change in the government subsidy will increase the actual wholesale price of the agricultural product less than the decrease in the sales price of the E-commerce platform.

4.6. Subsidizing "Farmer + Consumers"

Suppose the unit price of government subsidy is d and the proportion of subsidy to consumers is ρ, $0 < \rho < 1$, then the unit price of consumer subsidy is ρd. The unit price of the farmer subsidy is $(1-\rho)d$.

The market demand for the agricultural product is $q = D = D_0 - ap + bs + \sigma\rho d$.

The profit of the farmer is $\pi_f = \left[W + (1-\rho)d - C_f\right]q - \frac{1}{2}ks^2$

The profit of the E-commerce platform is $\pi_l = (p - C_l - W)q$

The system profit is $\pi = \pi_f + \pi_l = \left[p + (1-\rho)d - C_f - C_l\right]q - \frac{1}{2}ks^2$

The optimal green decision of the supply chain can be obtained, and the result is shown in Lemma 6.

Lemma 6. *Under the strategy of government subsidies "farmer + Consumers", the optimal decisions of the supply chain are:*

$$W_6{}^* = \frac{k(D_0 - aC_l + \sigma\rho d) + \left(3ak - 2b^2\right)\left[C_f - (1-\rho)d\right]}{2(2ak - b^2)} \tag{22}$$

$$s_6{}^* = \frac{b\left\{D_0 + \sigma\rho d - a\left[C_f + C_l - (1-\rho)d\right]\right\}}{2(2ak - b^2)} = \frac{b\left[D_0 + (\sigma - a)\rho d - a\left(C_f + C_l - d\right)\right]}{2(2ak - b^2)} \tag{23}$$

$$p_6{}^* = \frac{\left(3ak - b^2\right)(D_0 + \sigma\rho d) + a\left(ak - b^2\right)\left[C_f + C_l - (1-\rho)d\right]}{2a(2ak - b^2)} \tag{24}$$

then,

$$q_6{}^* = \frac{ak\left[D_0 - aC_f + C_l - (1-\rho)d\right]}{2(2ak - b^2)} \tag{25}$$

According to Proposition 6, the optimal profits of the E-commerce platform and the farmer and the overall system are further obtained:

$$\pi_{l6}{}^* = \frac{k\left\{D_0 + \sigma\rho d - a\left[C_f + C_l - (1-\rho)\right]d\right\}^2}{4(2ak - b^2)} = \frac{k\left[D_0 + (\sigma - a)\rho d - a\left(C_f + C_l - d\right)\right]^2}{4(2ak - b^2)} \tag{26}$$

$$\pi_{f6}{}^* = \frac{k\left\{D_0 + \sigma\rho d - a\left[C_f + C_l - (1-\rho)\right]d\right\}^2}{8(2ak - b^2)} = \frac{k\left[D_0 + (\sigma - a)\rho d - a\left(C_f + C_l - d\right)\right]^2}{8(2ak - b^2)} \tag{27}$$

$$\pi_6{}^* = \frac{3k\left\{D_0 + \sigma\rho d - a\left[C_f + C_l - (1-\rho)\right]d\right\}^2}{8(2ak - b^2)} = \frac{3k\left[D_0 + (\sigma - a)\rho d - a\left(C_f + C_l - d\right)\right]^2}{8(2ak - b^2)} \tag{28}$$

Similarly, it can be seen from the optimal decision that the government's strategy of subsidizing "farmer + Consumers" impacts the greenness and wholesale price of the agricultural product, which also impacts the sales price of the E-commerce platform. The supply chain decisions composed of the farmer and the E-commerce platform are not only affected by farmers' sensitivity to the agricultural product's greenness k, consumers' sensitivity to the price a, and consumers' sensitivity to the agricultural product's greenness b, but also by the government the subsidized price d and the sensitivity coefficient of consumers to government price subsidy σ. We further analyze the influence of optimal green effort and subsidy in the supply chain, and the result is shown in Corollary 13.

Corollary 13. $\frac{\partial s_6{}^*}{\partial d} < \frac{\partial s_5{}^*}{\partial d}, \frac{\partial s_6{}^*}{\partial d} < \frac{\partial s_2{}^*}{\partial d}$.

Proof. $\frac{\partial s_6{}^*}{\partial d} - \frac{\partial s_5{}^*}{\partial d} = \frac{(\sigma - a)(1-\rho)b}{2(2ak - b^2)} < 0$. $\frac{\partial s_6{}^*}{\partial d} - \frac{\partial s_2{}^*}{\partial d} = \frac{(\sigma - a)b}{2(2ak - b^2)} < 0$

Corollary 13 shows that under the government's strategy of subsidizing "farmer + consumers", the impact of subsidies on green efforts is positive. However, the effect is lower than that of the government subsidizing consumers alone and lower than that of the government subsidizing the supply chain. □

Corollary 14. $W_{f6} > W_1{}^*$, $p_{c6} < p_1{}^*$

Proof. The actual wholesale price of the agricultural product is

$W_{f6} = W_6{}^* + (1-\rho)d = \frac{k(D_0 - aC_l) + (3ak - 2b^2)C_f + k[\sigma\rho + (1-\rho)a]d}{2(2ak - b^2)}$, then
$W_{f6} - W_1{}^* = \frac{k[\sigma\rho + (1-\rho)a]d}{2(2ak - b^2)}$, so $W_{f6} > W_1{}^*$.
The actual purchase price of consumers is
$p_{c6} = p_6{}^* - \rho d = \frac{(3ak - b^2)[D_0 + (\sigma - a)\rho d] + a(ak - b^2)(C_f + C_l - d)}{2a(2ak - b^2)}$, then

$$p_{c6} - p_2{}^* < \frac{(3ak - b^2)(\sigma - a)\rho d}{2a(2ak - b^2)}$$

Because of $a > \sigma$, $p_{c6} < p_2{}^*$. While $p_2{}^* < p_1{}^*$, so $p_{c6} < p_1{}^*$.

Corollary 14 shows that under the government's strategy of subsidizing "farmer + Consumers", the actual wholesale price of the agricultural product is higher than that without subsidies, and the cost of consumers buying the agricultural product has fallen. That is, both the farmer and consumers benefit. □

Corollary 15. *When* $0 < \rho < \frac{a}{a+\sigma}$, $\frac{\partial W_{f6}}{\partial d} > \left|\frac{\partial p_6{}^*}{\partial d}\right|$; *when* $\frac{a}{a+\sigma} < \rho < 1$, $\frac{\partial W_{f6}}{\partial d} < \frac{\partial p_{l6}}{\partial d}$.

Proof. The actual wholesale price of the agricultural product is

$$W_{f6} = \frac{k\left(D_0 - aC_f\right) + (3ak - 2b^2)C_l + k[\sigma\rho + (1-\rho)a]d}{2(2ak - b^2)}$$

The actual sales price of the E-commerce platform is

$$p_{l6} = p_6{}^* = \frac{(3ak - b^2)(D_0 + \sigma\rho d) + a(ak - b^2)\left[C_f + C_l - (1-\rho)d\right]}{2a(2ak - b^2)}$$

Then $\frac{\partial W_{f6}}{\partial d} = \frac{k[\sigma\rho + (1-\rho)a]}{2(2ak - b^2)} > 0$ and $\frac{\partial p_{l6}}{\partial d} = \frac{(3ak - b^2)\sigma\rho - a(ak - b^2)(1-\rho)}{2a(2ak - b^2)}$
Case 1: $ak - b^2 < 0$

$$\frac{\partial p_{l6}}{\partial d} > 0,\ \frac{\partial W_{f6}}{\partial d} - \frac{\partial p_{l6}}{\partial d} = \frac{a - (a+\sigma)\rho}{2a}$$

So when $0 < \rho < \frac{a}{a+\sigma}$, $\frac{\partial W_{f6}}{\partial d} > \frac{\partial p_{l6}}{\partial d}$; when $\frac{a}{a+\sigma} < \rho < 1$, $\frac{\partial W_{f6}}{\partial d} < \frac{\partial p_{l6}}{\partial d}$.
Case 2: $ak - b^2 > 0$
When $0 < \rho < \frac{a(ak - b^2)}{(3ak - b^2)\sigma + a(ak - b^2)}$, $\frac{\partial p_{l6}}{\partial d} < 0$; when $\frac{a(ak - b^2)}{(3ak - b^2)\sigma + a(ak - b^2)} < \rho < 1$, $\frac{\partial p_{l6}}{\partial d} > 0$.

$$0 < \rho < \frac{a(ak - b^2)}{(3ak - b^2)\sigma + a(ak - b^2)},\ \frac{\partial W_{f6}}{\partial d} - \left|\frac{\partial p_{l6}}{\partial d}\right| = \frac{ab^2(1-\rho) + (4ak - b^2)\sigma\rho}{2a} > 0,\ \frac{\partial W_{f6}}{\partial d} > \left|\frac{\partial p_{l6}}{\partial d}\right|$$

$$\frac{a(ak - b^2)}{(3ak - b^2)\sigma + a(ak - b^2)} < \rho < 1,\ \frac{\partial W_{f6}}{\partial d} - \frac{\partial p_{l6}}{\partial d} = \frac{a - (a+\sigma)\rho}{2a}$$

So when $\frac{a(ak - b^2)}{(3ak - b^2)\sigma + a(ak - b^2)} < \rho < \frac{a}{a+\sigma}$, $\frac{\partial W_{f6}}{\partial d} > \frac{\partial p_{l6}}{\partial d}$; when $\frac{a}{a+\sigma} < \rho < 1$, $\frac{\partial W_{f6}}{\partial d} < \frac{\partial p_{l6}}{\partial d}$.

Then $0 < \rho < \frac{a(ak - b^2)}{(3ak - b^2)\sigma + a(ak - b^2)}$, $\frac{\partial W_{f6}}{\partial d} > \left|\frac{\partial p_{l6}}{\partial d}\right|$; $\frac{a(ak - b^2)}{(3ak - b^2)\sigma + a(ak - b^2)} < \rho < \frac{a}{a+\sigma}$, $\frac{\partial W_{f6}}{\partial d} > \frac{\partial p_{l6}}{\partial d}$; $\frac{a}{a+\sigma} < \rho < 1$, $\frac{\partial W_{f6}}{\partial d} < \frac{\partial p_{l6}}{\partial d}$. That is when $0 < \rho < \frac{a}{a+\sigma}$, $\frac{\partial W_{f6}}{\partial d} > \left|\frac{\partial p_{l6}}{\partial d}\right|$. While $\frac{a}{a+\sigma} < \rho < 1$, $\frac{\partial W_{f6}}{\partial d} < \frac{\partial p_{l6}}{\partial d}$.

Corollary 15 shows that when government subsidies are tilted towards farmers, the actual wholesale price of agricultural products changes by a larger margin than the selling price of e-commerce platforms. When government subsidies are skewed towards consumers, the actual selling price of e-commerce platforms changes more than the wholesale price of agricultural products. □

5. Comparative Analysis of the Effects of the Supply Chain under Different Government Subsidies

The structure of this part is as follows: First, the effects of the three strategies of government subsidies for the supply chain are compared and analysed. Then it analyses the effects of the supply chain in the two cases where the government does not subsidize and subsidize the farmer to decide whether to subsidize the government. Finally, it compares and analyses the effects of government subsidies to the farmer, to consumers, and to "farmer + consumers" and makes decisions about how the government subsidizes.

5.1. Comparison of the Effects of the Three Strategies of Government Subsidies Supply Chain

Proposition 1. $s_2{}^* = s_3{}^* = s_4{}^*$, $p_2{}^* = p_3{}^* = p_4{}^*$ *and* $q_2{}^* = q_3{}^* = q_4{}^*$, $R_{f2}{}^* = R_{f3}{}^* = R_{f4}{}^*$, $R_{l2}{}^* = R_{l3}{}^* = R_{l4}{}^*$ *and* $R_2{}^* = R_3{}^* = R_4{}^*$.

Proposition 1 shows that the effects of the three strategies of government subsidies for the supply chain are the same, except for the different wholesale prices due to different government subsidies and other decision variables. Therefore, the profit of each decision-maker and supply chain is the same.

Under the three methods, because of the different objects of government subsidies, the impact on the wholesale price of the agricultural product and the selling price of the E-commerce platform is not the same. See Table 2 for details.

Table 2. Analysis of the influence of government subsidy on decision variables of the supply chain.

Parameter	Subsidizing the Farmer	Subsidizing the E-Commerce Platform	Subsidizing the Farmer and E-Commerce Platform
$\frac{\partial s^*}{\partial d}$	$\frac{ab}{2(2ak-b^2)}$	$\frac{ab}{2(2ak-b^2)}$	$\frac{ab}{2(2ak-b^2)}$
$\frac{\partial W^*}{\partial d}$	$\frac{ak}{2(2ak-b^2)}$	$\frac{ak}{2(2ak-b^2)}$	$\frac{ak}{2(2ak-b^2)}$
W_f	$\frac{k[D_0-a(C_l-d)]+(3ak-2b^2)C_f}{2(2ak-b^2)}$	$\frac{k[D_0-a(C_l-d)]+(3ak-2b^2)C_f}{2(2ak-b^2)}$	$\frac{k[D_0-a(C_l-d)]+(3ak-2b^2)C_f}{2(2ak-b^2)}$
p_l	$\frac{(3ak-b^2)D_0+a(ak-b^2)(C_f+C_l-d)}{2a(2ak-b^2)}$	$\frac{(3ak-b^2)(D_0-ad)+a(ak-b^2)(C_f+C_l)}{2a(2ak-b^2)}$	$\frac{(3ak-b^2)D_0+a(ak-b^2)(C_f+C_l)+a[2\rho(2ak-b^2)-(ak-b^2)]d}{2a(2ak-b^2)}$
p_c	$\frac{(3ak-b^2)D_0+a(ak-b^2)(C_f+C_l-d)}{2a(2ak-b^2)}$	$\frac{(3ak-b^2)D_0+a(ak-b^2)(C_f+C_l-d)}{2a(2ak-b^2)}$	$\frac{(3ak-b^2)D_0+a(ak-b^2)(C_f+C_l-d)}{2a(2ak-b^2)}$

It can be seen from Table 2 that the three strategies of the government subsidy supply chain have the same impact on the greenness of the agricultural product and the actual wholesale price of the agricultural product. That is $\frac{\partial s_1{}^*}{\partial d} = \frac{\partial s_2{}^*}{\partial d} = \frac{\partial s_3{}^*}{\partial d}$, $\frac{\partial W_1{}^*}{\partial d} = \frac{\partial W_2{}^*}{\partial d} = \frac{\partial W_3{}^*}{\partial d}$. The actual wholesale price of the agricultural product and the actual purchase price of consumers are the same, except that the actual price of e-commerce platforms is different due to different government subsidy objects. That is $W_{f2} = W_{f3} = W_{f4}$, $p_{c2} = p_{c3} = p_{c4}$. The actual wholesale price of the agricultural product is higher than those without subsidies, while the actual purchase prices of consumers are lower than those without subsidies. It shows that under these three strategies, both farmers and consumers benefit.

The effect of the supply chain under the three different government subsidy supply chain strategies is almost the same. The possible reason is: this study assumes that the information between the farmer and the E-commerce platform is completely shared. Therefore, when one party receives a government subsidy, the other party will take the subsidy into consideration when making decisions, which leads to the effect of the three strategies of the subsidy supply chain as subsidies to the farmer. Therefore, when discussing the effects of government subsidies later, the government-subsidized farmer will be discussed as representatives of the government supply chain.

5.2. Comparative Analysis of Whether the Government Subsidizes Farmers or Not

Comparing the government subsidizing the farmer with the no-subsidy policy, a decision about whether to subsidize the government is made. The comparison results are shown in Table 3.

Table 3. Comparison of non-government subsidies and subsidizes the farmer.

Parameter	Non-Government Subsidizing	Subsidizing the Farmer
s^*	$\frac{b\left[D_0-a\left(C_f+C_l\right)\right]}{2(2ak-b^2)}$	$\frac{b\left[D_0-a\left(C_f+C_l-d\right)\right]}{2(2ak-b^2)}$
p^*	$\frac{\left(3ak-b^2\right)D_0+a\left(ak-b^2\right)\left(C_f+C_l\right)}{2a(2ak-b^2)}$	$\frac{\left(3ak-b^2\right)D_0+a\left(ak-b^2\right)\left(C_f+C_l-d\right)}{2a(2ak-b^2)}$
q^*	$\frac{ak\left[D_0-a\left(C_f+C_l\right)\right]}{2(2ak-b^2)}$	$\frac{ak\left[D_0-a\left(C_f+C_l-d\right)\right]}{2(2ak-b^2)}$
$\pi_l{}^*$	$\frac{k\left[D_0-a\left(C_f+C_l\right)\right]^2}{4(2ak-b^2)}$	$\frac{k\left[D_0-a\left(C_f+C_l-d\right)\right]^2}{4(2ak-b^2)}$
$\pi_f{}^*$	$\frac{k\left[D_0-a\left(C_f+C_l\right)\right]^2}{8(2ak-b^2)}$	$\frac{k\left[D_0-a\left(C_f+C_l-d\right)\right]^2}{8(2ak-b^2)}$
π^*	$\frac{3k\left[D_0-a\left(C_f+C_l\right)\right]^2}{8(2ak-b^2)}$	$\frac{3k\left[D_0-a\left(C_f+C_l-d\right)\right]^2}{8(2ak-b^2)}$

$$s_2{}^* - s_1{}^* = \frac{bad}{2(2ak-b^2)} > 0,\ s_2{}^* > s_1{}^*$$

$$p_2{}^* - p_1{}^* = -\frac{(ak-b^2)d}{2(2ak-b^2)}$$

When $ak - b^2 > 0$, $p_2{}^* < p_1{}^*$; when $ak - b^2 < 0$, $p_2{}^* > p_1{}^*$.

$$q_2{}^* - q_1{}^* = \frac{a^2kd}{2(2ak-b^2)} > 0,\ q_2{}^* > q_1{}^*$$

$$\pi_{l2}{}^* - \pi_{l1}{}^* = \frac{kad\left[2D_0 + ad - 2a\left(C_f + C_l\right)\right]}{4(2ak-b^2)} > 0,\ \pi_{l2}{}^* > \pi_{l1}{}^*$$

$$\pi_{f2}{}^* - \pi_{f1}{}^* = \frac{kad\left[2D_0 + ad - 2a\left(C_f + C_l\right)\right]}{8(2ak-b^2)} > 0,\ \pi_{f2}{}^* > \pi_{fl}{}^*$$

$$\pi_2{}^* - \pi_1{}^* = \frac{3kad\left[2D_0 + ad - 2a\left(C_f + C_l\right)\right]}{8(2ak-b^2)} > 0,\ \pi_2{}^* > \pi_1{}^*$$

It can be seen from the calculation in Table 3 that compared with no subsidy, a government subsidy to the farmer will bring about an increase in greenness, a decrease in sales unit price, an increase in sales volume and the increase in profit of decision-making bodies. That is $s_2{}^* > s_1{}^*$, $q_2{}^* > q_1{}^*$, $\pi_{l2}{}^* > \pi_{l1}{}^*$, $\pi_{f2}{}^* > \pi_{f1}{}^*$, $\pi_2{}^* > \pi_1{}^*$. Therefore, the effect of government subsidies is better than the no-subsidy strategy, and the government should decide to subsidize.

5.3. Analysis of Government Subsidy Strategy

Comparing the three strategies of government subsidies to the farmer, consumers and "farmer + consumers", the impacts of government subsidies on various decision-making subjects of supply, the improvement of the actual wholesale price and the greenness of the agricultural product are analyzed to make decisions on how the government subsidies.

From Table 4 we can see that: compared with government subsidies to consumers and government subsidies "farmer + consumers", the government subsidizes a farmer can improve the greenness of the agricultural product, with lower prices of the agricultural product, higher sales, and higher total profits of decision-making entities and systems. That is ${s_2}^* > {s_6}^* > {s_5}^*$, ${p_2}^* < {p_6}^* < {p_5}^*$, ${q_2}^* > {q_6}^* > {q_5}^*$, ${\pi_{l2}}^* > {\pi_{l6}}^* > {\pi_{l5}}^*$, ${\pi_{f2}}^* > {\pi_{f6}}^* > {\pi_{f5}}^*$, ${\pi_2}^* > {\pi_6}^* > {\pi_5}^*$. Therefore, from the perspective of the effect on the greenness of the agricultural product, the sales price of the agricultural product, sales volume and the profits of the decision-making bodies of the supply chain, the effect of government subsidies on the farmer is better than that of government subsidies "farmer + consumers", and the effect of government subsidies to "the farmer + consumers" is better than government subsidies to consumers.

Table 4. Comparison of government subsidies to consumers and subsidies "farmer + consumers".

Parameter	Subsidizing the Farmer	Subsidizing Consumers	Subsidizing "Farmer + Consumers"
s^*	$\frac{b\left[D_0-a\left(C_f+C_l-d\right)\right]}{2(2ak-b^2)}$	$\frac{b\left[D_0+\sigma d-a\left(C_f+C_l\right)\right]}{2(2ak-b^2)}$	$\frac{b\left[D_0+(\sigma-a)\rho d-a\left(C_f+C_l-d\right)\right]}{2(2ak-b^2)}$
p^*	$\frac{\left(3ak-b^2\right)D_0+a\left(ak-b^2\right)\left(C_f+C_l-d\right)}{2a(2ak-b^2)}$	$\frac{\left(3ak-b^2\right)(D_0+\sigma d)+a\left(ak-b^2\right)\left(C_f+C_l\right)}{2a(2ak-b^2)}$	$\frac{\left(3ak-b^2\right)(D_0+\sigma\rho d)+a\left(ak-b^2\right)\left[C_f+C_l-(1-\rho)d\right]}{2a(2ak-b^2)}$
q^*	$\frac{ak\left[D_0-a\left(C_f+C_l-d\right)\right]}{2(2ak-b^2)}$	$\frac{ak\left[D_0+\sigma d-a\left(C_f+C_l\right)\right]}{2(2ak-b^2)}$	$\frac{ak\left[D_0+(\sigma-a)\rho d-a\left(C_f+C_l-d\right)\right]}{2(2ak-b^2)}$
${\pi_l}^*$	$\frac{k\left[D_0-a\left(C_f+C_l-d\right)\right]^2}{4(2ak-b^2)}$	$\frac{k\left[D_0+\sigma d-a\left(C_f+C_l\right)\right]^2}{4(2ak-b^2)}$	$\frac{k\left[D_0+(\sigma-a)\rho d-a\left(C_f+C_l-d\right)\right]^2}{4(2ak-b^2)}$
${\pi_f}^*$	$\frac{k\left[D_0-a\left(C_f+C_l-d\right)\right]^2}{8(2ak-b^2)}$	$\frac{k\left[D_0+\sigma d-a\left(C_f+C_l\right)\right]^2}{8(2ak-b^2)}$	$\frac{k\left[D_0+(\sigma-a)\rho d-a\left(C_f+C_l-d\right)\right]^2}{8(2ak-b^2)}$
π^*	$\frac{3k\left[D_0-a\left(C_f+C_l-d\right)\right]^2}{8(2ak-b^2)}$	$\frac{3k\left[D_0+\sigma d-a\left(C_f+C_l\right)\right]^2}{8(2ak-b^2)}$	$\frac{3k\left[D_0+(\sigma-a)\rho d-a\left(C_f+C_l-d\right)\right]^2}{8(2ak-b^2)}$

$${s_5}^* - {s_6}^* = \frac{b(\sigma-a)(1-\rho)d}{2(2ak-b^2)} < 0,\ {s_2}^* - {s_6}^* = \frac{b(a-\sigma)\rho d}{2(2ak-b^2)} > 0,\ \text{so } {s_2}^* > {s_6}^* > {s_5}^*$$

$${p_5}^* - {p_6}^* = (1-\rho)\frac{\left[\left(3ak-b^2\right)\sigma + a\left(ak-b^2\right)\right]d}{2a(2ak-b^2)},\ {p_2}^* - {p_6}^* = -\frac{\left[a\left(ak-b^2\right)+\sigma\left(3ak-b^2\right)\right]d}{2a(2ak-b^2)}$$

When $ak-b^2 > 0$, ${p_5}^* > {p_6}^*$, ${p_6}^* > {p_2}^*$, so ${p_5}^* > {p_6}^* > {p_2}^*$

$${q_5}^* - {q_6}^* = \frac{ak(\sigma-a)(1-\rho)d}{2(2ak-b^2)} < 0,\ {q_2}^* - {q_6}^* = \frac{ak(a-\sigma)\rho d}{2(2ak-b^2)},\ \text{so } {q_2}^* > {q_6}^* > {q_5}^*$$

$${\pi_{l5}}^* - {\pi_{l6}}^* = \frac{k(\sigma-a)(1-\rho)d\left[2D_0+(a+\sigma)d+(\sigma-a)\rho d-2a\left(C_f+C_l\right)\right]^2}{4(2ak-b^2)} < 0$$

$${\pi_{l2}}^* - {\pi_{l6}}^* = \frac{k(a-\sigma)\rho d\left[2D_0+(\sigma-a)\rho d-2a\left(C_f+C_l-d\right)\right]^2}{4(2ak-b^2)} > 0,\ \text{so } {\pi_{l2}}^* > {\pi_{l6}}^* > {\pi_{l5}}^*$$

$${\pi_{f5}}^* - {\pi_{f6}}^* = \frac{k(\sigma-a)(1-\rho)d\left[2D_0+(a+\sigma)d+(\sigma-a)\rho d-2a\left(C_f+C_l\right)\right]^2}{8(2ak-b^2)} < 0,$$

$${\pi_{f2}}^* - {\pi_{f6}}^* = \frac{k(a-\sigma)d\left[2D_0+(\sigma-a)d-2a\left(C_f+C_l-d\right)\right]^2}{8(2ak-b^2)} > 0,\ \text{so } {\pi_{f2}}^* > {\pi_{f6}}^* > {\pi_{f5}}^*$$

$$\pi_5{}^* - \pi_6{}^* = \frac{3k(\sigma - a)(1-\rho)d\left[2D_0 + (a+\sigma)d + (\sigma - a)\rho d - 2a\left(C_f + C_l\right)\right]^2}{8(2ak - b^2)} < 0$$

$$\pi_2{}^* - \pi_6{}^* = \frac{3k(a-\sigma)d\left[2D_0 + (\sigma - a)d - 2a\left(C_f + C_l - d\right)\right]^2}{8(2ak - b^2)} > 0, \text{ so } \pi_2{}^* > \pi_6{}^* > \pi_5{}^*$$

5.4. Analysis of the Effect of Government Subsidy

Government subsidies not only impact the greenness, wholesale price and selling price of the agricultural product but also impact the actual wholesale price of the agricultural product, the actual selling price of the agricultural product and the actual purchase price of consumers.

$$\frac{\partial s_2{}^*}{\partial d} - \frac{\partial s_6{}^*}{\partial d} = \frac{(a-\sigma)\rho}{2(2ak - b^2)} > 0,\ \frac{\partial s_6{}^*}{\partial d} - \frac{\partial s_5{}^*}{\partial d} = \frac{(a-\sigma)(1-\rho)}{2(2ak-b^2)} > 0, \text{ so } \frac{\partial s_2{}^*}{\partial d} > \frac{\partial s_6{}^*}{\partial d} > \frac{\partial s_5{}^*}{\partial d}$$

$$\frac{\partial W_{f2}}{\partial d} - \frac{\partial W_{f6}}{\partial d} = \frac{(a-\sigma)\rho}{2(2ak - b^2)} > 0,\ \frac{\partial W_{f6}}{\partial d} - \frac{\partial W_{f5}}{\partial d} = \frac{(a-\sigma)(1-\rho)}{2(2ak-b^2)} > 0, \text{ so } \frac{\partial W_{f2}}{\partial d} > \frac{\partial W_{f6}}{\partial d} > \frac{\partial W_{f5}}{\partial d}$$

$$p_{c2} - p_{c6} = \frac{\left(3ak - b^2\right)(a-\sigma)\rho d}{2a(2ak-b^2)} > 0,\ p_{c6} - p_{c5} = \frac{\left(3ak - b^2\right)(a-\sigma)(1-\rho)d}{2a(2ak-b^2)} > 0$$

So $p_{c2} > p_{c6} > p_{c5}$.

From Table 5 we can see that: for the farmer, the increase in greenness and actual wholesale price of the agricultural product for each additional unit of government subsidy is the highest when the government subsidizes the farmer, next when the government subsidizes "farmer and consumers", and the lowest when the government subsidizes consumers. That is $\frac{\partial s_2{}^*}{\partial d} > \frac{\partial s_6{}^*}{\partial d} > \frac{\partial s_5{}^*}{\partial d}$ and $\frac{\partial W_{f2}}{\partial d} > \frac{\partial W_{f6}}{\partial d} > \frac{\partial W_{f5}}{\partial d}$.

Table 5. Comparison of the impact of government subsidy strategies on greenness and agricultural wholesale prices.

Parameter	Subsidizing the Farmer	Subsidizing Consumers	Subsidizing "Farmer + Consumers"
$\frac{\partial s^*}{\partial d}$	$\frac{ab}{2(2ak-b^2)}$	$\frac{\sigma b}{2(2ak-b^2)}$	$\frac{b[(1-\rho)a+\sigma\rho]}{2(2ak-b^2)}$
W_f	$\frac{k(D_0-aC_l+ad)+\left(3ak-2b^2\right)C_f}{2(2ak-b^2)}$	$\frac{k(D_0-aC_l+\sigma d)+\left(3ak-2b^2\right)C_f}{2(2ak-b^2)}$	$\frac{k(D_0-aC_l)+\left(3ak-2b^2\right)C_f+[(1-\rho)a+\sigma\rho]kd}{2(2ak-b^2)}$
$\frac{\partial W_f}{\partial d}$	$\frac{ak}{2(2ak-b^2)}$	$\frac{\sigma k}{2(2ak-b^2)}$	$\frac{[(1-\rho)a+\sigma\rho]k}{2(2ak-b^2)}$
p_c	$\frac{\left(3ak-b^2\right)D_0+a\left(ak-b^2\right)\left(C_f+C_l-d\right)}{2a(2ak-b^2)}$	$\frac{\left(3ak-b^2\right)(D_0+\sigma d)+a\left(ak-b^2\right)\left(C_f+C_l\right)-2a\left(2ak-b^2\right)d}{2a(2ak-b^2)}$	$\frac{\left(3ak-b^2\right)[D_0+(\sigma-a)\rho d]+a\left(ak-b^2\right)\left(C_f+C_l-d\right)}{2a(2ak-b^2)}$

For consumers when the government gradually transfers subsidies to consumers, the actual purchase price of consumers will decrease. That is $p_{c2} > p_{c6} > p_{c5}$.

5.5. Summary

Whether government subsidies or not, the effect of government subsidies is significantly better than that of no government subsidies, all government subsidy strategies can improve the greenness of the agricultural product, lowering the price of the agricultural product, increasing sales, and increasing the overall profit of the supply chain.

From the comparison of the three strategies of government subsidies to the farmer, consumers and "farmer + consumers", it can be seen that from the perspective of improving the greenness of the agricultural product, government subsidies to the farmer have the best effect. From the standpoint of government subsidies to the wholesale price of the agricultural product, the actual wholesale price is the highest under the strategy of government subsidies to the farmer. From the perspective of the effect of government subsidies on the profit of decision-making variables and decision-makers in the supply chain, the effect of government subsidies to the farmer is better than that of government subsidies to "farmer + consumers", and the effect of government subsidies to "farmer + consumers" is better than that of government subsidies to consumers. That is ${s_2}^* > {s_6}^* > {s_5}^*$, ${p_2}^* < {p_6}^* < {p_5}^*$, ${q_2}^* > {q_6}^* > {q_5}^*$, ${\pi_{f2}}^* > {\pi_{f6}}^* > {\pi_{f5}}^*$, ${\pi_{l2}}^* > {\pi_{l6}}^* > {\pi_{l5}}^*$, ${\pi_2}^* > {\pi_6}^* > {\pi_5}^*$. Therefore, the effect of government subsidies on the farmer is the best. It can improve the greenness of the agricultural product, reduce the price of the agricultural product, increase the sales volume, and increase the overall profit of the supply chain.

6. Case Analysis

To verify the effects of different government subsidies, this paper gives specific examples for analysis. Referring to the practice of Yang et al. [46], the allocation of various parameters is as follows: $D_0 = 200$, $a = 8$, $b = 9$, $k = 12$.The demand function of the agricultural product is $D = 200 - 8p + 9s$. $k = 12$ and the cost function of preservation of the farmer is $g(s) = 6s^2$. Let $C_f = 20$, $C_l = 10$, $\sigma = 5$, $d = 1$, $\rho = 0.5$. Due to the balance of supply and demand, there will be $q = D = 200 - 8p + 9s$.

6.1. Comparison of the Effects of Subsidized Supply Chains

Substituting the known values into formulas (8)–(28), the optimal decision-making, profit and overall profit value of the system for each subject of the supply chain under the three strategies of the government-subsidized supply chain are obtained. As shown in Table 6.

Table 6. Comparison of optimal decision and profit level under government subsidy supply chain.

Parameter	Subsidizing a Farmer	Subsidy the E-Commerce Platform	Subsidizing "Farmer + E-Commerce Platform"
s	4.32	4.32	4.32
p	47.18	47.18	47.18
q	61.44	61.44	61.44
W	16.68	17.68	17.48
W_f	17.68	17.68	17.68
π_l	645.12	645.12	645.12
π_f	322.56	322.56	322.56
π	967.68	967.68	967.68

It can be seen from Table 6 that for the farmer and consumers, the actual wholesale price of a farmer is the same as the purchase price of consumers under the three strategies of the subsidy supply chain. At the same time, the profit of each decision variable and decision subject is consistent, so the subsidy effect is the same. However, for the government, subsidizing a farmer individually is not only in line with policy requirements but also convenient, so subsidizing the farmer individually is the best choice for government subsidies.

6.2. Comparison of the Effects of No Government Subsidies and Subsidized Farmers

Substituting the known values into formulas (1)–(14), the optimal decision-making, profit, and overall profit value of the system for each entity in the supply chain under the two strategies of no government subsidies and government subsidies to a farmer are obtained, as shown in Table 7.

Table 7. Comparison of optimal decision-making and profit levels between government-subsidized a farmer and non-subsidized farmers.

Parameter	Non-Government Subsidizing	Subsidizing the Farmer
s	4.54	4.86
p	24.05	23.99
q	48.43	51.89
W	12.05	12.48
W_f	12.05	13.48
π_l	339.03	389.19
π_f	169.51	194.59
π	508.54	583.78

It can be seen from Table 7 that, compared with the non-government subsidy, the greenness, actual wholesale price and sales volume of the agricultural product increase, the price of the agricultural product decreases, and the profits of the farmer, e-commerce platform, and supply chain increase under the government subsidy strategy. It shows that government subsidies can benefit the farmer and the E-commerce platform and bring benefits to consumers. Government subsidies can have multiple effects.

6.3. Comparison of the Effects of Subsidizing a Farmer, Subsidizing Consumers and Subsidizing "Farmer + Consumers"

Substituting the known values into formulas (8)–(14) and (15)–(28), the optimal decision-making, profit, and overall profit value of the system for each entity in the supply chain under the three strategies of government-subsidized a farmer, consumers, and "farmer + consumers" are obtained. As shown in Table 8.

Table 8. Comparison of optimal decision-making and profit levels between government-subsidized the farmer, consumers, and "farmers + consumers".

Parameter	Subsidizing the Farmer	Subsidizing Consumers	Subsidizing "Farmer + Consumers"
s	4.86	4.74	4.80
p	23.99	24.64	24.31
p_c	23.99	23.64	23.81
q	51.89	50.59	51.24
W	12.48	12.32	11.91
W_f	13.48	12.32	12.41
π_l	389.19	369.97	379.52
π_f	194.59	184.99	189.76
π	583.78	554.96	569.28

It can be seen from Table 8 that compared with the three strategies, under the strategy of government subsidies to the farmer, the greenness, actual wholesale price, and sales volume of the agricultural product are the highest. The price of the agricultural product is the lowest, and the profits of the farmer, the E-commerce, and the supply chain are the highest. This shows that government subsidies can benefit farmers and the E-commerce platform.

6.4. Sensitivity Analysis of Government Subsidies to the Farmer

When the price of the government's unit subsidy to farmers changes, the greenness, wholesale price, and the sales volume of an agricultural product will increase with the increase in the unit price subsidy, while the selling price of an agricultural product will decrease with the increase in the unit price subsidy, the profits of e-commerce platforms and farmers have increased with the increase in unit price subsidies. The impact of changes in government unit price subsidies on the profits of various entities in the supply chain is shown in Figure 1 and Table 9.

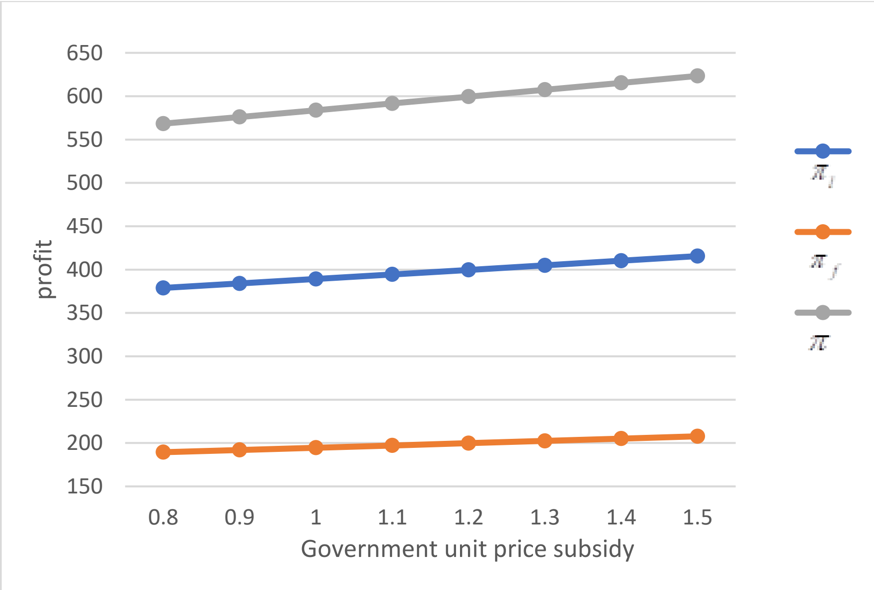

Figure 1. Sensitivity analysis of government unit price subsidy.

Table 9. Sensitivity analysis of government unit price subsidy.

Parameter	$d = 0.8$	$d = 0.9$	$d = 1$	$d = 1.1$	$d = 1.2$	$d = 1.3$	$d = 1.4$	$d = 1.5$
s	4.80	4.83	4.86	4.90	4.93	4.96	4.99	5.03
p	24.00	23.993	23.99	23.986	23.97	23.996	23.959	23.95
q	51.20	51.55	51.89	52.24	52.58	52.93	53.28	53.62
W	12.4	12.44	12.48	12.53	12.57	12.62	12.66	12.70
W_f	13.2	13.34	13.48	13.63	13.77	13.92	14.06	14.20
π_l	378.88	384.02	389.19	394.40	399.64	404.91	410.22	415.57
π_f	189.44	192.01	194.59	197.20	199.82	202.46	205.11	207.78
π	568.32	576.03	583.78	591.60	599.46	607.37	615.33	623.35

6.5. Sensitivity Analysis of Government Subsidy "Farmers + Consumers"

When government subsidies are gradually transferred to consumers, the actual wholesale price of the agricultural product will decrease due to the transfer of government subsidies. As a result, farmers' enthusiasm has declined; thus, the greenness of agricultural products has declined. In addition, E-commerce enterprises transfer government subsidies by raising prices, and the actual purchase price of consumers drops due to government subsidies. As a result, the total profits of all decision-making bodies and systems declined. Table 10 The impact of the change in the proportion of government subsidies on various decision-making variables and decision-makers is shown in Table 10. The effect of the change in the proportion of government subsidies on the profits of various entities in the supply chain is shown in Figure 2 and Table 10.

Table 10. Sensitivity analysis of changes in government subsidy proportion.

Parameter	$\rho = 0.1$	$\rho = 0.2$	$\rho = 0.3$	$\rho = 0.4$	$\rho = 0.5$	$\rho = 0.6$	$\rho = 0.7$	$\rho = 0.8$
s	4.85	4.84	4.83	4.82	4.80	4.79	4.78	4.77
p	24.05	24.12	24.18	24.26	24.31	24.38	24.44	24.51
p_c	23.95	23.92	23.88	23.85	23.81	23.78	23.74	23.71
q	51.76	51.63	51.50	51.37	51.24	51.11	50.98	50.85
W	11.54	11.65	11.74	11.82	11.91	11.99	12.07	12.16
W_f	12.44	12.45	12.44	12.42	12.41	12.39	12.37	12.36
π_l	387.25	385.31	383.37	381.44	379.52	377.60	375.69	373.78
π_f	193.62	192.65	191.69	190.72	189.76	188.80	187.84	186.89
π	580.87	577.96	575.06	572.17	569.28	566.40	563.53	560.67

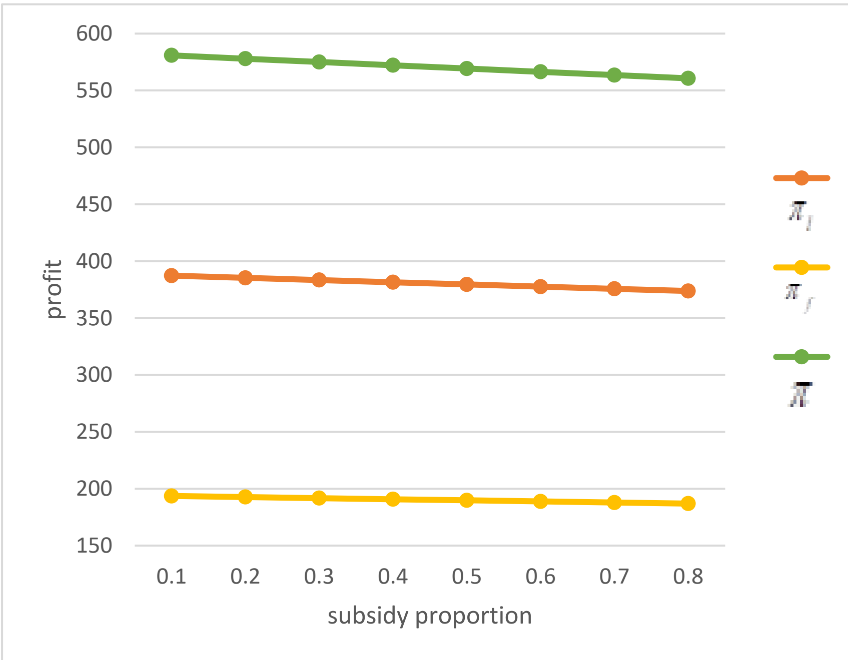

Figure 2. Sensitivity analysis of changes in the proportion of government subsidies.

7. Conclusions and Suggestions

7.1. Research Conclusions

Based on the Stackelberg game theory, this paper first takes an agricultural product as an example to build a decision-making model of supply chains composed of a farmer and an E-commerce platform. By introducing the greenness of the agricultural product, it studies the decision-making variables of the supply chain and the profit of each subject under the condition of no government subsidies as the comparison base. This paper constructs decision-making models under five government subsidy strategies, obtains the decision variables and profits of each decision-making subject under different subsidy strategies, and analyzes the impact of different subsidy strategies on the farmer's wholesale prices, consumer's purchase price, and greenness.

Second, through comparative analysis, it discusses the following aspects: (1) The influence of the three strategies of the government subsidy supply chain on the decision variables of the supply chain and the profit of the decision-making body. The results show that the effects of the three government subsidy strategies are almost the same. (2) Under the two strategies of non-government subsidy and government subsidy to the farmer, the influence of supply chain decision variables and decision-makers' profit is analyzed. It concluded that a government subsidy is significantly better than no subsidy, so the government should decide subsidy. (3) Compare the impacts of the three strategies of government subsidies to the farmer, subsidies to consumers, and subsidies to "farmer + consumers" on the decision variables of the supply chain and the profit of the decision-making body. It concluded that under the government's strategy of subsidizing the farmer, the farmer and the E-commerce platform have made the most profits. Finally, it concluded that the government's strategy of subsidizing rural households is consistent with the current policy and that the effect is the best and has strong operability.

Finally, this study was verified by a numerical example analysis. At the same time, the sensitivity of government subsidies is discussed.

7.2. Recommendations

The government must consider subsidization effects with the country vigorously advocating targeted development in green agricultural products. This paper studies the impact of government subsidization on the decision-making of a two-level supply chain composed of a farmer and an E-commerce platform by comparing different objects and different ways of price subsidies for agricultural products. The government subsidy strategy is best for the farmer or the E-commerce platform. Not only can it increase the actual wholesale price of the farmer, the greenness, and sales of agricultural products, but it also increases the profits of the farmer and the E-commerce platform. The government's unit price subsidies have the best effect on improving the greenness of agricultural products.

7.2.1. Optimize Government Subsidies and Improve the Greenness of Agricultural Products

Applying government subsidies to the agricultural e-commerce supply chain is a gradual process. In the early stage, price subsidies can rapidly increase the sales of agricultural products and then profits. However, in the following stage, it is necessary to continuously encourage farmers to improve the greenness of agricultural products. In this case, subsidies for the greenness of agricultural products may be more effective.

7.2.2. Enhance the Quality of Agricultural Products, Increase Technological Investment, and Promote the Greenness

For farmers, the quality of agricultural products, particularly the greenness of agricultural products, is a crucial factor in determining the sales and profits of agricultural products. Therefore, farmers need to increase their investment in green technology for agricultural products to steadily improve their greenness. Thereby, they can improve the popularity and reputation of agricultural products and increase the sales of agricultural products.

7.2.3. Create a Green Zone for Agricultural Products to Increase Sales of Agricultural Products

With the growth of consumers' quality of life, their emphasis on the greenness of agricultural products has also increased. For e-commerce platforms, it is necessary to satisfy the green demands of consumers. Creating a green agricultural product sales zone on the e-commerce platform can attract consumers and facilitate shopping on the e-commerce platform, thereby effectively improving the sales of agricultural products.

7.3. Research Limitations

This study has the following limitations. First, in practical application, the demand function is affected by many factors. This paper only considers the influence of price and greenness and uses a simple linear relationship. The follow-up study will consider more influencing factors, and the demand function model will be more complex. Second, referring to many scholars' research, the farmer's cost function to improve the agricultural product's greenness may differ from the actual situation. Third, this study only considers the effect of government subsidies from the perspective of the wholesale price of an agricultural product. Government subsidies may be for selling prices or other conditions like greenness. This study should have considered them in detail.

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