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Optimal Decision-Making of Retailer-Led Dual-Channel Green Supply Chain with Fairness Concerns under Government Subsidies

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Abstract: Green innovation is the inevitable trend in the development of the supply chain, and thus the government adopts subsidy policies for the relevant enterprises to enhance their enthusiasm for green development. In view of the manufacturers' fairness concerns in the dual-channel green supply chain that is composed of manufacturers and retailers, we propose a novel Stackelberg game model led by retailers and analyze the impact of manufacturers' fairness concerns on the decision-making of manufacturers and retailers in the dual-channel green supply chain under government subsidies. The results show that only the wholesale price of products, manufacturers' profits, and retailers' profits are affected by manufacturer's fair concerns. When manufacturer has fair concerns, product greenness and profits of supply chain members rise with the increase in government subsidies. The results can offer an effective reference for the dual-channel supply chain members with fairness concerns to make optimal decisions under government subsidies.

Keywords: government subsidies; dual-channel green supply chain; fairness concerns; retailer-led

MSC: 90B06

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1. Introduction

With the rapid development of the economy, environmental degradation has become increasingly obvious, leading to the continuous depletion of natural resources. For example, carbon emissions are recognized as the leading cause of global warming. These environmental problems have attracted the attention of the international community, and many governments have issued a series of international conventions to protect the ecological environment, including the Kyoto Protocol in 1997 and the Climate Change Conference held in Copenhagen in 2010, which indicate that the international community attaches great importance to ecological protection [1]. Therefore, the sustainable green development mode with low consumption and emission has become an inevitable trend. As an effective and sustainable means to overcome resource and environmental constraints and promote sustainable development, green innovation has become the main determinant of green supply chain development [2]. Meanwhile, the implementation of the green supply chain can not only improve ecological problems but also increase the financial performance of supply chain enterprises and improve their competitiveness [3]. With the continuous development of the green supply chain, the sustainable management of the supply chain has become a concern of all walks of life, and the external pressure from the government, consumers, and the media is also growing [4]. For example, the supermarket industry in Britain and Japan, the aerospace industry in Britain and the convenience store industry in Japan are all implementing the green strategy, which reflected the improving environmental awareness and growing business types [5].

On one hand, as the main body of macro-control, the governments have paid more attention to improving the environmental awareness of enterprises and consumers. To

encourage enterprises to develop and produce green products, some governments have introduced a series of incentives and subsidies for green manufacturing to ensure that economic growth is stable and environmental benefits are achieved at the same time. For example, the US Department of Energy implemented a management loan program to accelerate the commercial deployment of innovative new clean technologies and invested $30 billion to support more than 30 projects in different green industries [6]. In 2012, the European Commission invested 41.8 million euros in the green campaign for electric vehicles and funded energy technology research and development [7]. In 2016, the Scottish government spent 70 million pounds on subsidies to encourage the circular economy [8]. Moreover, in the Notice on Promoting the Green Development of E-commerce Enterprises [9] issued by the Ministry of Commerce in 2021, the Chinese government emphasized the importance and necessity of green development, which can ensure the high-quality development of e-commerce and also pointed out that building a modern economy should rely on green development. According to the above research, members of the supply chain can get incentives through various government subsidies. Therefore, to establish a system of sustainable green supply chain, it is necessary to bring government subsidies into the system for decision-making research.

On the other hand, due to the rapid development of e-commerce, customers' shopping behavior is changing, and people are getting used to online shopping. In 2021, the number of online-shopping users in China has reached 842 million, accounting for 81.6% of the total Internet users [10]. The way of purchasing products on e-commerce platform can increase the choice of customers, demonstrating that the online markets have a broad prospect. Some enterprises develop the online sale channel while maintaining the original offline sale channel, and thus the dual-channel supply chain development model arises spontaneously. For example, some manufacturers, such as Dell, Apple, Nike, and HP, have adopted a dual-channel supply chain structure to distribute their products. Meanwhile, some companies, such as Amazon, Alibaba, and JD, provide sale platforms for these manufacturers that choose the dual-channel strategy. As a giant enterprise in the household appliance, Suning only used offline sale mode at the beginning, but the development of e-commerce in recent years forced Suning to open up the online channel. The diversification of channels urges manufacturers to establish online sales to increase their market share, which also makes up for the defects of the traditional sale channel. However, in the case of the coexistence of dual channels, the difference in market share of manufacturers in each channel will affect consumers' choice, cause changes in channel demands, and thus affect the income of supply chain members. Under such an environment of the dual-channel supply chain, it is a realistic and urgent problem to explore the impact of the market share of manufacturers' online channel on the overall supply chain.

In the development process of green supply chain, although many enterprises take sustainable development as their future strategy, the core meaning is still to focus on their own interests. Manufacturers that are responsible for production and research development pay special attention to their own returns. When supply chain members think that their own investment is inconsistent with the return, they will pay extra attention to the fairness of channel profit distribution, resulting in manufacturers' fairness concerns [11]. Meanwhile, in the real business environment, due to the progress of information technology and familiarity with the market, some retailers have become powerful and gradually gained the leading position in supply chain channels, such as Suning, Vanguard, Gome, Wal Mart, and Home Depot, dominate the behavior decisions of members of the supply chain [12]. Therefore, when considering the governments' green innovation subsidies to supply chain members, it is necessary to pay attention to the fair concerns of manufacturers under the leadership of retailers in the supply chain. The manufacturers implementing green innovative technologies, especially small and medium-sized ones, have become a vulnerable group in cooperation with powerful retailers. For example, the "price war" between Gome and Gree continues to affect the relationship between the two. The "no gross loss" rule of Gome triggered Gree's fairness concerns. Gree realized that there was

an uneven profit distribution between retailers and thus ended the cooperation. After reaching a fair deal, Gree and Gome started cooperation again. Nowadays, much research on green supply chains considers fairness concerns of members in the supply chain, but most only focus on the fairness of retailers, ignoring the fairness concerns of manufacturers. Moreover, in the dual-channel green supply chain, the pricing of products, terminal sales prices, and the prices of retailers' wholesale products from suppliers are different, and the online channel opened by manufacturers will compete with the offline channel dominated by retailers, which will affect the distribution decisions of channel profits and trigger the mechanism of manufacturer's fairness concerns. Therefore, it is of practical significance to consider the manufacturer's fair concerns.

Based on the above analysis, we construct a game model of dual-channel green supply chain under government subsidies and retailers' dominance with the consideration of the manufacturer's fairness concerns, which expands the traditional game model of single-channel green supply chain. Based on the situation of government green subsidies and retailers' dominance, we study the impact of manufacturer's fairness concerns on members' decision-making behaviors, in order to promote the green innovation of supply chain enterprises and the sustainable development, and meanwhile provides the government with theoretical support for making decisions.

Therefore, the following issues are mainly studied in this paper:

(1) Based on the situation that the government grants green subsidies to manufacturers, how do manufacturers' fairness concerns affect manufacturers' and retailers' optimal decisions and profits?

(2) What is the impact of different levels of government green subsidies to manufacturers on the supply chain?

(3) Under the green subsidies of the government, how do the optimal decisions and optimal profits of manufacturers and retailers change with the green efficiency of products?

(4) How will the change of market share for manufacturers' network channel affect the supply chain?

As there are few literatures related to the introduction of government subsidies and manufacturers' fairness concerns in the retailer-led dual channel green supply chain, the novelty of this paper lies in:

(1) The fairness concerns of manufacturers are introduced into the dual-channel green supply chain with government green subsidies, and the impact of government green subsidies, manufacturers' fair concern intensity and other factors on the decision-making of members in the dual-channel green supply chain is discussed.

(2) Retailers act as leaders in the dual-channel green supply chain with government green subsidies, while manufacturers act as followers in the supply chain. Under this structure of the supply chain, we discuss the impact of government green subsidies, manufacturers' fair concern intensity and other factors on the decision-making of members in the dual-channel green supply chain.

The rest of this paper is structured as follows. Section 2 reviews the related literature. In Section 3, the conditional assumptions and the model are established. Section 4 analyzes the model. Section 5 discusses the results. Finally, Section 6 gives the conclusion of this paper.

2. Literature Review

2.1. Dual-Channel Green Supply Chain

Green supply chain was first proposed by the Manufacturing Research Association of Michigan State University in 1996 in a study of "environmentally responsible of manufacturing", which is a modern supply chain management model that considers both resource efficiency and environmental impact. The dual-channel green supply chain is a supply chain structure combining green production and dual-channel operation. In other words, a network channel is established outside the original traditional offline channel.

In recent years, dual-channel green supply chain has attracted attention from all walks of life, and its abundant research has strong theoretical basis and practical guiding significance for policy makers. For supply chain enterprises, the dual channel supply chain model has a bright prospect [13].

He et al. [14] believed that compared with the traditional single-channel model, retailers adopting the dual-channel model can attract more consumers due to the diversity of choices. He et al. [15] studied the dual-channel green supply chain led by manufacturers and investigated the influence of retailers' efforts on the overall profit of the supply chain. Aslani et al. [16] analyzed the coordination between product pricing and product greenness in the dual-channel supply chain under the condition of channel interruption. Li et al. [17] studied the dual-channel green supply chain and analyzed the pricing and greening strategies of supply chain members under the centralized and decentralized conditions. Li et al. [18] discussed the pricing and greening strategies of supply chain members in different coordination modes based on the unified pricing strategy in the dual-channel green supply chain and concluded that the greening pricing strategies of supply chain are greatly affected by several factors: customer loyalty to retail channels, green cost and green sensitivity. Barman et al. [19] considered the double-echelon dual-channel green supply chain of a single manufacturer and retailer and concluded that both the demand degree of retail channel and network channel are affected by product price and product green degree. Gao J. et al. [20] considered the relationship between competition and coordination of dual-channel green supply chain with ecolabel policy, indicating that ecolabel policy can improve the economic and environmental performance of supply chain.

2.2. Government Green Subsidies

On the one hand, the production of green products requires a large amount of investment, resulting in a low profit margin of enterprises. On the other hand, the green innovation of products is limited by enterprise's technology, capital and other problems, and cannot meet the requirements of sustainable development [21]. Therefore, the government encourages enterprises to carry out green innovation through green subsidies.

Meng et al. [22] discussed the product coordination pricing policy in the dual-channel supply chain under the conditions of government subsidies and consumer preferences and came up with the optimal solution. Lou et al. [23] studied the government's green subsidies and the optimal strategies of manufacturers and retailers under the two-level supply chain. Li et al. [24] considered the impact of two types of government subsidies on green technology investment and green coordination under cap-and-trade mechanism. Yu et al. [25] discussed the decision-making problem of manufacturers in determining the level of green products and the production quantity of green products and considered the optimization model of manufacturers with green preference and government subsidies. Yang et al. [26] mainly studied the influence of channel leadership and government intervention on retail price, green level and expected profit with the condition of ambiguity and uncertainty. Madani et al. [27] discussed the product pricing, carbon tariff decision and green input of enterprises under government supervision. In the evolutionary game model, Sun et al. [28] considered three kinds of government subsidy cases and studied the evolution model of green investment in the two-tier supply chain based on the government subsidy mechanism. Liu et al. [29] studied the impact of government subsidies on the profits of green supply chain members by three-stage Stackelberg model.

2.3. Green Supply Chain with Fairness Concerns

Perfectly rational decision states are merely theoretical assumptions. In reality, decision makers not only consider the maximization of their own interests, but also consider the interests of the other side. Enterprises in the supply chain will inevitably have the problem of profit distribution. Manufacturers in charge of production will pay extra attention to their own costs, resulting in manufacturer's fair concern behavior, and pay attention to the fairness of supply chain channel distribution [30]. The theory of Fairness Concerns holds

that when the partners think there is unfair distribution, they will punish the other side in some way even if it will harm their own interests.

Kim et al. [31] believe that the concept of equity plays a positive role in supply chain innovation, strengthening resource sharing among supply chain members and maintaining the stability of member relations. Zhang et al. [32] discussed how green preference of green suppliers affects product greenness and supply chain profit, and how to allocate supply chain surplus in the context of fair preference based on "cooperative game theory". Wang et al. [33] believed that manufacturers' fair preference would lead to the decline of product greenness and supply chain operation efficiency in green supply chain. Li et al. [34] believe that there is a negative relationship between the emission reduction cost of manufacturers and the fairness preference of retailers. Yang et al. [35] analyzed the influence of different fairness considerations on green supply chain and found that under the retailer-dominated structure, retail price, product greenness and total profit of supply chain would not be affected by fairness concerns. Jian et al. [36] consider the influence of manufacturers' fairness concerns on retailers' sales, product greenness, recovery rate and product pricing decision in green closed-loop supply chain. Li et al. [37] considered green product design in the supply chain and studied the influence of retailers' fairness concerns on green product design schemes under different circumstances.

2.4. Analysis

The existing literature has laid a good theoretical foundation for the research of this paper, but there are still some gaps in the current research which mainly includes the following points.

(1) On the study of dual-channel supply chain, many literatures focus on the influence of consumer behavior preference on supply chain channels and the pricing coordination problems existing in dual-channel supply chain. On the one hand, the profit distribution link in the supply chain is ignored. On the other hand, it is unreasonable to assume that all members in the green supply chain are in a completely rational state, and the fair concern behavior is not taken into account.

(2) Government subsidies play a positive role in supply chain decision-making, but the subsidy objects are mostly limited to supply chain members without dual-channel opening, and few pay attention to government green subsidies in dual-channel green supply chain.

(3) In the study of fairness concern, many scholars have discussed the fairness concern behavior of supply chain members from different perspectives. However, the existing studies on government subsidies only consider the fairness concerns of retailers in manufacturer-led supply chains and ignore retailers. With the development of modern business, the position of retailers in the supply chain is improving day by day. As the main body of supply chain, the fairness concern behavior of many small and medium-sized manufacturers is also worth to be investigated.

3. Model Description

3.1. Model Assumptions

This paper takes the two-channel and two-level green supply chain consisting of one manufacturer and one retailer as the research objects. The studies mainly focus on optimal decision of the two-channel green supply chain dominated by retailer considering fairness concerns under the government subsidy policy. After receiving the government green innovation subsidies, the manufactures supply green products to retailers through traditional retail channels (denoted as r), and on the other hand, they directly sell to consumers through online channels (denoted as d). Since retail giants such as Tesco, Costco and Aeon have great power of discourse and high user preferences in supply channels, this paper sets retailer as the dominant of Stackelberg game.

In the game model, the retailer's decision behavior depends on the manufacturer's decision behavior. First, manufacturers set direct and wholesale prices based on a given retail price in order to maximize their profits. Secondly, retailers can set their own optimal

retail price according to the manufacturer's pricing to ensure that they can get the maximum profit. Figure 1 illustrates the structure of the dual-channel green supply chain.

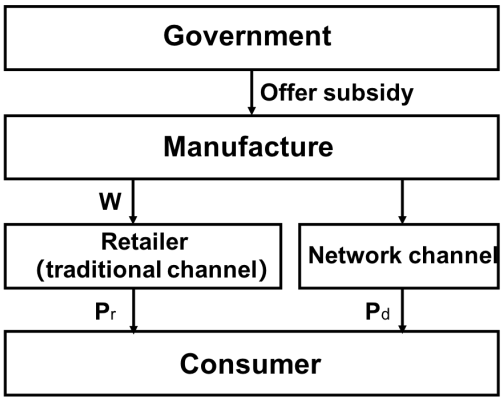

Figure 1. The structure of the dual-channel green supply chain.

Based on the above background, assumptions are made as follows.

(1) In the traditional channel, the wholesale price set by the manufacturer is w, the retail price set by the retailer is $p_r(p_r > w)$, the price at which the manufacturer directly sells green products to consumers through the network channel is p_d, the carbon emission reduction in the production process (the product green degree) is g, and the sensitivity coefficient of consumers to product greenness is $\gamma(\gamma > 0)$. The market demand for green products is jointly affected by p_r, p_d, and g.

(2) The R&D cost of green products produced by manufacturers is $c(g) = kg^2/2$ $(k > 0)$ [11], where k is the cost coefficient. To facilitate the analysis and discussion, the product green efficiency is defined as $E_g = \frac{\gamma^2}{k}$. When products with the same green degree are produced, the lower the green cost or higher sensitivity to green products will lead to higher efficiency of product green.

(3) When a manufacturer has fairness concerns, its goal is to maximize its own utility, which is defined as U_m.

(4) The amount of subsidy given by the government to manufacturers per unit of carbon emission reduction is s.

Table 1 defines the model parameters.

Table 1. Model parameters and definitions.

Decision Variables	Implications
w	Wholesale price
δ	Retailer profit for single product in traditional channels
p_r	Retail price of retailers in the traditional channel
p_d	Direct selling price of manufacturers in the network channel
g	Product green degree
Relevant Parameters	**Implications**
c	Fixed cost of products
k	Cost coefficient of carbon emission reduction, $k > 0$
β	sales price sensitivity coeffificient, $\beta > 0$
θ	Coefficient of cross price sensitivity among different channels, $\theta > 0$
γ	Coefficient of consumer green preference, $\gamma > 0$
λ	Coefficient of manufacturer's fairness concerns, $\lambda > 0$
a	Market share of the online direct channel
Q	Potential market demand for green products
s	Government subsidies for unit carbon emission reduction
$*$	Optimum situation
Functions	**Implications**
D_r	Market demand of traditional retail channel
D_m	Market demand of network direct selling channel
π_r	Retailer profit
π_m	Manufacture profit
π_{sc}	Profit of supply chain
U_m	Manufacturer's utility function

Based on the above assumptions:
(1) The market demand of the traditional retail channel is defined as

$$D_r = (1-a)Q - \beta p_r + \theta p_d + \gamma g \tag{1}$$

(2) The market demand of the online direct channel [13] is defined as

$$D_d = aQ - \beta p_d + \theta p_r + \gamma g \tag{2}$$

(3) The manufacturer's profit is defined as

$$\pi_m = (w-c)D_r + (p_d - c)D_d + sg - kg^2/2 \tag{3}$$

(4) The retailer's profit is defined as

$$\pi_r = (p_r - w)D_r \tag{4}$$

(5) The utility of the manufacturer is defined as

$$U_m = \pi_m(1+\lambda) - \lambda\pi_r \tag{5}$$

3.2. Decision-Making Model of Dual Channel Green Supply Chain with Manufacturers' Fairness Concerns under Government Subsidies

The manufacturers have the negative effect of envy due to the unfair distribution of income. The retailer is the leader in the supply chain and can obtain a larger share of profits. Therefore, the variable $\delta = p_r - w$ is introduced, which is the retailer's profit per unit product. The retailer's decisions depend on the manufacturer's decisions.

The inverse induction method is used to solve the model. First, the partial derivatives of w, p_d and g of Equation (6) is calculated to obtain the Hessian matrix as follows.

$$H = \begin{bmatrix} \frac{\partial^2 U_m}{\partial w^2} & \frac{\partial^2 U_m}{\partial w \partial p_d^\lambda} & \frac{\partial^2 U_m}{\partial w \partial g} \\ \frac{\partial^2 U_m}{\partial p_d \partial w} & \frac{\partial^2 U_m}{\partial p_d^2} & \frac{\partial^2 U_m}{\partial p_d \partial g} \\ \frac{\partial^2 U_m}{\partial g \partial w} & \frac{\partial^2 U_m}{\partial g \partial p_d^\lambda} & \frac{\partial^2 U_m}{\partial g^2} \end{bmatrix} = \begin{bmatrix} -2\beta(1+\lambda) & 2\theta(1+\lambda) & \gamma(1+\lambda) \\ 2\theta(1+\lambda) & -2\beta(1+\lambda) & \gamma(1+\lambda) \\ \gamma(1+\lambda) & \gamma(1+\lambda) & -k(1+\lambda) \end{bmatrix} \tag{6}$$

When U_m exist the maximum, the above Hessian matrix should be a negative definite matrix. Thus, the first principal sub-formula $-2\beta(1+\lambda) < 0$, the second one $4(\beta-\theta)(\beta+\theta)(1+\lambda) > 0$, and the third one $-4(\beta+\theta)(\lambda+1)^3\left(\beta k - \gamma^2 - k\theta\right) < 0$. When $\beta > \theta$ and $\beta k - \gamma^2 - k\theta > 0$ are set, there exist an optimal solution (w^*, p_d^*, g^*) that can maximize the utility of manufacturers.

The first derivative of U_m with respect to w, p_d and g is calculated as

$$\frac{\partial U_m}{\partial p_d} = \theta\delta + (1+\lambda)(aQ + c\beta - 2\beta p_d - c\theta + g\gamma + 2\theta w)$$

$$\frac{\partial U_m}{\partial w} = -\beta\delta - (1+\lambda)((-1+a)Q - c\beta + 2\beta w + c\theta - g\gamma - 2\theta p_d)$$

$$\frac{\partial U_m}{\partial g} = -\gamma\lambda\delta + (1+\lambda)(s - gk + \gamma(w + p_d - 2c))$$

Next, the above variables are set to 0, and w, p_d and g can be calculated, respectively.

$$w = \frac{(-QA_2 + 2kA_5 + \gamma A_4)(1+\lambda) - B_1\gamma^2\delta(2\lambda-1) - 2B_1B_2k\delta}{4B_1B_3(\lambda+1)}$$

$$p_d = \frac{(QA_2 + 2kA_3 + \gamma A_4)(1+\lambda) - B_1\gamma^2\delta(2\lambda+1)}{4B_1B_3(\lambda+1)}$$

$$g = -\frac{A_1(\lambda+1) - B_2\gamma\delta(1+2\lambda)}{2B_3(\lambda+1)}$$

where

$$A_1 = Q\gamma - 2\beta\gamma c + 2\beta s + 2\gamma\theta c - 2\theta s$$
$$A_2 = 2a\beta k - 2a\gamma^2 - 2ak\theta + \gamma^2$$
$$A_3 = Q\theta + \beta^2 c - c\theta^2$$
$$A_4 = 2\beta s + 2\theta s - 4\beta\gamma c - 4\gamma\theta c$$
$$A_5 = Q\beta + \beta^2 c - c\theta^2$$
$$B_1 = \beta + \theta$$
$$B_2 = \beta - \theta$$
$$B_3 = \beta k - \gamma^2 - k\theta$$

Next, the above variables are substituted into Equation (4) and the first-order partial derivative of unit product profit is calculated as

$$\frac{\mathrm{d}\pi_r}{\mathrm{d}\delta} = -\frac{\begin{array}{c}[-2A_1B_1\gamma - A_2B_1Q + 2A_3\beta k + A_4B_2\gamma - 2A_5k\theta + 4B_1B_3Q(a-1)](2\lambda+1) \\ -4B_1B_2\beta\delta k + 2B_1\delta\gamma^2(2\lambda+1)(2B_2+\theta) + 8B_1B_3\beta\delta(\lambda+1) - 2B_1\beta\delta\gamma^2(2\lambda-1)\end{array}}{4B_1B_3(\lambda+1)}$$

Next, the above variable is set to 0, and the unit optimal product profit can be calculated as

$$\delta^* = \frac{(\lambda+1)(-A_2Q + 2A_6k + A_7)}{2B_4(2\lambda+1)}$$

where

$$A_6 = Q\beta - Q\theta - \beta^2 c + 2\beta c\theta - c\theta^2$$
$$A_7 = 2\gamma s(\beta - \theta)$$
$$B_4 = 2k\beta(\beta - \theta) - \gamma^2(\beta + \theta)$$

Next, the optimal product wholesale price w^*, online channel direct sale price p_d^*, and product green degree g^* can be obtained through elimination and simplification as

$$w^* = -\frac{2B_4(2\lambda+1)(A_2Q - 2A_3k - A_4\gamma) - [2B_1B_2k + B_1\gamma^2(2\lambda-1)](A_2Q - 2A_6k - A_7)}{8B_1B_3B_4(2\lambda+1)} \tag{7}$$

$$p_d^* = \frac{A_2B_1Q\gamma^2 + 2A_2B_4Q + 2A_4B_4\gamma + 4A_5B_4k - 2A_6B_1\gamma^2k - A_7B_1\gamma^2}{8B_1B_3B_4} \tag{8}$$

$$g^* = -\frac{-2A_1B_4 - A_2B_2Q\gamma + 2A_6B_2\gamma k + A_7B_2\gamma}{4B_3B_4} \tag{9}$$

By introducing the above optimal solution into Equations (1)–(4), the manufacturer's optimal profit π_m^*, the retailer's optimal profit π_r^* and the supply chain's profit π_{sc}^* can be obtained.

4. Model Analysis

Proposition 1. $\frac{\partial p_d^*}{\partial\lambda} = 0$, $\frac{\partial p_r}{\partial\lambda} = 0$, $\frac{\partial g^*}{\partial\lambda} = 0$, $\frac{\partial D_r^*}{\partial\lambda} = 0$, $\frac{\partial D_d^*}{\partial\lambda} = 0$.

Proof. It can be proved by derivation analysis.

Inference 1 indicated that, under the subsidies of green innovation provided by the government to manufacturers, the fair concerns of manufacturers do not affect the direct selling price of the online channel, the retail price of the traditional channel, the product greenness, and the market demand of the two channels. □

Proposition 2. $\frac{\partial^2 w}{\partial\lambda\partial a} < 0$.

Proof. $\frac{\partial^2 w}{\partial\lambda\partial a} = -\frac{Q(\beta k - \gamma^2 - k\theta)}{(2k\beta(\beta-\theta) - \gamma^2(\beta+\theta))(1+2\lambda)^2}$ and $\beta > \theta$, thus $\beta - \theta < \frac{2\beta(\beta-\theta)}{\beta+\theta}$.

Since $\frac{\gamma^2}{k} < \beta - \theta$, there must be $\frac{\gamma^2}{k} < \frac{2\beta(\beta-\theta)}{\beta+\theta}$, $2k\beta(\beta-\theta) - \gamma^2(\beta+\theta) > 0$.

Therefore, $\frac{\partial^2 w}{\partial\lambda\partial a} < 0$.

Inference 2 showed the sensitivity of wholesale prices to their fair concerns decrease with the increase in market share of the online channel. □

Proposition 3. $\frac{\partial\pi_m^*}{\partial\lambda} > 0$.

Proof. In $\frac{\partial\pi_m^*}{\partial\lambda} = \frac{\left(-2Qa\beta k+2Qa\gamma^2+2Qak\theta+2Q\beta k-Q\gamma^2-2Qk\theta-2\beta^2ck+4\beta ck\theta+2\beta\gamma s-2ck\theta^2-2\gamma s\theta\right)^2}{16(2\lambda+1)^2(\beta k-\gamma^2-k\theta)(2k\beta(\beta-\theta)-\gamma^2(\beta+\theta))}$, the numerator is always greater than 0. Since $\beta k - \gamma^2 - k\theta > 0$ and $2k\beta(\beta-\theta) - \gamma^2(\beta+\theta) > 0$, thus $\frac{\partial\pi_m^*}{\partial\lambda} > 0$.

Inference 3 proved that the manufacturers' profits increase with the enhancement of manufacturers' fairness concerns. □

Proposition 4. $\frac{\partial\pi_r^*}{\partial\lambda} < 0$.

Proof.

$$\frac{\partial\pi_r^*}{\partial\lambda} = -\frac{\left(-2Qa\beta k + 2Qa\gamma^2 + 2Qak\theta + 2Q\beta k - Q\gamma^2 - 2Qk\theta - 2\beta^2 ck + 4\beta ck\theta + 2\beta\gamma s - 2ck\theta^2 - 2\gamma s\theta\right)^2}{16(2\lambda+1)^2(\beta k - \gamma^2 - k\theta)(2\beta^2 k - \beta\gamma^2 - 2\beta k\theta - \gamma^2\theta)}$$

In this equation, the numerator is always greater than 0. Since $\beta k - \gamma^2 - k\theta > 0$ and $2k\beta(\beta-\theta) - \gamma^2(\beta+\theta) > 0$, $\frac{\partial\pi_r^*}{\partial\lambda} < 0$ always set up.

Inference 4 proved that the retailers' profits decrease with the enhancement of manufacturers' fairness concerns. □

5. Results and Discussions

To verify the inferences from Section 4, numerical examples are used to discuss the effects of government green subsidies and the degree of manufacturer's fairness concern on price and profit from different supply chain objects in this section. The relevant parameters were set as follows.

$$\beta = 1.5, \theta = 0.5, c = 20, Q = 100, k = 5, s = 1, a \in [0,1], \lambda \in [0,1).$$

5.1. The Impact of Manufacturers' Fairness Concerns on Supply Chain under Different Product Green Efficiency

According to the condition that Hessian matrix is negative definite matrix and the numerical setting in this section, we can assume that the range of product green efficiency is $0 < E_g < 1$, the value of product low green efficiency is $E_g = 0.2(\gamma = 1)$ and the value of product high green efficiency is $E_g = 0.8(\gamma = 2)$.

According to Figure 2, three characteristics can be found. First and foremost, when the product green efficiency and network market share are fixed, the wholesale price of the product will increase with the enhancement of the fairness concern intensity of the manufacturer. On the other hand, retailers' profit per unit product will decrease as manufacturers' fairness concerns increase. The reason is that the manufacturers, as the followers in the supply chain, will set higher wholesale prices in order to improve their own utility. What's more, When the product green efficiency is constant, the wholesale price of the product will decrease with the increase in the network market share. In order to stabilize the market demand, retailers need to maintain the same selling price, which can only reduce the sales profit per unit of product. Last but not the least, when the network market share is fixed, the wholesale price and the profit per unit product will rise along with the improvement of product green efficiency.

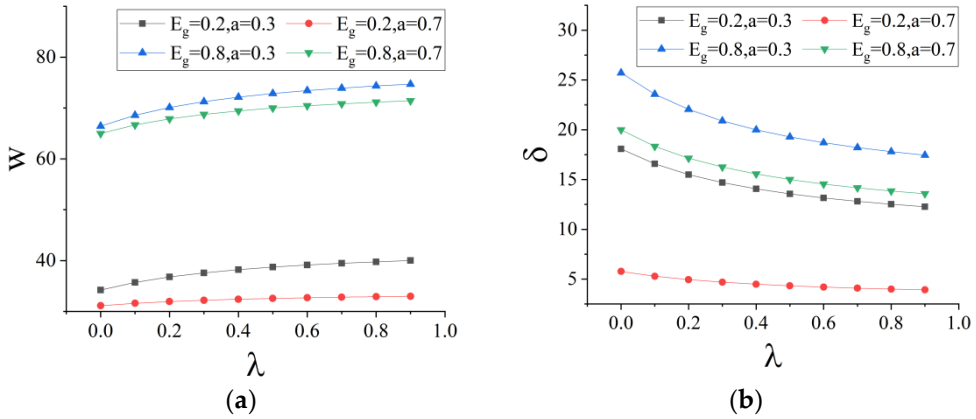

Figure 2. The impact of fairness concerns of manufacturer on the wholesale price and profit per unit of product. (**a**) The impact of fairness concerns of manufacturer on the wholesale price; (**b**) The impact of fairness concerns of manufacturer on profit per unit of product.

As can be seen from Figure 3a, first, when the product green efficiency is fixed, the direct selling price of the network channel is positively correlated with the market share of the network channel. It is generally believed that when a manufacturer's network market share is relatively large, the manufacturer will increase its profit by raising the selling price. Secondly, When the market share of the network channel is certain, the direct selling price of the network channel will also rise with the improvement of product green efficiency. At this point, consumers will increase their demand for green products, and the profit margin for manufacturers will increase by raising prices. Thirdly, when the product green efficiency and the network market share are fixed, the network channel direct selling price has nothing to do with the fairness concern coefficient of manufacturers. In combination with the above content, the reason for this phenomenon lies in the external factors that affect the manufacturers' decision on the direct price of products.

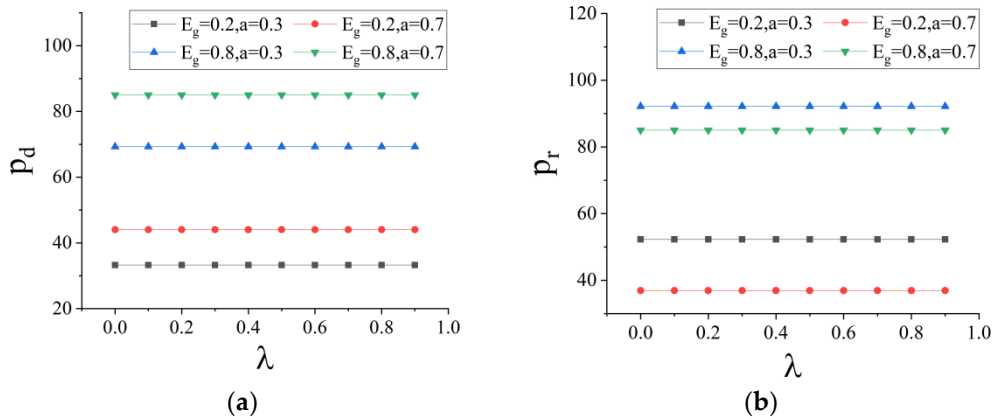

Figure 3. The impact of fairness concerns of manufacture on online direct selling price and offline direct selling price. (**a**) The impact of fairness concerns of manufacture on online direct selling price; (**b**) The impact of fairness concerns of manufacture on offline direct selling price.

As to Figure 3b, when product green efficiency is constant, the retail price of traditional channels is negatively correlated with the market share of network channels. This may be due to the fact that retailers need to improve their competitiveness by reducing their own prices when the market share of manufacturers' online direct sales channels is large. Meanwhile, when the market share of the network channel is fixed, the retail price of the traditional channel is higher under the condition of high green efficiency than under the condition of low green efficiency. What's more, when the product green efficiency and the

network market share are fixed, the fairness concern behavior of the manufacturer will not affect the change of the traditional channel retail price.

Figure 4a shows that the manufacturer's profit is positively correlated with the market share of online direct sales channels under the condition of fixed product green efficiency. Next, when the market share of the network direct marketing channel is constant, the higher the efficiency of product greening, the greater the profit of the manufacturer. Therefore, in order to obtain higher profits, manufacturers can cultivate consumers' green preference for this type of products through certain marketing strategies or reduce the cost of carbon emission reduction through technological innovation, so as to improve the efficiency of product greening. Then, when the product green efficiency and the market share of the network direct selling channel are fixed, the manufacturer's profit will raise with the increase in its own fairness concerns, but its sensitivity to the change of its fairness concerns will decrease.

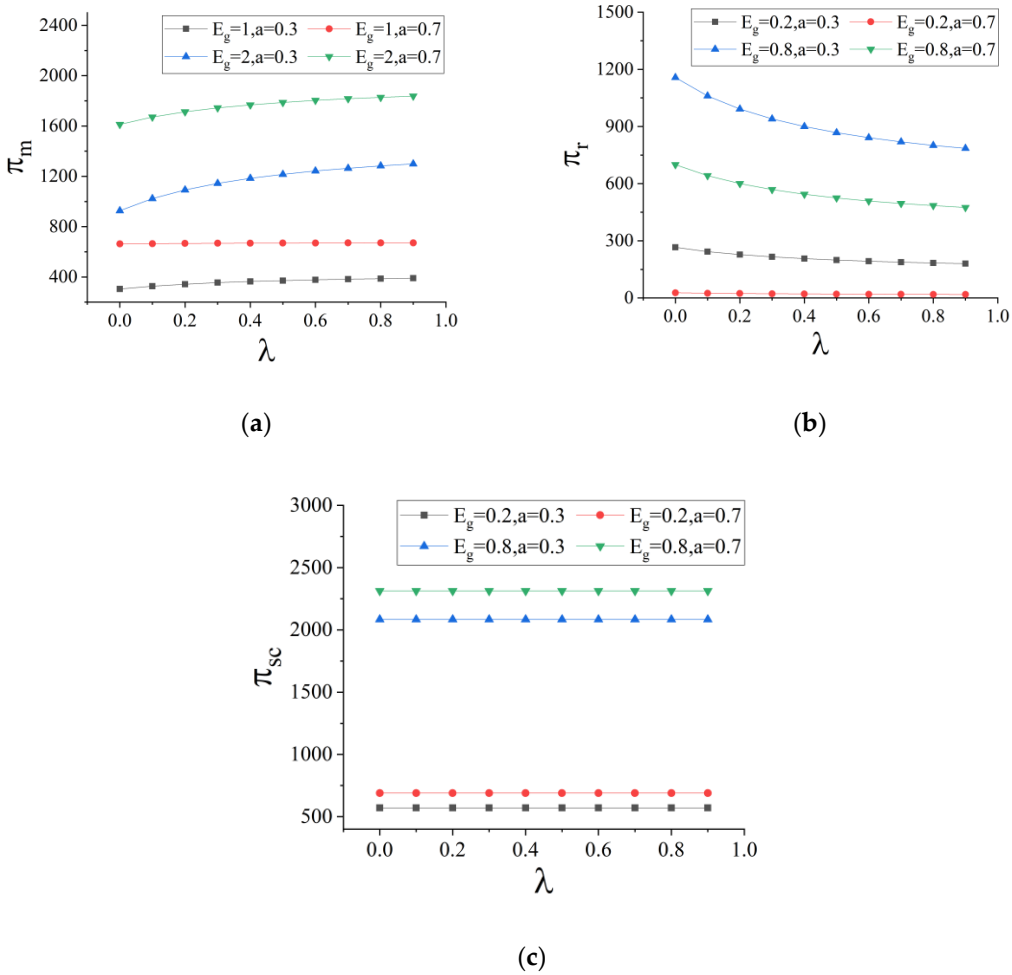

Figure 4. The impact of fairness concerns of manufacturer on the profits of manufacturer, retailer and supply chain. (**a**) The impact of fairness concerns of manufacturer on the profits of manufacturer; (**b**) The impact of fairness concerns of manufacturer on the profits of retailer; (**c**) The impact of fairness concerns of manufacturer on the profits of supply chain.

Figure 4b indicates that, first, the manufacturer's fairness concern behavior will affect the retailer's profit change, when the product green efficiency and network market share are fixed. The stronger the manufacturer's fairness concern is, the lower the retailer's profit will be. Secondly, under the condition of fixed product green efficiency, retailer's profits will decline with the increase in the market share of online direct sales channels. Finally, when the network market share is fixed, the retailer's profit will also go up with the improvement of product green efficiency.

According to Figure 4c, when the product green efficiency is constant, the overall profit of the supply chain will increase with the expansion of the market share of the network channel. The reason is that once the market share of the network opened by the manufacturer is relatively large, the manufacturer can increase its profit by raising the selling price. Furthermore, the overall profit of the supply chain will also rise with the improvement of the efficiency of product greening under the certain market share of network channel. At this time, consumers' preference for green products will expand the demand, and the manufacturer will increase the profit by raising the price. Finally, when product green efficiency and network market share are fixed, the overall profit of supply chain and the fairness concern coefficient of manufacturers are irrelevant.

As to Figure 5, first, when product green efficiency and network market share are fixed, manufacturer's fairness concern behavior will not affect product greenness. This is because the manufacturer will actively produce green products due to the green subsidies from the government even if the profit distribution in the supply chain is not ideal. Secondly, when the green efficiency of the product is constant, the greenness of the product will be improved with the increase in the network market share. Therefore, the network channel opened by manufacturers can effectively motivate them to produce green products if the market prospect is good. Thirdly, when the network market share is fixed, product greenness does not influence product green efficiency.

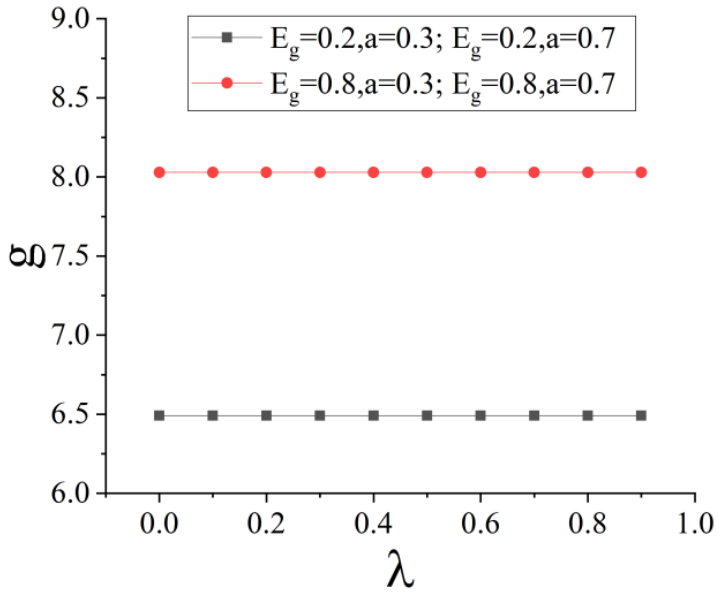

Figure 5. The impact of fairness concerns manufacturers on the product green degree.

5.2. The Impact of Manufacturers' Fairness Concerns on Government Subsidies

According to the above analysis, after comparing the situation of each decision variable in the two cases, it is found that the government will provide further subsidies only when the product green efficiency is low. According to the division of green efficiency of products mentioned above, this section assumes that $E_g = 0.2$ and the proportion of network market share is equal to that of traditional channels. The other parameters are set as follows. $\beta = 1.5$, $\theta = 0.5$, $c = 20$, $Q = 100$, $a = 0.5$, $\lambda = 1$, $\gamma = 1$, $k = 5$, $s \in [1, 10]$.

Table 2 describes the changes of supply chain decisions under different government green subsidies when manufacturers have fairness concerns. It can be seen that both the wholesale price and the price of two channels climb with the increase in the government's green subsidies. When the subsidy is fixed, the retailer's price will be slightly higher than the manufacturer's price.

Table 2. The optimal decision under different government subsidies.

s	w^*	p_d^*	p_r^*
0	36.11	38.03	43.8
1	36.21	38.15	43.96
2	36.32	38.27	44.12
3	36.43	38.39	44.27
4	36.54	38.51	44.43
5	36.64	38.63	44.59
6	36.75	38.75	44.75
7	36.86	38.87	44.91
8	36.96	38.99	45.07
9	37.07	39.11	45.23

Table 3 describes the changes of product greenness and supply chain profits under different subsidies when manufacturers have fairness concerns. With the increase in the subsidy value, the greenness of the product will increase. At the same time, profits for manufacturers, retailers and supply chains will rise. Moreover, at the same level of subsidies, manufacturers' profits would be higher than retailer.

Table 3. Product green degree and supply chain profit under different government subsidies.

s	g	π_r^*	π_m^*	π_{sc}^*
0	6.06	72.12	436.3	508.41
1	6.3	73.08	442.23	515.31
2	6.54	74.05	448.41	522.46
3	6.78	75.03	454.82	529.85
4	7.02	76.01	461.48	537.49
5	7.26	77	468.37	545.37
6	7.5	78	475.5	553.5
7	7.74	79	482.87	561.87
8	7.98	80.01	490.48	570.49
9	8.22	81.03	498.32	579.35

6. Conclusions

The shortage of resources and the deterioration of the environment make the demand for green products is growing. With the rapid development of e-commerce, many manufacturing enterprises have opened network channels. To gain a long-term advantage, companies must respond to the government's call to produce green products that meet the requirements for present society. The management of dual-channel green supply chain is an important embodiment of modern enterprise management in achieving sustainable development and responding to social demands. However, the decision-making process of the supply chain will be affected by the rational state of the decision-maker, leading to the difference between the actual result of the decision and the ideal optimal decision, which may bring damage to the supply chain members and enterprises.

Based on the comprehensive consideration of the government's green subsidies to manufacturers, this paper sets the retailer as the dominant player in the supply chain and constructs a dual-channel green supply chain model composed of a retailer and a manufacturer with fair concern behavior. A Stackelberg game model is established based

on two cases of manufacturer with and without fairness concern behavior. Moreover, we further discuss the impact of manufacturers' fairness concerns on supply chain decision-making. The main research conclusions of this paper are listed as follows:

(1) Under government subsidies, only wholesale product prices, manufacturer's profits and retailer's profits are affected by manufacturer's fairness concerns. The change of manufacturer's profit and wholesale price is positively correlated with the change of manufacturer's fairness concern intensity, while the change of retailer's profit is negatively correlated with manufacturer's fairness concern intensity.
(2) When manufacturers have fairness concerns, wholesale prices, pricing of both channels (including traditional channel and network channel), product greenness, and supply chain profits all increase with the increase in government subsidies.
(3) The price among different channels, profit among manufacturer and retailers and the change of product greenness are all positively correlated with the change of product greenness efficiency.
(4) When the green efficiency of product remains unchanged, the direct selling price of network channel, manufacturer's profit, supply chain profit and product greenness go up with the increase in market share of network channel. Whereas, the retail price of traditional channels, wholesale price and profit of retailer will decline with the raise of market share of online channels.

Combined with the current situation and research results, several enlightenments can be obtained. First, from the perspective of the government, formulating a reasonable green subsidy policy not only encourages enterprises to produce green products that meet the demand, but also has great significance for promoting the development of green supply chain and sustainable development. Secondly, from the perspective of manufacturers, improving the green efficiency of products is conducive to reducing their own costs and improving corporate profits. Moreover, in a retailer-dominated supply chain, the fairness concern behavior of the manufacturer can increase its own profit and reduce the profit from the retailer, which contributes to improving the enthusiasm of producing green products. At the same time, the fair concern behavior of manufacturers also helps to reduce the retail price of products and improve the enthusiasm of consumers to buy green products.

However, there are still some omissions in this study, which can be improved in further research. First and foremost, this paper only considers the fairness concerns of manufacturers and ignores the fairness concerns of retailers. Therefore, further research can consider the influence of the supply chain when both objects have fairness concerns. What's more, only the decentralized decision model is used in this paper. The discussion among the coordination problem in the retailer-led dual-channel green supply chain considering fairness concern and government subsidies should be made by using the centralized decision-making model. Finally, examples or empirical evidence which are consistent with the conclusions of this study still need to be explored to increase the applicability of the paper.

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