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Green Supply Chain Decision and Management under Manufacturer's Fairness Concern and Risk Aversion

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Abstract: This study focuses on the impact of a supply chain manufacturer's fairness concern and risk aversion on the green supply chain and constructs a two-level green supply chain consisting of a manufacturer and a retailer. It compares three models: the manufacturer is a risk-neutral and fair-neutral, the manufacturer is a risk-averse and fair-neutral, and the manufacturer is a risk-averse and fair-concerned decision maker. In three cases, this paper examines how the manufacturer's risk aversion and fairness concerns the impact product green level, retail price, and the wholesale price in the green supply chain. Consumers are sensitive to pricing strategies and product green level. The results are as follows: the manufacturer's risk aversion leads to an increase in the retailer's profit, and the manufacturer's profit decreases with the increase in the risk aversion coefficient. Second, when demand meets certain conditions and the manufacturer has advantageous fairness concerns, the manufacturer benefits from fairness concerns, the retailer's profit decreases with the manufacturer's fairness concerns coefficient, and the manufacturer's risk aversion will lead to a decline in the product green level. Third, when the manufacturer believes that the risk is relatively large, they reduce the technology investment of green products; thus, the fairness concerns of the manufacturer will affect the investment of green products and increase the green level of products. For enterprises: When supply chain members face various risks, they need to consider the specific needs of consumers and other members' behavioral preferences. They can put forward a more scientific prediction of market demand and rational decision making. For customers: they should not only pay attention to changes in market prices, but should also pay attention to changes in the behavioral preferences of supply chain members, as customers are in line with their own interests based on the choice of high-quality green production.

Keywords: risk aversion; green supply chain; fairness concerns; Stackelberg game; supply chain management

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1. Introduction

1.1. Context

In 2021, 'double carbon', namely carbon peak and carbon neutrality, was first written into the government work report: China strives to achieve a carbon peak by 2030 and carbon neutrality by 2060. Therefore, the construction of a green supply chain is the future direction of enterprise development. With the improvement of public environmental awareness and the limitation of national policies on carbon emissions, consumers are more sensitive to the green level of products, enhancing the importance of green supply chain management. Some enterprises have begun the road of differentiation based on green technology and have achieved a good reputation and benefits, such as Nike's environmentally friendly shoes and Gree's fluorine-free environmental protection inverter air conditioning investment research (News from Tencent). These enterprises have made some contributions to the sustainable development of the green supply chain by investing in green products. These emerging green products respond to government emission reduction policies and meet the special needs of consumers. With the instability of the market and the increasing competition, enterprises are more sensitive to risks and the profits of members in the supply chain system. The enterprise's risk aversion and fairness concerns will affect the relevant decisions of supply chain members. For example, Xiaopeng Automobile transferred its main business to the sale of environmentally friendly electric vehicles, but it suffered a loss for half a year due to the risk of the raw material supply caused by the new coronavirus epidemic and the manufacturers' concerns about the unfair distribution of channel profits (News from NetEase). Therefore, in research on the green supply chain, the risk aversion and fairness concerns are important factors to be considered. In this paper, the Stackelberg model is considered to describe these factors. The Stackelberg model is a production leadership model proposed by the German economist H. Von Stackelberg in 1934. The model reflects the asymmetric competition among enterprises.

It is assumed that decision makers are to maximize their own interests as the goal of decision making in classical economics, which is a process known as perfect rationality; however, subsequent studies have shown that decision makers cannot guarantee complete rationality. With economic globalization, the relationship between upstream and downstream enterprises is increasingly close. The behavioral preferences of members, such as risk aversion and fairness concerns, are increasingly concerned by enterprises and decision makers. The acceleration of market globalization has increased the risk of the supply chain and stimulated different attitudes of market participants to risk. Some enterprises prefer to sacrifice profits to avoid risks. At the same time, the supply chain becomes more fragile, and it becomes difficult for the supply chain to cope with the threat of various risks. For example, in the shipping industry, China–US trade frictions have led the US to reduce the volume of container ships arriving in the United States by raising tariffs and closing routes, thus losing about 10% of net profits; in the supply chain of agricultural products, most parts of China were hit by the novel coronavirus at the beginning of 2022, resulting in a sharp reduction in demand for agricultural products. It is more urgent to study supply chain risk aversion. Fairness concern is an irrational behavior: supply chain members not only pay attention to their own interests or utility, but also pay attention to the utility of other members in the supply chain. Fairness concerns in the upstream of the supply chain exacerbate conflicts of interest, further increasing the probability of risk faced by members. For example, Huawei and Qualcomm have been developing high-tech chips for decades. In addition to ordering chip raw materials from Qualcomm, Huawei also orders related raw materials from suppliers from Dunhao and Foxconn. In 2019, Qualcomm was dissatisfied with the channel profits' distribution and no longer supplied the raw materials, exposing Huawei to the risk of insufficient supply. In business, enterprises will be affected by a variety of psychological preferences, so members will have a variety of behavioral preferences, including fairness concerns and risk aversion.

1.2. Related Literature

To further explore the influence of behavioral preferences on decision making and the supply chain members' profits, this paper quantifies the two behavioral preferences and establishes a theoretical model, specifically analyzing the irrational behavior's impacts on the overall supply chain. This paper offers some innovations in this field based on predecessors.

In the previous literature search, it was found that the risk attitude of supply chain decision makers has attracted the attention of scholars. Trkman and Mc-Cormack [1] showed that the degree of the risk aversion of manufacturers and retailers decreased with the overall utility. Regarding the decision making of supply chain members, Choi et al. [2] used the mean standard deviation method called M-SD to explore the optimal decision-making problem of a risk-averse manufacturer and two retailers. They found that the wholesale price decreased with the risk-averse coefficient. Zhou et al. [3] studied the overall impact of the risk aversion of the manufacturer and supplier on the supply chain for cooperative advertising ordering. Russo et al. [4] explored the different effects on supply chain operation by comparing the static and dynamic risk aversion of retailers. Xu et al. [5] analyzed the influence of risk aversion on the optimal decision of supply chain members. Based on the conditional value-at-risk theory, Wu et al. [6] found that the optimal order quantity, sales price, and expected profit will decrease with the increase in the risk aversion coefficient. Cao et al. [7] analyzed the impact of risk aversion behavior on green product pricing and supply chain members' revenue when N distributors have risk aversion behavior in a complex supply chain. The study found that the deepening of risk aversion will reduce retail prices and the expected utility of the supply chain system. In the supply chain of agricultural products, Bellemare et al. [8] assumed that farmers have risk-averse behavior in the face of market conditions. Liu et al. [9] used buyback contracts and revenue sharing contracts to coordinate the supply chain of risk-averse retailers. Luo et al. [10] also found that buy-back contracts can coordinate supply chains under risk aversion. Some researchers performed a scientometric analysis and a comprehensive review about risk aversion (Liang et al. [11]) and risk assessment (Peron et al. [12]) using management methods. When combing through the above literature, it is not difficult to find that most of the previous studies focused on the risk aversion of traditional supply chain members, or basically had risk aversion behavior in the downstream of the supply chain.

Fairness concern behavior is common in human society [13]. Risk aversion behavior is also a bounded rational behavior of decision makers. Experimental research also explores fairness concerns in the supply chain [14]. Kumar et al. [15] found that different states of fairness concerns perceived by manufacturers have different effects on the automobile distribution supply chain. Ho et al. [16] examined two different types of fairness concerns' impact on the decisions of supply chain members. Pan et al. [17] found that when the retailer has no fair concern, the manufacturer has the greatest utility; when retailers have peer fairness concerns, retailers have the largest utility. Liu et al. [18] found that in a competitive supply chain consisting of two suppliers, the utility of the integrator increases with the peer concern coefficient of the supplier, but the utility of the integrator decreases with the fairness concern coefficients of the supplier. Guan et al. [19] found that when demand is related to price and cumulative reputation, when fairness concerns meet certain conditions, the supply chain will reach a coordinated state. Ma et al. [20] established a closed-loop supply chain decision model and introduced the retailer's fairness concern. They discussed the impact of psychological preferences such as fairness concerns on the level of market effort. The research found that the retailer's fairness concerns increased with its utility. Zheng et al. [21] introduced the retailer's fairness concern and discussed the influence of psychological preferences on centralized decision-making and decentralized decision-making models. With the above literature, it can be found that most of the research on fairness preference focuses on the downstream of the supply chain. Most of them do not pay much attention to the upstream manufacturers and the behavior preferences of green supply chain members.

In recent years, many scholars have conducted in-depth research on the green supply chain from different aspects and achieved rich research results. Zhu et al. [22] explored the optimal decision and market competition relationship of green products in the supply chain. Jiang et al. [23] constructed a two-level green supply chain composed of a risk-neutral manufacturer and a risk-averse retailer, studying the interaction between retailer risk aversion, product greenness, and pricing. Song et al. [24] significantly coordinated a green supply chain through a revenue sharing contract to improve the green investment level of the supply chain. From the perspective of consumers' green preference, Zhang et al. [25] improved the green investment level of enterprises by establishing two-part tariffs. Yang et al. [26] analyzed the green investment problem of two competing manufacturers from two aspects of price competition and quality competition to propose the best green investment strategy. Wang et al. [27] studied the pricing strategy of a green investment channel and sales effort in a dual-channel supply chain under demand uncertainty, and they analyzed the optimal decisions of manufacturers and retailers. Zhang et al. [28] explored consumer environmental awareness on environmental quality and pricing in the green product consisting of a manufacturer and retailer under the retailer's fairness concerns. They revealed that fairness concerns change a retailer's profit with CEA. He et al. [29] explored a supply chain consisting of a manufacturer under carbon tax regulation and an online retailer. They determined how carbon emissions affect the optimal decisions of the supply chain members. Li et al. [30] found that retailers under fairness concerns will have a reaction that is harmful to other members in the green supply chain. Saha et al. [31] explored the impact of a logistics delivery service on customers' satisfaction and perception in the green chain. Yu et al. [32] studied how CEA affects manufacturer's production strategies in the green chain. Zhang et al. [33] explored how the carbon cap and aversion of risk affects the supply members' pricing strategies. Xu et al. [5] used revenue sharing contracts and online price discount contracts to improve supply chain efficiency under carbon trading policies. Yi et al. [34] explored the impact of carbon tax and energy-saving product subsidies on business operations. Zhou and Wen. [35] establish a carbon-constrained operations model and explored the impact of consumers' low-carbon preference on the market-driven demand. Amalesh et al. [36] established a supply chain model that consists of a manufacturer producing both perfect and imperfect products and retailers. Wang and Zhang [37] explored some advanced payment policies in the supply chain. They found that the production costs of green products should be subsidized to incentivize retailers. Labiba et al. [38] explored these optimization techniques in green supply chain management and made suggestions about sustainable product practice.

In summary, most research has only introduced a single behavior preference of supply chain members. However, in the actual operation of the supply chain, supply chain members have a variety of behavioral preferences. Secondly, most of the literature focuses on the behavior preference in the downstream of the supply chain, rarely involving the upstream decision makers. Thirdly, few studies focus on the behavioral preferences of green supply chain members and consumers' sensitivity to green products. In this paper, the risk aversion and fairness concern behavior factors of the manufacturer will be introduced at the same time. Then, the influence of the two behavior preferences on the supply chain equilibrium and the overall utility will be explored to enrich the supply chain decision theory and method. This study and previous literature on the impact of two behavioral preferences on the supply chain are shown in Table 1. Through a comparative analysis, this paper makes a certain supplement to the research field of green low-carbon supply chain decision making with fairness concerns and risk aversion.

Table 1. Comparison between previous literature and this paper.

	Fairness Concerns	Risk Aversion	Research Content
Our paper	Upstream manufacturer	Manufacturer	Green supply chain decision and management
Kumar et al. [15]	Upstream manufacturer	Risk neutral	the automobile distribution supply chain
Ho et al. [16]	Downstream retailer	Risk neutral	fairness concerns' impact on the supply chain
Pan et al. [17]	Downstream retailer	Risk neutral	fairness concerns' impact on pricing decisions
Liu et al. [9]	Fair neutral	Risk-averse retailers	revenue sharing contracts coordinate the supply chain
Bellemare et al. [8]	Fair neutral	Risk-averse retailers	Risk-averse behavior's impact on market conditions

2. Model Descriptions

There is a two-tier supply chain consisting of a strong manufacturer and a weak retailer where the manufacturer dominates and is the leader. The retailers are risk neutral and fair neutral, while the manufacturer can be divided into the three types according to different behavioral preferences: risk neutral and fair neutral, risk averse and fair neutral, and risk averse and fair concerned.

These parameters are set as follows. According to the market and previous literature, for example, A represents the uncertain market size and its mean is a $(a > 0)$. The variance is δ^2 and satisfies $\delta > 0$. The price elasticity coefficient of market demand is b $(b > 0)$.

The sensitivity coefficient of consumers to product greenness is k and satisfies $k > 0$. The price of the retailer's unit product is p and the demand function is $D = A - bp + k\tau$. To simplify the model operation, the problem of the overcapacity or insufficient capacity of the manufacturer is not considered in the research, where the market sales volume is q, $D = q$. The manufacturer's unit production cost is c and the wholesale price is w. The subscripts R and M represent the retailer and the manufacturer, respectively.

In order to describe the model and fit the reality better, this research has the following assumptions: First, the investment cost of green technology is $\frac{1}{2}\rho\tau^2$, and according to the background of the text, the manufacturer fully bears the technical cost, whereby ρ is the green investment coefficient. Second, consumers, in response to the call of the state and because of their own preferences, tend to choose low-carbon products or green products, where k represents the consumer green sensitivity coefficient and τ represents the product green degree. According to previous literature, both parameters are greater than 0. Third, to operate normally, the parameters such as production cost and retail price should satisfy $p > w > c > 0$. Fourth, the average market size is a value greater than the cost c. Fifth, the superscripts 1, 2, and 3 indicate that the manufacturer is a risk-neutral and fair-neutral decision maker, a risk-aversion and fair-neutral decision maker, and a risk-aversion and fairness-concern decision maker, respectively. Some of the parameters have been listed as follows in Table 2.

Table 2. Parameters.

Notation	Definition
a	Potential market demand's mean
b	Price sensitivity
τ	the product green degree
c	cost per unit of product
δ	Potential market demand's variance
k	the consumer green sensitivity coefficient
w	wholesale price
φ	the manufacturer's risk aversion coefficient
p	retail price
ρ	green investment coefficient
α	disadvantageous inequality parameter
β	advantageous inequality parameter

2.1. The Risk-Neutral and Fair-Neutral Manufacturer

According to assumptions, the Stackelberg game is more in line with the actual market situation. According to the process of supply chain events, based on the actual situation, the manufacturer first produces the product at the unit cost c as the leader of the supply chain. To meet the market demand and the low-carbon preference of consumers, the wholesale price of the product can be determined as w_1, and the product green level is τ_1. Then, the retailer orders q_1 products according to the manufacturer's wholesale price to set the product retail price p_1 in the market. The model can be solved using the inverse method (Appendix A):

$$\begin{cases} E_1(\pi_M) = (a - bp_1 + k\tau)(w_1 - c) - \frac{1}{2}\rho\tau_1^2 \\ E_1(\pi_R) = (a - bp_1 + k\tau)(p_1 - w_1) \end{cases}$$

Proposition 1. *When the manufacturer and retailer have no risk-averse behavior, both are risk neutral, and the optimal decision and optimal profit of the supply chain members are as follows:*

$$w_1^* = \frac{ck^2 - 2(a + bc)\rho}{k^2 - 4b\rho}$$

$$p_1^* = \frac{ck^2 - 3a\rho - bc\rho}{k^2 - 4b\rho}$$

$$\pi_R^* = \frac{b(a\rho - bc\rho)^2}{(k^2 - 4b\rho)^2}$$

$$\pi_M^* = \frac{(a - bc)^2\rho}{-2k^2 + 8b\rho}$$

Theorem 1. *According to proposition 1, the manufacturer's optimal decision w_1^* increases with the consumer green sensitivity coefficient k. So, the manufacturer's optimal profit also increases with the sensitivity coefficient k. When the manufacturer makes the optimal decision, the retailer makes the optimal decision p_1^*, increasing with k.*

Theorem 1 shows that in the case of the unchanged market environment, the risk-neutral manufacturer will tend to be 'risky' at this time. To ensure the growth of the market share, as consumers pay attention to product emission reduction and green level, the manufacturer takes the initiative to increase investment in green products and increase the wholesale price. As consumer demand increases, retailers increase the retail price in order to increase profits and offset some of the increased costs. Finally, the green product market enters a virtuous circle.

2.2. The Risk-Averse and Fair-Neutral Manufacturer

When the manufacturer has risk aversion behavior, the 'mean-variance method' is used to set the manufacturer's expected profit function as:

$$E_2(\pi_M) = (a - bp_2 + k\tau_2)(w_2 - c) - \varphi(w_2 - c)^2\delta^2 - \frac{1}{2}\rho\tau_2^2$$

where φ represents the manufacturer's risk aversion coefficient ($\varphi > 0$), and the manufacturer's risk aversion varies with the value of φ. Similar to the above, the model is described as:

$$\begin{cases} MaxE_2(\pi_M) = (a - bp_2 + k\tau_2)(w_2 - c) - \varphi(w_2 - c)^2\delta^2 - \frac{1}{2}\rho\tau_2^2 \\ MaxE_2(\pi_R) = (a - bp_2 + k\tau)(p_2 - w_2) \end{cases}$$

Proposition 2. *When the manufacturer is risk averse and the retailer is risk neutral, where both are fair neutral, the optimal decision and optimal profit of the supply chain members are as follows:*

$$w_2^* = c + \frac{2(a - bc)\rho}{-k^2 + 4\rho(b + 2\delta^2\varphi)}$$

$$p_2^* = \frac{b\left(-ck^2 + 3a\rho + bc\rho\right) + 4(a + bc)\delta^2\rho\varphi}{b(-k^2 + 4\rho(b + 2\delta^2\varphi))}$$

$$\pi_R^* = \frac{(a - bc)^2\rho^2\left(b + 4\delta^2\varphi\right)^2}{b[k^2 - 4\rho(b + 2\delta^2\varphi)]^2}$$

$$\pi_M^* = \frac{(a - bc)^2\rho}{-2k^2 + 8\rho(b + 2\delta^2\varphi)}$$

Theorem 2. *Proposition 2 shows that the manufacturer's optimal decision w_2 decreases with the risk aversion coefficient φ, and the manufacturer's optimal profit also decreases with the risk* *aversion coefficient φ. When the manufacturer makes decisions, according to the known situation, the retailer's optimal decision p_2^* decreases with the risk aversion coefficient φ, and the retailer's optimal profit increases with φ.*

Theorem 2 shows that in the case of a constant market environment, because of risk aversion, the manufacturer tends to be 'conservative' to ensure long-term cooperation with retailers. With the deepening of risk aversion, the manufacturer takes the initiative to reduce the wholesale price. The retailer tends to lower retail prices to ensure an increase in market share but achieves a 'small profit and quick return' effect. For consumers, the manufacturer's risk aversion provokes them to buy more green or low-carbon products.

2.3. The Risk-Averse and Fairness-Concerned Manufacturer

According to the process of supply chain events, unlike Section 2.1, the manufacturer first produces the product at unit cost c. The manufacturer predicts the retailer's optimal decision in advance because of its own preferences, and then the wholesale price of the product can be determined as w_3. The retailer orders q_3 products according to the manufacturer's wholesale price to set the product retail price p_3 for sale in the market.

When the manufacturer has fairness concerns, it can be divided into the following two situations: if the manufacturer perceives that its profit is lower than the retailer's, it will suffer additional negative utility due to jealousy, which is called the negative utility caused by disadvantageous unfairness. On the contrary, if their own utility is higher than that of the retailers, they will suffer from the negative utility of sympathy, which is called the negative utility caused by advantageous fairness. At this point, the manufacturer's expected profit function can be described as follows, according to Cui et al. [39]:

$$E_3(\pi_M) = E_2(\pi_M) - M_2 - M_1$$

where

$$M_2 = \beta Max\{[E_2(\pi_M) - E_2(\pi_R)], 0\}$$
$$M_1 = \alpha Max\{[E_2(\pi_R) - E_2(\pi_M)], 0\}$$

where α is the manufacturer's disadvantageous fairness concern coefficient and β is the manufacturer's advantageous fairness concern coefficient. The hypothesis is satisfied: $0 \le \beta \le \alpha < 1$.

Proposition 3. *When the retailer is risk neutral and fair neutral, the manufacturer is affected by risk aversion under the manufacturer's fairness concern. Different from the previous literature (the manufacturer's profit is greater than the retailer's profit), the manufacturer is more disadvantageous than the retailer and has smaller profit because of a high degree of risk aversion.*

Proposition 3 shows that under an unchanged market environment, the manufacturer will tend to be 'conservative' and 'overcautious' because of the dual impact of risk aversion and fairness concerns. As the degree of risk aversion deepens, the manufacturer actively reduces the wholesale price. But at the same time, the manufacturer pays attention to the retailer's profits and will reduce the number of green products. Disadvantageous fairness concerns have caused manufacturers to suffer losses. For green industries, enterprises should take more care of the effectiveness of competitors or partners.

Similar to the above, the following game model is solved by inverse induction:

(I). If $0 < \varphi < -\frac{b}{8\delta^2} + \frac{1}{8}\sqrt{\frac{-2bk^2+5b^2\rho}{\delta^4\rho}}$, the manufacturer has advantageous fairness concerns. Therefore, the optimization problem is as follows:

$$\begin{cases} MaxE_3(\pi_M) = E_2(\pi_M) - M_2 \\ MaxE_3(\pi_R) = (a - bp_3)(p_3 - w_3) \end{cases}$$

The optimal decision and profit of the manufacturer and the retailer are calculated and simplified as:

$$w_3^* = \frac{2b^2c(-1+\beta)\rho + 2ab(-1+2\beta)\rho + 4ck^2\beta\delta^2\varphi - bc(-1+\beta)\left(k^2 - 8\delta^2\rho\varphi\right)}{2b^2(-2+3\beta)\rho + 4k^2\beta\delta^2\varphi - b(-1+\beta)(k^2 - 8\delta^2\rho\varphi)}$$

$$p_3^* = \frac{b^2c(-1+\beta)\rho + 4\delta^2\left[ck^2\beta + a(-1+\beta)\rho\right]\varphi + b\left[a(-3+5\beta)\rho - c\left(k^2 - 4\delta^2\rho\varphi\right)\right]}{2b^2(-2+3\beta)\rho + 4k^2\beta\delta^2\varphi - b(-1+\beta)(k^2 - 8\delta^2\rho\varphi)}$$

$$E_3^*(\pi_R) = \frac{b(a-bc)^2(-1+\beta)^2\rho^2\left(b+4\delta^2\varphi\right)^2}{\left(2b^2(-2+3\beta)\rho + 4k^2\beta\delta^2\varphi - b(-1+\beta)(k^2 - 8\delta^2\rho\varphi)\right)^2}$$

where

$$M_3 = (a-bc)\rho a 4b^3\left(1 - 3\beta + 2\beta^2\right) - 8abk^2\beta^2\delta^2\varphi - 16ak^2\beta^2\delta^4\varphi^2$$

$$M_4 = ab^2(k^2\left(1 - 4\beta + 3\beta^2\right) + 8a(1-2\beta)\delta^2\rho\varphi$$

$$M_5 = ab(2b^3c\left(2 - 5\beta + 3\beta^2\right)\rho - 8ak^2\beta\delta^2\varphi\left[k(\tau - 2\beta\tau) + 2c\beta\delta^2\varphi\right]$$

$$U_3^*(M) = \frac{M_3 + M_4 + M_5}{2\left(2b^2(-2+3\beta)\rho + 4k^2\beta\delta^2\varphi - b(-1+\beta)(k^2 - 8\delta^2\rho\varphi)\right)^2}$$

Theorem 3. *When $0 < \beta < \frac{1}{2}$, the manufacturer's optimal decision w_3^* decreases with the risk aversion coefficient φ, and the manufacturer's green investment decreases with the increase in the risk aversion's degree. When the manufacturer makes the optimal decision, the retailer's optimal decision p_3^* decreases with φ according to the known situation.*

Theorem 3 shows that under an unchanged market environment, the manufacturer will be more 'conservative' and pay attention to the retailer's lower profits because of the influence of risk aversion and advantageous fairness concern. The manufacturer not only ensures long-term cooperation with the retailer but also suffers from the 'guilt' caused by the advantageous fairness concern. With the deepening of risk aversion, the leader prefers to reduce the wholesale price to increase the retailer's profit; because of the market demand's uncertainty, the manufacturer's expected demand is inconsistent with the actual demand, causing a decline in investments in green products. Retailers will lower retail prices for 'small profit and quick return' purposes.

Theorem 4. *When $0 < \beta < \frac{1}{2}$ and the market size is larger, after the manufacturer's optimal decision, the optimal utility $E_3^*(\pi_M)$ decreases with the risk aversion coefficient φ. After the retailer's decision based on the known information, the optimal profit $E_3^*(\pi_R)$ increases with the risk aversion coefficient φ.*

Theorem 4 shows that in the market, the manufacturer is affected by risk aversion and chooses to reduce control over market forces. Therefore, the manufacturer will obtain less profit. And the retailer will obtain more market power to benefit more from the sales.

Proposition 4. *When $0 < \varphi < 1$, the manufacturer's optimal decision w_3^* decreases with the fairness concern coefficient β, and the manufacturer's green investment increases with the increase in the advantageous fairness concern coefficient. When the manufacturer makes the optimal decision, the retailer's optimal decision p_3^* decreases with the fairness concern coefficient β.*

Proposition 4 shows that in the case of the unchanged market environment, the manufacturer will be affected by the 'guilt' brought on by the advantageous fairness concern. Then, the manufacturer tends to transfer some profits to the retailer. The manufacturer makes the product more attractive for consumers and increases green technology investments. Therefore, the product green degree increases, so the retailer will acquire more orders. With the deepening of fairness concerns, manufacturers reduce the wholesale price, and retailers will reduce prices to achieve more sales and profit.

Theorem 5. *When the market size is larger, the fairness concern coefficient satisfies* $0 < \beta < \frac{1}{2}$. *After the retailer's decision based on the known market information, the optimal profit* $E_3^*(\pi_M)$ *decreases with the fairness concern coefficient* β. *Otherwise, the retailer's optimal profit* $E_3^*(\pi_R)$ *increases with* β.

Theorem 6. *When the market size is larger,* φ *and* β *satisfy* $(0 < \beta < \frac{1}{2}$ *and* $0 < \varphi < 1)$ *or* $(0 < \beta < \frac{1}{2}$ *and* $0 < \varphi < \frac{1}{2})$, *and the optimal utility* $E_3^*(\pi_M)$ *decreases with the fair concern coefficient* β. *Otherwise,* $E_3^*(\pi_M)$ *increases with the fairness concern coefficient* β.

Theorems 5 and 6 show that under the unchanged market environment, the manufacturer will be affected by 'guilt' because of the advantageous fairness concerns. Although the market size becomes smaller, the cost of the retailer is reduced to increase its profit. However, if the manufacturer's unfair feelings are obvious, the retailer's order quantity becomes larger. Under the action of two factors, the manufacturer still has the first-mover advantage, and the manufacturer's profit increases.

(II) If $\varphi > -\frac{b}{8\delta^2} + \frac{1}{8}\sqrt{\frac{-2bk^2+5b^2\rho}{\delta^4\rho}}$, the manufacturer has disadvantageous fairness concerns. Therefore, the optimization problem is as follows:

$$\begin{cases} MaxE_4(\pi_M) = E_2(\pi_M) - M_1 \\ MaxE_4(\pi_R) = (a - bp_4)(p_4 - w_3) \end{cases}$$

The optimal decision and profit of the manufacturer and the retailer are calculated and simplified as:

$$w_3^* = \frac{2b^2c(-1+\alpha)\rho + 2ab(-1+2\alpha)\rho + 4ck^2\beta\delta^2\varphi - bc(-1+\alpha)\left(k^2 - 8\delta^2\rho\varphi\right)}{2b^2(-2+3\alpha)\rho + 4k^2\beta\delta^2\varphi - b(-1+\alpha)(k^2 - 8\delta^2\rho\varphi)}$$

$$p_3^* = \frac{b^2c(-1+\alpha)\rho + 4\delta^2\left[ck^2\beta + a(-1+\alpha)\rho\right]\varphi + b\left[a(-3+5\alpha)\rho - c\left(k^2 - 4\delta^2\rho\varphi\right)\right]}{2b^2(-2+3\alpha)\rho + 4k^2\beta\delta^2\varphi - b(-1+\alpha)(k^2 - 8\delta^2\rho\varphi)}$$

$$\tau_3^* = \frac{M_6 + M_7 + M_8 + M_9}{2b^2(-2+3\alpha)\rho + 4k^2\alpha\delta^2\varphi - b(-1+\alpha)(k^2 - 8\delta^2\rho\varphi) + M_{10}}$$

where

$$M_6 = (a - bc)k(2b^4(-4 + 6\beta + \alpha(-6 - \alpha(4+\alpha) + (9 + 2\alpha(3+\alpha))\beta))\rho$$

$$M_7 = -64k^2\alpha(1+\alpha)^2\beta\delta^6\varphi^3 + 16b(1+\alpha)\delta^4\varphi^2(k^2(\beta + \alpha(-1-\alpha+\beta+2\alpha\beta)) - 8\alpha\delta^2$$

$$M_8 = b^3(-k^2(2+\alpha(3+2\alpha))(-1+\beta) + 8(-4+5\beta+\alpha(-5+\alpha(3+\alpha)(-1+\beta)$$

$$M_9 = 4b^2\delta^2\varphi(k^2(1+\beta+\alpha(1+2\beta+\alpha(1+\alpha+\beta-\alpha\beta))) - 8(1+\alpha)\delta^2$$

$$M_{10} = b^2\left(-k^2(2+\alpha(3+2\alpha)) + 16(1+\alpha)^2(2+\alpha)\delta^2\rho\varphi\right)$$

In case II, from the analysis, the manufacturer's disadvantageous fairness concern is caused by its own low utility. When the disadvantageous fairness concern coefficient is large, it indicates that the manufacturer is no longer in the dominant position in the supply chain. The profit is quite different than expected, causing the manufacturer to reduce the green technology investment; as a result, the reduction in the product green level results in the increase in the wholesale price. Even the cooperation relationship between supply chain members will break down, and this is also because the retailer does not have fairness concerns. For them, the impact of deepening their disadvantageous fairness concerns will not only increase the wholesale price but also reduce the green degree of products. The manufacturer is no longer in a dominant position in the supply chain, violating the research hypothesis. Therefore, the specific decisions of members in the supply chain are not considered in the research.

3. Numerical Studies

This paper will describe the impact of two behavioral preferences of the manufacturer on the optimal decision making and utility of supply chain members through numerical experiments. The values of the parameters are as follows in Table 3.

Table 3. The value of parameters.

Parameters	Ranges	Values
a	$a > c > 0$	100
c	$c > 0$	10
δ	$\delta > 0$	2
b	$b > 0$	3
k	$k > 0$	1
ρ	$\rho > 0$	5

3.1. Influence of Manufacturer's Risk Aversion on Optimal Decision of Manufacturer and Retailer

Theorem 1. *is verified below:*

Theorem 1 was verified above: the manufacturer's optimal decision increases with the consumer green sensitivity coefficient k. The retailer is more likely to make the optimal decision as k increases. In the market, the manufacturer will tend to be 'risky' at this time. As consumer demand increases, retailers increase retail prices to increase profits and offset some of the increased costs. Finally, the green product market is fully controlled by the manufacturer, and the retailer's power is reduced. It can be seen from Figures 1–4 that the manufacturer's optimal decision decreases with the risk aversion coefficient φ. The manufacturer's optimal profit is also inversely proportional to φ. When the manufacturer makes the optimal decision, according to the known situation, the retailer's optimal decision p_2^* decreases with φ. The retailer's optimal profit increases with φ. With the increase in the risk aversion coefficient, the manufacturer is more and more 'cautious' and the wholesale price is lower because the cost remains unchanged and the utility is reduced; thus, the retailer will reduce the retail price to increase the market demand.

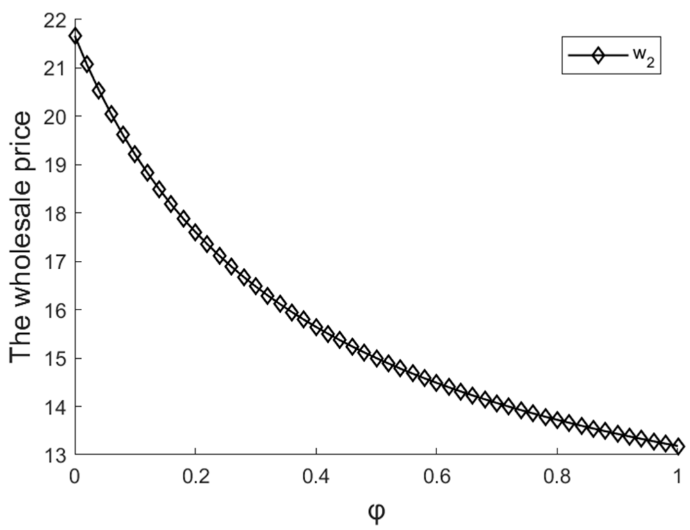

Figure 1. The optimal decision of the fair-neutral and risk-neutral manufacturer.

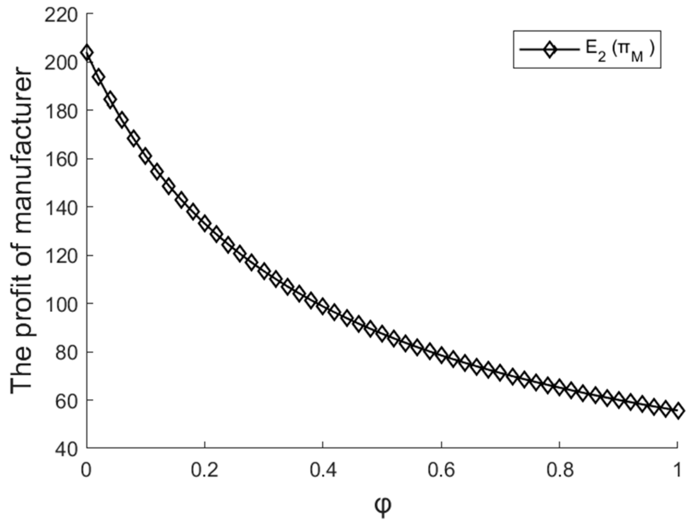

Figure 2. The optimal decision of the fair-neutral and risk-averse manufacturer.

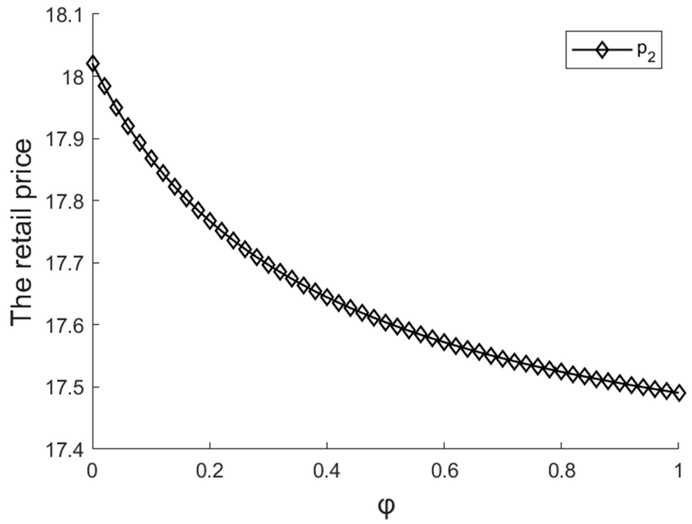

Figure 3. The optimal decision of the retailer.

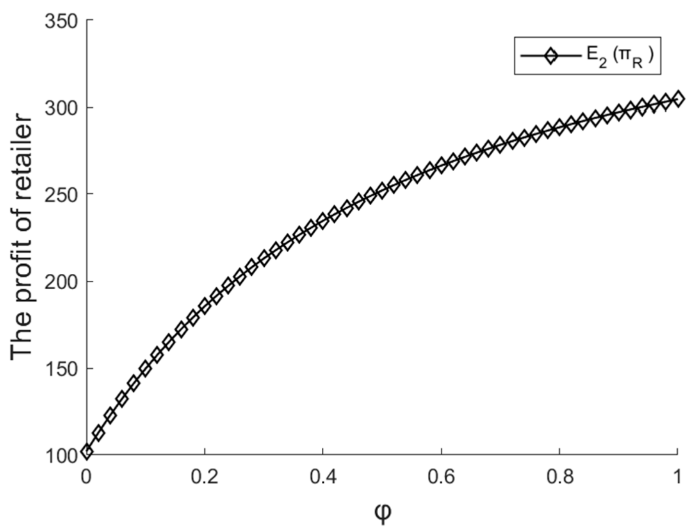

Figure 4. The optimal profit of the retailer.

3.2. The Impact of Manufacturer's Risk Aversion and Fairness Concern on the Optimal Decisions

Next, the remaining theorem is verified by numerical experiments to explore the impact of the two behavioral preferences of the manufacturer on the green supply chain.

Example 1. *Assume* $a = 100$, $c = 10$, $\delta = 2$, $b = 3$. *When the manufacturer is the decision maker of risk aversion and fairness concerns, Table 4 shows the value of* w_3^* *and* p_3^* *given the values of the risk aversion coefficient* φ *and fairness concern coefficient* β.

Table 4. Values of Wholesale Price and Order Quantity Varying with Fairness Concern Coefficient.

(w_3^*, p_3^*)	β = 0.2	β = 0.4	β = 0.6
$\varphi = 0.1$	(17.6,19.2)	(10.1,18.2)	(9.7,17.2)
$\varphi = 0.3$	(17.3,19)	(10.4,17.8)	(9.6,16.6)
$\varphi = 0.5$	(17.0,18.8)	(10.5,17.5)	(9.5,16)
$\varphi = 0.7$	(16.9,18.1)	(10.3,17.1)	(9.3,15.8)
$\varphi = 0.9$	(16.1,17.8)	(10.6,16.8)	(8.6,15.5)

It can be seen from Table 4 that when $0 < \beta < \frac{1}{2}$ and the market size is large, the optimal decision p_3^* obtained by the retailer decreases with φ. When $0 < \varphi < 1$, the manufacturer's optimal decision w_3^* decreases with the fairness concern coefficient β; thus, the retailer's optimal decision p_3^* decreases with β. The manufacturer uses their first-mover advantage and market dominance to ensure the feelings of advantageous fairness. The manufacturer will significantly reduce the wholesale price so that the product order quantity will increase. The retailer will take the initiative to reduce product prices.

3.3. The Impact of Manufacturer's Risk Aversion and Fairness Concern on Retailer's Profit

Example 2. *Assume* $a = 100$, $c = 10$, $\delta = 2$, $b = 3$. *When the manufacturer is a risk aver-se and fairness-concern decision maker, Table 5 shows the value of* $E_2(\pi_R)$ *when* φ *and* β *change.*

Table 5. Values of retailer's utility Varying with Coefficient φ and β.

$E_2(\pi_R)$	β = 0.2	β = 0.4	β = 0.6
$\varphi = 0.1$	180.1	119.8	−62.5
$\varphi = 0.3$	141.9	82.6	−117.3
$\varphi = 0.5$	115.1	62.3	−184.3
$\varphi = 0.7$	96.4	50.2	−266.5

Because the manufacturer has advantageous fairness concern, they will provide more benefit to the retailer, but the manufacturer also has the risk preference, resulting in a reduction in the manufacturer input. Resulting from two factors, the retailer's profit is reduced.

3.4. The Impact of Manufacturer's Risk Aversion and Fairness Concern on the Green Level of Products

Example 3. *Assume* $a = 100$, $c = 10$, $\delta = 2$, $b = 3$, $k = 1, \rho = 5$. *When the manufacturer is a risk-averse and fairness-concern decision maker, Table 6 shows the value of* τ *when* $Coefficient$ φ *and* β *change.*

Table 6. Values of τ Varying with Coefficient φ and β.

τ	β = 0.2	β = 0.4	β = 0.6	β = 0.8
$\varphi = 0.1$	16.3	17.6	20.1	22.8
$\varphi = 0.3$	11.5	12.2	18.3	18.9
$\varphi = 0.5$	9.1	10.1	15.4	16.9
$\varphi = 0.7$	7.6	8.2	9.9	11.5

As the degree of risk aversion deepens, the expected demand of the manufacturer is inconsistent with the actual demand, making the manufacturer reduce investment in green products, resulting in green degree's production. With the deepening of fairness concerns, to maintain their relationship with the retailer, the manufacturer increases the amount of their green technology investment so that the product green degree increases, and the retailer places more orders to ease the manufacturer's 'guilt' sentiment.

3.5. The Impact of Manufacturer's Risk Aversion and Fairness Concern on Own Utility

Example 4. *Assume* $a = 100$, $c = 10$, $\delta = 2$, $b = 3$, $k = 1$, $\rho = 5$. *When the manufacturer is a risk-averse and fairness-concern decision maker, Table 7 shows the value of* $E_3(\pi_M)$ *when* $Coefficient$ φ *and* β *change.*

Table 7. Values of $E_3(\pi_M)$ Varying with Coefficient φ and β.

$E_3(\pi_M)$	β = 0.2	β = 0.4	β = 0.6	β = 0.8
$\varphi = 0.1$	161.3	115.6	76.1	162.8
$\varphi = 0.3$	115.7	77.2	48.3	115.9
$\varphi = 0.5$	90.0	57.8	35.4	89.9
$\varphi = 0.7$	73.6	46.2	27.9	73.5

It can be seen from Table 6 that when $0 < \beta < \frac{1}{2}$ and the market size is large, the optimal utility $E_3(\pi_M)$ decreases with the risk aversion coefficient φ.

When $\delta \geq 1.4$ and the fairness concern coefficient satisfies $0 < \beta < \frac{1}{2}$, after the manufacturer's optimal decision, the most effective use is that $E_3(\pi_M)$ decreases with β. Otherwise, the optimal profit $E_3(\pi_M)$ increases with the fairness concern coefficient β, as shown in Figure 5 below.

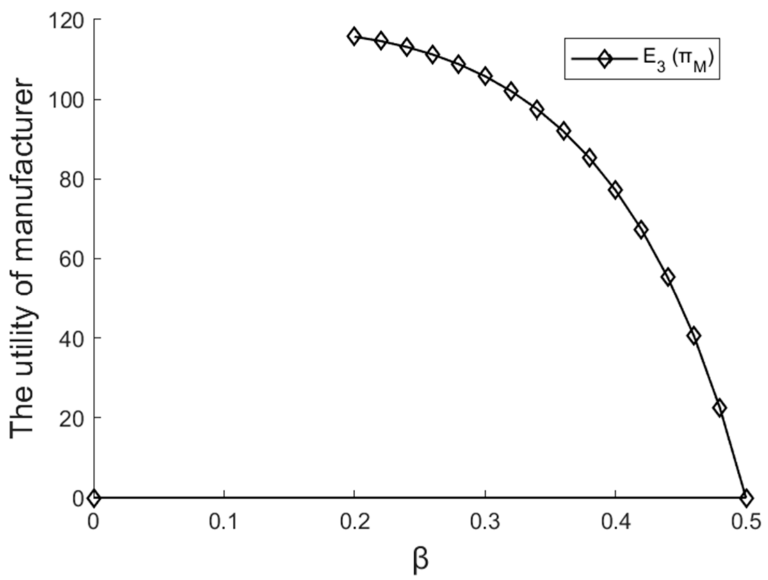

Figure 5. $E_3(\pi_M)$ Varying with β.

4. Discussion and Future Research

4.1. Conclusions

Due to the influence of external factors and psychological factors in the market, decision makers in the market will have a variety of behavioral preferences. This paper takes the two-stage green low-carbon supply chain as the research object. Then, we explored the impact of the manufacturer's risk aversion and fairness concerns on the optimal decision of green product supply chain members and the overall supply chain. In the manufacturer-led market, the manufacturer first determines the wholesale price and product's green level. Then, the retailer decides the optimal order quantity according to the manufacturer's decision.

The research finds that when the market size meets certain requirements, (I) the retailer's profit increases with the manufacturer's risk aversion coefficient and the manufacturer's profit decreases with its risk aversion coefficient. (II) When the manufacturer's unfair feeling is obvious, the retailer and the manufacturer's profit decreases with the fairness concern coefficient. (III) When the manufacturer's own sense of unfairness is not obvious, the manufacturer does not make much profit, so the retailer's order quantity becomes larger under two factors. The manufacturer still has a first-mover advantage and its profit increases with its fairness concern coefficient. The retailer's profit decreases with the manufacturer's fairness concern coefficient. (IV) In the case of the constant market environment, the manufacturer's risk aversion will lead to a decline in product green degree. The manufacturer believes that the market risk is relatively large and will reduce the green product technology investment. To maintain partnerships with retailers under fairness concerns, the manufacturer increases the green degree. Studies have shown that supply chain members in the face of market risk also need to consider the specific needs of consumers and the behavior of other members. (V) Supply chain members' behavior preferences such as fairness concerns and risk aversion will have an impact on decision making. On the one hand, as a whole, for green low-carbon supply chain enterprises, they need to pay more attention to the rest of the members' behaviors and profits; on the other hand, a more efficient prediction of consumers' product green degree is required. It is important for enterprises to reduce the risk attitude and fairness concerns on corporate decision making. 'Feeling the stones across the river at the same time,' enterprises should also focus on market risk and rational investment.

4.2. Limitations and Challenges

This section mainly discusses some of this paper's limitations. This research has the following shortcomings: First, this study does not consider the situation of deterministic demand; because the controllable factors increase, the impact of fairness concerns and risk aversion on the green supply chain will change. Secondly, this paper only considers two behavioral preferences of manufacturers, but in the actual operation of the market, multiple decision makers may have behavioral preferences.

4.3. Future Research

This section mainly discusses some new ideas for the future. In the future, the decision-making behavior preference of multiple subjects in the supply chain regarding the pricing strategy selection can be studied. Future research can cover a more complex network structure of the supply chain and even customers' choices based on behavioral preferences, often including several suppliers and retailers, so future research models can consider the game behavior of multiple members.

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Appendix A. Proofs

Proof of Proposition 1.

$$\begin{cases} E_1(\pi_M) = (a - bp_1 + k\tau)(w_1 - c) - \frac{1}{2}\rho\tau_1^2 \\ E_1(\pi_R) = (a - bp_1 + k\tau)(p_1 - w_1) \end{cases}$$

For this paper, we can obtain the unique optimal decision given by the following first order. It is obvious for us to derive $\frac{\partial^2 E_1(\pi_R)}{\partial p_1^2} < 0$.

$$\frac{\partial E_1(\pi_R)}{\partial p_1} = a - 2bp_1 + k\tau_1 + bw_1$$

$$\frac{\partial^2 E_1(\pi_R)}{\partial p_1^2} < 0$$

Then, the optimal solutions can be obtained following:

$$p_1^* = \frac{a + bw_1 + k\tau_1}{2b} \tag{A1}$$

Recalling p_1^* given by (A1), we can obtain $E_1(\pi_M)$ and w_1^* in (A2):

$$E_1(\pi_M) = \left(a - b * \frac{a + bw_1 + k\tau_1}{2b} + k\tau_1\right)(w_1 - c) - \frac{1}{2}\rho\tau_1^2$$

$$\frac{\partial E_1(\pi_M)}{\partial w_1} = \frac{1}{2}(a + bc - 2bw_1 + k\tau_1)$$

$$\frac{\partial^2 E_1(\pi_M)}{\partial w_1^2} < 0$$

$$w_1^* = \frac{a + bc + k\tau_1}{2b} \tag{A2}$$

The optimal decisions of the manufacturer can be realized as follows, due to the first differential order:

$$\frac{\partial E_1(\pi_M)}{\partial \tau_1} = \frac{1}{4}\left[ak - ck + \left(k^2 - 4\rho b\right)\tau\right]$$

$$\tau_1^* = \frac{ak - bck}{-k^2 + 4b\rho} \tag{A3}$$

$$w_1^* = \frac{ck^2 - 2(a + bc)\rho}{k^2 - 4b\rho} \tag{A4}$$

$$p_1^* = \frac{ck^2 - 3a\rho - bc\rho}{k^2 - 4b\rho} \tag{A5}$$

$$\pi_R^* = \frac{b(a\rho - bc\rho)^2}{(k^2 - 4b\rho)^2} \tag{A6}$$

$$\pi_M^* = \frac{(a - bc)^2\rho}{-2k^2 + 8b\rho} \tag{A7}$$

The proof has been completed. □

Proof of Theorem 1.

For the manufacturer's and retailer's decisions shown in (A3)–(A7), we can derive the following the first order differential order:

$$\frac{\partial w_1}{\partial k} = \frac{4(a - bc)k\rho}{(k^2 - 4b\rho)^2} > 0$$

$$\frac{\partial \tau_1^*}{\partial k} = \frac{(a - bc)(k^2 + 4b\rho)}{(k^2 - 4b\rho)^2} > 0$$

$$\frac{\partial p_1^*}{\partial k} = \frac{6(a - bc)k\rho}{(k^2 - 4b\rho)^2} > 0$$

The proof is completed. □

Proof of Proposition 2.

The manufacturer's and retailer's problems are shown in (A8):

$$\begin{cases} MaxE_2(\pi_M) = (a - bp_2 + k\tau_2)(w_2 - c) - \varphi(w_2 - c)^2\delta^2 - \frac{1}{2}\rho\tau_2^2 \\ MaxE_2(\pi_R) = (a - bp_2 + k\tau)(p_2 - w_2) \end{cases} \tag{A8}$$

Similarly, we can obtain the optimal decision of the retailer:

$$\frac{\partial E_2(\pi_R)}{\partial p_2} = a - 2bp_2 + k\tau_2 + bw_2$$

$$\frac{\partial^2 E_2(\pi_R)}{\partial p_2^2} < 0$$

$$p_2^* = \frac{a + bw_2 + k\tau_2}{2b} \tag{A9}$$

Recalling p_2^* in (A9), $E_2(\pi_M)$ can be rewritten as follows; then, the optimal decisions can be obtained:

$$E_2(\pi_M) = \left(a - b * \frac{a + bw_2 + k\tau_2}{2b} + k\tau_2\right)(w_2 - c) - \frac{1}{2}\rho\tau_2^2 - \varphi(w_2 - c)^2\delta^2$$

$$\frac{\partial E_2(\pi_M)}{\partial w_2} = \frac{1}{2}\left[a + b(c - 2w_2) + k\tau_2 + 4c\delta^2\varphi - 4w_2\delta^2\varphi\right]$$

$$\frac{\partial^2 E_1(\pi_M)}{\partial w_1^2} < 0$$

$$w_2^* = \frac{a + bc + k\tau + 4c\delta^2\varphi}{2(b + 2\delta^2\varphi)} \tag{A10}$$

$$\frac{\partial E_2(\pi_M)}{\partial \tau_2} = -\rho\tau_2 + \frac{k(a - bc + k\tau_2)}{4(b + 2\delta^2\varphi)}$$

$$\tau_2^* = \frac{-ak + bck}{k^2 - 4b\rho - 8\delta^2\rho\varphi} \tag{A11}$$

$$w_2^* = c + \frac{2(a - bc)\rho}{-k^2 + 4\rho(b + 2\delta^2\varphi)}$$

$$p_2^* = \frac{b\left(-ck^2 + 3a\rho + bc\rho\right) + 4(a + bc)\delta^2\rho\varphi}{b(-k^2 + 4\rho(b + 2\delta^2\varphi))}$$

$$\pi_R^* = \frac{(a - bc)^2\rho^2\left(b + 4\delta^2\varphi\right)^2}{b[k^2 - 4\rho(b + 2\delta^2\varphi)]^2}$$

$$\pi_M^* = \frac{(a - bc)^2\rho}{-2k^2 + 8\rho(b + 2\delta^2\varphi)}$$

The proof is completed. □

Proof of Theorem 2.

For the manufacturer's and retailer's decisions shown in (A10)–(A11), we can derive the following the first order differential order:

It is known that $a > bc$ in this paper:

$$\frac{\partial w_2}{\partial \varphi} = -\frac{16(a - bc)\delta^2\rho^2}{(k^2 - 4\rho(b + 2\delta^2\varphi))^2} < 0$$

$$\frac{\partial p_2^*}{\partial \varphi} = -\frac{4(a - bc)\delta^2\rho\left(k^2 + 2b\rho\right)}{b(k^2 - 4\rho(b + 2\delta^2\varphi))^2} < 0$$

If $-k^2 + 2b\rho > 0$, the first differential orders can be obtained:

$$\frac{\partial \pi_R^*}{\partial \varphi} = \frac{8(a - bc)^2\delta^2\rho^2\left(-k^2 + 2b\rho\right)\left(b + 4\delta^2\varphi\right)}{b[-k^2 + 4\rho(b + 2\delta^2\varphi)]^3} > 0$$

$$\frac{\partial \pi_M^*}{\partial \varphi} = -\frac{4(a - bc)^2\delta^2\rho^2}{[k^2 - 4\rho(b + 2\delta^2\varphi)]^2} < 0$$

The proof is completed. □

Proof of Proposition 3.

$E_2(\pi_M) - E_2(\pi_R)$ can be written as:

$$E_2(\pi_M) - E_2(\pi_R) = \frac{(a - bc)^2\rho\left[2b^2\rho - 32\delta^4\rho\varphi^2 - b\left(k^2 + 8\delta^2\rho\varphi\right)\right]}{2b(k^2 - 4\rho(b + 2\delta^2\varphi))^2}$$

If $E_2(\pi_M) - E_2(\pi_R) > 0$, there are some constraints, such as $a > bc$, $0 < b < 1, c > 0$, $\rho > 0, \varphi > 0, k > 0$.

Therefore, it is deduced as follows:

$$E_2(\pi_M) - E_2(\pi_R) > 0 \Longleftrightarrow 0 < \varphi < -\frac{b}{8\delta^2} + \frac{1}{8}\sqrt{\frac{-2bk^2 + 5b^2\rho}{\delta^4\rho}}$$

The proof is completed. □

Proof of Theorem 3.

If $0 < \varphi < -\frac{b}{8\delta^2} + \frac{1}{8}\sqrt{\frac{-2bk^2+5b^2\rho}{\delta^4\rho}}$ and the manufacturers are under fairness concerns, the problem can be written as:

$$\begin{cases} MaxE_3(\pi_M) = E_2(\pi_M) - M_2 \\ MaxE_3(\pi_R) = (a - bp_3)(p_3 - w_3) \end{cases}$$

We can obtain the first different order:

$$\frac{\partial E_3(\pi_R)}{\partial p_3} = a - 2bp_3 + k\tau_3 + bw_3$$

The second order can be deduced:

$$\frac{\partial^2 E_3(\pi_R)}{\partial p_3^2} < 0$$

The optimal decision of the retailer can be obtained:

$$p_3^* = \frac{a + bw_3 + k\tau_3}{2b}$$

Recalling p_3^* and substituting into $E_3(\pi_M)$, we can obtain the manufacturer's optimal decisions

$$E_3(\pi_M) = E_2(\pi_M) - M_2 = (1-\beta)E_2(\pi_M) + \beta E_2(\pi_R)$$

When $\frac{\partial E_3(\pi_M)}{\partial w_3} = 0$, $\frac{\partial^2 E_1(\pi_M)}{\partial w_1^2} < 0$

$$w_3^* = \frac{-a - bc + 2a\beta + bc\beta - k\tau + 2k\beta\tau - 4c\delta^2\varphi + 4c\beta\delta^2\varphi}{-2b + 3b\beta - 4\delta^2\varphi + 4\beta\delta^2\varphi}$$

When $\frac{\partial E_3(\pi_M)}{\partial \tau_3} = 0$,

$$\tau_2^* = \frac{(a - bc)k\left[b(-1+\beta) - 4\beta\delta^2\varphi\right]}{2b^2(-2+3\beta)\rho + 4k^2\beta\delta^2\varphi - b(-1+\beta)(k^2 - 8\delta^2\rho\varphi)}$$

$$w_3^* = \frac{2b^2c(-1+\beta)\rho + 2ab(-1+2\beta)\rho + 4ck^2\beta\delta^2\varphi - bc(-1+\beta)\left(k^2 - 8\delta^2\rho\varphi\right)}{2b^2(-2+3\beta)\rho + 4k^2\beta\delta^2\varphi - b(-1+\beta)(k^2 - 8\delta^2\rho\varphi)}$$

$$p_3^* = \frac{b^2c(-1+\beta)\rho + 4\delta^2\left(ck^2\beta + a(-1+\beta)\rho\right)\varphi + b\left(a(-3+5\beta)\rho - c(-1+\beta)\left(k^2 - 4\delta^2\rho\varphi\right)\right)}{2b^2(-2+3\beta)\rho + 4k^2\beta\delta^2\varphi - b(-1+\beta)(k^2 - 8\delta^2\rho\varphi)}$$

Substitute τ_2^*, w_3^* and p_3^* into $E_3(\pi_M)$ or $E_3(\pi_R)$, we can obtain the optimal profits and utility of the retailer and manufacturer:

$$w_3^* = \frac{2b^2c(-1+\beta)\rho + 2ab(-1+2\beta)\rho + 4ck^2\beta\delta^2\varphi - bc(-1+\beta)\left(k^2 - 8\delta^2\rho\varphi\right)}{2b^2(-2+3\beta)\rho + 4k^2\beta\delta^2\varphi - b(-1+\beta)(k^2 - 8\delta^2\rho\varphi)} \tag{A12}$$

$$p_3^* = \frac{b^2c(-1+\beta)\rho + 4\delta^2\left[ck^2\beta + a(-1+\beta)\rho\right]\varphi + b\left[a(-3+5\beta)\rho - c\left(k^2 - 4\delta^2\rho\varphi\right)\right]}{2b^2(-2+3\beta)\rho + 4k^2\beta\delta^2\varphi - b(-1+\beta)(k^2 - 8\delta^2\rho\varphi)} \tag{A13}$$

$$E_3^*(\pi_R) = \frac{b(a-bc)^2(-1+\beta)^2\rho^2\left(b + 4\delta^2\varphi\right)^2}{\left(2b^2(-2+3\beta)\rho + 4k^2\beta\delta^2\varphi - b(-1+\beta)(k^2 - 8\delta^2\rho\varphi)\right)^2} \tag{A14}$$

$$U_3^*(M) = \frac{M_3 + M_4 + M_5}{2(2b^2(-2+3\beta)\rho + 4k^2\beta\delta^2\varphi - b(-1+\beta)(k^2 - 8\delta^2\rho\varphi))^2} \tag{A15}$$

where $M_3 - M_5$ can be derived:

$$M_3 = (a - bc)\rho a 4b^3\left(1 - 3\beta + 2\beta^2\right) - 8abk^2\beta^2\delta^2\varphi - 16ak^2\beta^2\delta^4\varphi^2$$

$$M_4 = ab^2(k^2\left(1 - 4\beta + 3\beta^2\right) + 8a(1 - 2\beta)\delta^2\rho\varphi$$

$$M_5 = ab(2b^3c\left(2 - 5\beta + 3\beta^2\right)\rho - 8ak^2\beta\delta^2\varphi\left[k(\tau - 2\beta\tau) + 2c\beta\delta^2\varphi\right]$$

For the manufacturer's and retailer's decisions shown in (12)–(15), we can derive the following first-order differential order:

$$\frac{\partial w_3}{\partial \varphi} = \frac{-4(a - bc)(\beta - 1)(2\beta - 1)\delta^2}{2[b(3\beta - 2) + 4(\beta - 1)\delta^2\varphi]^2}$$

$$\frac{\partial p_3^*}{\partial \varphi} = -\frac{2(a - bc)(\beta - 1)(2\beta - 1)\delta^2}{[b(3\beta - 2) + 4(\beta - 1)\delta^2\varphi]^2}$$

$$\frac{\partial w_3}{\partial \varphi} > 0 \Longrightarrow 0 < \beta < \frac{1}{2}$$

$$\frac{\partial p_3^*}{\partial \varphi} > 0 \Longrightarrow 0 < \beta < \frac{1}{2}$$

$$\frac{\partial \tau_3^*}{\partial \varphi} = \frac{8b^2(-a + bc)k(1 - 2\beta)^2\delta^2\rho}{[2b^2(-2 + 3\beta)\rho + 4k^2\beta\delta^2\varphi - b(-1 + \beta)(k^2 - 8\delta^2\rho\varphi)]^2}$$

$$\frac{\partial \tau_3^*}{\partial \varphi} < 0$$

The proof is completed. □

Proof of Theorem 4.

When the market size becomes larger $(a > bc)$, the following constraints can be listed:

$$s.t\begin{cases} 0 < \beta < 1 \\ a > bc \\ \rho > 0 \end{cases}$$

$\frac{\partial E_3^*(\pi_R)}{\partial \varphi} > 0$ can be achieved:

$$\frac{\partial E_3^*(\pi_R)}{\partial \varphi} > 0 \Longleftrightarrow 0 < \beta < \frac{1}{2}\ and\ a > bc$$

The proof is completed. □

Proof of Proposition 4.

When the market size becomes larger $(a > bc)$, the following constraints can be listed:

$$s.t\begin{cases} 0 < \beta < 1 \\ a > bc \\ \rho > 0 \end{cases}$$

The first differential order can be obtained as follows:

$$\frac{\partial w_3}{\partial \varphi} = -\frac{(a - bc)\left(b + 4\delta^2\varphi\right)\delta^2}{2[b(3\beta - 2) + 4(\beta - 1)\delta^2\varphi]^2}$$

$$\frac{\partial p_3^*}{\partial \varphi} = -\frac{(a-bc)\left(b+4\delta^2\varphi\right)}{2\left[b(3\beta-2)+4(\beta-1)\delta^2\varphi\right]^2}$$

$$\frac{\partial w_3}{\partial \varphi} < 0 \Longleftrightarrow 0 < \varphi < 1$$

$$\frac{\partial p_3^*}{\partial \varphi} < 0 \Longleftrightarrow 0 < \varphi < 1$$

$$\frac{\partial \tau_3^*}{\partial \beta} = \frac{2b(a-bc)k\rho\left(b+4\delta^2\varphi\right)^2}{\left(2b^2(-2+3\beta)\rho+4k^2\beta\delta^2\varphi-b(-1+\beta)(k^2-8\delta^2\rho\varphi)\right)^2} > 0$$

The proof is completed. □

Proof of Condition II.

If $\varphi > -\frac{b}{8\delta^2}+\frac{1}{8}\sqrt{\frac{-2bk^2+5b^2\rho}{\delta^4\rho}}$ and the manufacturer is under disadvantageous fairness concerns, the problem can be written as:

$$\begin{cases} MaxE_4(\pi_M) = E_2(\pi_M) - M_1 \\ MaxE_4(\pi_R) = (a-bp_4)(p_4-w_3) \end{cases}$$

We can obtain the first different order:

$$\frac{\partial E_4(\pi_R)}{\partial p_4} = a - 2bp_4 + k\tau_4 + bw_4$$

The second order can be deduced:

$$\frac{\partial^2 E_4(\pi_R)}{\partial p_4^2} < 0$$

The optimal decision of the retailer can be obtained:

$$p_4^* = \frac{a+bw_4+k\tau_4}{2b}$$

Recalling p_4^* and substituting into $E_3(\pi_M)$, we can obtain the manufacturer's optimal decisions

$$E_4(\pi_M) = E_2(\pi_M) - M_1 = (1+\alpha)E_2(\pi_M) - \alpha E_2(\pi_R)$$

$$w_4^* = \frac{2b^2c(-1+\alpha)\rho+2ab(-1+2\alpha)\rho+4ck^2\beta\delta^2\varphi-bc(-1+\alpha)\left(k^2-8\delta^2\rho\varphi\right)}{2b^2(-2+3\alpha)\rho+4k^2\beta\delta^2\varphi-b(-1+\alpha)(k^2-8\delta^2\rho\varphi)}$$

Similarly, by substituting τ_4^*, w_4^*, p_4^* into $E_4(\pi_M)$ and $E_4(\pi_R)$, we can obtain the optimal profits, utility, and decisions of the retailer and manufacturer:

$$w_4^* = \frac{2b^2c(-1+\alpha)\rho+2ab(-1+2\alpha)\rho+4ck^2\beta\delta^2\varphi-bc(-1+\alpha)\left(k^2-8\delta^2\rho\varphi\right)}{2b^2(-2+3\alpha)\rho+4k^2\beta\delta^2\varphi-b(-1+\alpha)(k^2-8\delta^2\rho\varphi)} \quad \text{(A16)}$$

$$p_4^* = \frac{b^2c(-1+\alpha)\rho+4\delta^2\left[ck^2\beta+a(-1+\alpha)\rho\right]\varphi+b\left[a(-3+5\alpha)\rho-c\left(k^2-4\delta^2\rho\varphi\right)\right]}{2b^2(-2+3\alpha)\rho+4k^2\beta\delta^2\varphi-b(-1+\alpha)(k^2-8\delta^2\rho\varphi)} \quad \text{(A17)}$$

$$\tau_4^* = \frac{M_6+M_7+M_8+M_9}{2b^2(-2+3\alpha)\rho+4k^2\alpha\delta^2\varphi-b(-1+\alpha)(k^2-8\delta^2\rho\varphi)+M_{10}}$$

where $M_6 - M_{10}$ can be denoted:

$$M_6 = (a - bc)k(2b^4(-4 + 6\beta + \alpha(-6 - \alpha(4 + \alpha) + (9 + 2\alpha(3 + \alpha))\beta))\rho$$

$$M_7 = -64k^2\alpha(1 + \alpha)^2\beta\delta^6\varphi^3 + 16b(1 + \alpha)\delta^4\varphi^2(k^2(\beta + \alpha(-1 - \alpha + \beta + 2\alpha\beta)) - 8\alpha\delta^2$$

$$M_8 = b^3(-k^2(2 + \alpha(3 + 2\alpha))(-1 + \beta) + 8(-4 + 5\beta + \alpha(-5 + \alpha(3 + \alpha)(-1 + \beta)$$

$$M_9 = 4b^2\delta^2\varphi(k^2(1 + \beta + \alpha(1 + 2\beta + \alpha(1 + \alpha + \beta - \alpha\beta))) - 8(1 + \alpha)\delta^2$$

$$M_{10} = b^2\left(-k^2(2 + \alpha(3 + 2\alpha)) + 16(1 + \alpha)^2(2 + \alpha)\delta^2\rho\varphi\right)$$

The proof is completed. □

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