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The Impact of Dual-Fairness Concerns Under Different Power Structures on Green-Supply-Chain Decisions

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ABSTRACT

By analyzing the impact of different fairness concerns on a green supply chain, this study determines the optimal decisions under different power structures and conducts a comparative analysis of them. The findings of this study are summarized as follows: 1) under the manufacturer-dominated structure, retail price, wholesale price, product greenness, the manufacturer's profit, the total profit of the supply chain, the manufacturer's utility, and the retailer's utility are all negatively correlated with fairness concerns, but positively correlated with the retailer's profit; 2) under the retailer-dominated structure, fairness concerns have no impact on retail price, product greenness, or the total profit of the supply chain, are positively correlated with wholesale price and the manufacturer's profit and utility, and are negatively correlated with the retailer's profit and utility; 3) under the Nash equilibrium structure, fairness concerns have no impact on the green supply chain.

KEYWORDS

Different Power Structures, Dual-Fairness, Green Supply Chain, Manufacturer's Fairness Concern, Retailer's Fairness Concern, Stackelberg Game

INTRODUCTION

Consumers' rising green consciousness and global green barriers provide an impetus for the rapid development of green supply chains and significantly improve social environments. This also compels manufacturers to make an investment towards launching green products to gain a competitive advantage. However, their improvements in green technologies incur additional costs in green investment but fail to maximize their benefits and even aggravate the tensions between manufacturers and retailers. Hence, the balancing of green investment and profit allocation has become the focus of fairness concerns between manufacturers and retailers.

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Fairness concerns are a universal phenomenon in peoples' daily lives. For example, people may care about their greater workload and longer working hours but lower pay compared to their colleagues or others. This may arouse a sense of unfairness and negative moods, reducing their work efficiency(see Ho et al., 2009, 2014). Similarly, fairness concerns also exist in commercial transactions. For example, Xuzhou Wanji Trading Co., Ltd. terminated their cooperation with Procter & Gamble due to unfair pricing (see Li et al., 2018). Chrysler, a leading automobile manufacturer, treated their distributors unfairly through price discrimination, reducing the performance and consequently the competitiveness of their supply chain(see Nie and Du, 2017). Therefore, fairness concerns have a non-negligible impact on the optimality of decisions. In particular, under different game structures, fairness concerns will vary with the rights and statuses of dominators and followers.

Based on the analysis above, we raise the following questions: 1) Under different power structures, what are the differences in the impact of fairness concerns on green-supply-chain decisions? 2) Do different fairness concerns have any impact on the overall benefits of a green supply chain? 3) Do fairness concerns make any difference to a green supply chain?

To address the above questions, we build a two-tier green supply chain comprising risk-neutral manufacturers and retailers. In this green supply chain, market information is symmetrical, manufacturers assume the cost of green investment and determine the wholesale price and "greenness" of green products, and retailers sell the green products to consumers at retail price. This system uses Nash bargaining as the reference point and game models to comprise the three structures (i.e., manufacturer-dominated, retailer-dominated, and Nash equilibrium) and determines the optimal retail price, optimal wholesale price, and product greenness under the three scenarios (i.e., retailer's fairness concerns, manufacturer's fairness concerns, and no retailer's or manufacturer's fairness concerns). Hence, it is able to analyze the impact of fairness concerns on supply chain decisions under Different power Structures.

This study makes the following contributions: 1) using Nash bargaining as the reference point of fairness, this study analyzes two scenarios (i.e., the manufacturer has fairness concerns and the retailer has fairness concerns); and 2) this study analyzes the impact of different fairness concerns on green-supply-chain decisions under three structures of rights. Basically, existing related literature considers only one or two of the three structures of rights. In addition, the cost of green investment distinguishes a green supply chain from a traditional supply chain.

The remainder of this paper is organized as follows: Part 2 provides a literature review; Part 3 describes the green-supply-chain models based on Nash bargaining; Part 4 analyzes the impact of different fairness concerns on supply-chain-optimal decisions under three structures of rights; Part 5 compares the supply-chain-optimal decisions under three structures of rights; Part 6 describes a numerical simulation and provides verification by calculating examples; Part 7 provides a summary and specifies key points for subsequent studies.

LITERATURE REVIEW

There are three types of literature associated with this study: 1) literature on green-supply-chain management; 2) literature on the impact of structures of rights on supply-chain decisions; and 3) literature on the impact of fairness preferences on green supply chains.

Regarding green-supply-chain management, there are large quantities of research that mainly focus on carbon emissions, green product design, and governmental intervention. Jiang and Chen (2016) studied a two-tier supply chain comprising one low-carbon manufacturer and one retailer, built centralized and decentralized supply-chain models considering consumer behavior and carbon trading, analyzed the optimal price, production volume, carbon trading, and green investment ratios under the two models, and carried out supply-chain coordination through an income- and cost-sharing contract. Wang et al. (2016) studied two-tier supply-chain coordination in a low-carbon environment, analyzed equilibrium decisions in a retailer-dominated game model for carbon abatement, and carried out supply-chain coordination through a cost-sharing contract and a contract on additional charges for wholesale prices. Chen and Wang(2017) studied a hybrid product supply chain comprising one supplier and one manufacturer, built Stackelberg game models for the carbon emission trading mechanism, and analyzed supply chain decisions under centralized and decentralized models. Using the game theory approach, Xu et al. (2017) studied product- and emission-reduction decisions under an order-oriented two-tier supply chain and carried out supply-chain coordination through a wholesale price contract, a cost-sharing contract, and a two-part tariff contract. On the premise that green consumers were available, Bi et al. (2017)built a game model to discuss the following two issues: 1) How does a governmental program with limited or sufficient budgetary subsidies stimulate enterprises to select carbon-abatement technologies? 2) How do manufacturing enterprises select carbon-abatement technologies when cost and market demand are considered? Hafezalkotob (2018) studied two-tier competitive supply chains for green and non-green products and conducted a game analysis under two modes of government intervention, including direct taxes and dues, and trading licenses.

The second type of associated literature pertains to the impact of Different power Structures on supply-chain decisions. Chen and Wang(2015) studied a supply chain comprising one mobile phone manufacturer and one telecom service operator and discussed the impact of the selection of supply-chain channels under three structures of rights (i.e., a vertical Nash structure, a manufacturer-dominated structure, and an operator-dominated structure). In the context of big data, Liu et al. (2017) studied the impact of targeted advertising and product greenness on the pricing policies of green supply chains and provided a comparison of decisions made under four structures of rights. Luo et al. (2017) analyzed a hybrid product supply chain comprising two manufacturers and one retailer, built game models under three structures of rights, and analyzed the impact of pricing decisions on a good-branded product and an average-branded product under three structures of rights (i.e., manufacturer-dominated, retailer-dominated, and vertical Nash). Chen et al. (2017)studied sustainable supply chains under a carbon-abatement mechanism, built three game models to analyze the impact of three structures of rights on supply-chain decisions, and carried out supply-chain coordination through a two-part tariff contract. Chen et al. (2017) studied a supply chain comprising one manufacturer and two retailers and built game models with three structures of rights (i.e., manufacturer-dominated, vertical Nash, and retailer-dominated) to analyze the impact of two-dimensional structures of rights on supply chain decisions. Based on an analysis of the impact of consumer values on consumer purchasing behavior, Luo et al. (2018) analyzed the retail supply chains of two substitute products, built game models with three structures of rights (i.e., manufacturer-dominated, vertical Nash, and retailer-dominated), and analyzed the impact of consumer values and structures of rights on retailer decisions.

The third type of associated literature pertains to the impact of fairness preferences on green supply chains. More and more scholars have begun to explore fairness concerns based on consumers' environmental consciousness. Zhou et al. (2016) studied a supply chain comprising one manufacturer and one retailer, built a manufacturer-dominated Stackelberg game model to analyze the impact of the retailer's fairness concerns on supply-chain decisions, and carried out supply-chain coordination through cooperative advertising and carbon-abatement cost-sharing contracts. Du et al. (2017) studied a supply chain comprising suppliers and manufacturers with fairness concerns, built a Stackelberg game model that considered the efforts of green investment, and analyzed the impact of green-investment efforts and fairness concerns on supply-chain decisions. Liu et al. (2017) built a manufacturer-dominated Stackelberg game model that considered carbon tax rules and consumers' low-carbon preferences, analyzed the impact of manufacturer and retailer fairness preferences on supply-chain decisions under centralized and decentralized decision systems, and carried out supply-chain coordination through an income-sharing contract. Li et al. (2018) studied a green supply chain comprising one manufacturer and one retailer with fairness concerns, built a centralized and a decentralized game model to analyze the impact of the retailer's fairness concerns on green-supply-chain decisions, and carried out supply-chain coordination through an income-sharing contract. Based on an analysis of consumers' environmental consciousness and carbon abatement, Zhang et al. (2018)

built a manufacturer-dominated game model to analyze the impact of the retailer's fairness concerns and policies on government subsidies on supply-chain-optimal decisions.

The studies above reveal that with the development of green supply chains, the structures of rights and fairness concerns have a non-negligible impact on green-supply-chain decisions. Compared with the existing associated literature, this paper makes the following contributions: 1) this study uses the reference solution to bargaining problems as the reference point of fairness and applies fairness concerns to green supply chains; and 2) this study analyzes not only the manufacturer's fairness concerns, but also the retailer's fairness concerns under Different power Structures, aligning the results closer to reality. Hence, we build game models under Different power Structures (i.e., manufacturer-dominated, retailer-dominated, and Nash equilibrium) to analyze the impact of fairness preferences on green-supply-chain decisions and performance.

MODEL DESCRIPTION AND CONSTRUCTION

This study focuses on a two-tier green supply chain comprising a risk-neutral manufacturer and a risk-neutral retailer, in which the manufacturer determines the greenness and wholesale price of products and the retailer determines the retail price of products. Figure 1 shows the structure of the green supply chain. Fairness concerns vary with the structure of rights, and consequently have different impacts on the manufacturer's and retailer's decisions. Therefore, the supply chain needs to not only consider the cost of production and green investment, but also to balance the impact of fairness concerns on it.

Table 1 describes the meanings of the symbols contained in this paper.

The market demand of green products is affected by both product greenness and retail price and is inversely proportional to retail price but proportional to product greenness. The green product investment cost is assumed by the manufacturer; the higher the product investment, the higher the product greenness. With reference to related literature (see Liu et al., 2012; Swami and Swami, 2013; Song and Gao, 2018), this study assumes that the market demand function is a linear function with respect to retail price and product greenness, and the green product investment is a quadratic function regarding product greenness.

The market demand function can be expressed as follows:

$$D = a - p + \alpha g$$

The green investment cost function can be expressed as follows:

Figure 1. Structure of green supply chain

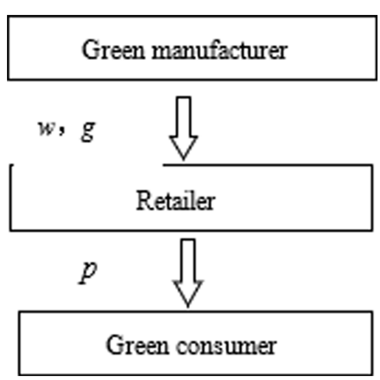


Table 1. Meanings of symbols

Parameter	Description	Parameter	Description
p	Retail price of green products	g	Product greenness
D	Market demand of green products	a	Potential market demand $\left(a > c\right)$
c	Production cost per unit product $\left(0 < c < p\right)$	β	Green investment coefficient
c_g	Cost of investment in a green product	π_r	Retailer's profit
q	Retailer's order quantity	π_m	Manufacturer's profit
w	Wholesale price of products	π	Total profit of green supply chain
α	Consumers' green preference coefficient	λ	Fairness concern coefficient

$$C_g = \beta g^2$$

We obtain the related functions below according to the market demand and green investment cost functions:

The retailer's profit function can be expressed as follows:

$$\pi_r = \left(p - w\right)\left(a - p + \alpha g\right) \tag{1}$$

The green manufacturer's profit function can be expressed as follows:

$$\pi_m = \left(w - c\right)\left(a - p + \alpha g\right) - \beta g^2 \tag{2}$$

The total profit function of the green supply chain can be expressed as follows:

$$\pi_T = \left(p - c\right)\left(a - p + \alpha g\right) - \beta g^2 \tag{3}$$

When fairness concerns exist in the supply chain, fairness aims to maximize its own utility, and participants of the supply chain use the profits of their peers as their reference point. Specifically, if the participants think their own profit exceeds that of their peers', the utility of fairness will increase; otherwise, the utility of fairness will decrease. Income differences can bring about a change in the utility function. As specified by Du et al. (2014), Chen et al. (2017), and Li et al. (2018), the reference solution is set to Nash bargaining as the reference point of fairness $\left(\bar{\pi}_m, \bar{\pi}_r\right)$. The retailer's and manufacturer's utility functions are then obtained:

$$u_m = \pi_m + \lambda_m \left(\pi_m - \overline{\pi}_m\right) = \left(1 + \lambda_m\right)\pi_m - \lambda_m \overline{\pi}_m$$
$$u_r = \pi_r + \lambda_r \left(\pi_r - \overline{\pi}_r\right) = \left(1 + \lambda_r\right)\pi_r - \lambda_r \overline{\pi}_r$$

where, u_m, u_r respectively indicate the manufacturer's and retailer's utility functions, λ_m, λ_r respectively indicate the manufacturer's and retailer's fairness concern coefficients, $\overline{\pi}_m, \overline{\pi}_r$ respectively indicate the manufacturer's and retailer's fairness solutions, and π indicates the profit of the supply chain. The results of $\overline{\pi}_m + \overline{\pi}_r = \pi$ and $\pi_m + \pi_r = \pi$ are then obtained.

According to the associated literature (see Nash, 1950, 1953), the Nash solution can be obtained through the following model:

$$\max_{\pi_r, \pi_m} u_m u_r$$
$$s.t. \begin{cases} \pi_m + \pi_r = \pi \\ u_m, u_r > 0 \end{cases}$$

Using the calculation method specified by Du et al. (2014), we obtain the manufacturer's and retailer's fairness solutions to Nash bargaining $\left(\overline{\pi}_m, \overline{\pi}_r\right)$:

$$\overline{\pi}_m = \frac{1 + \lambda_m}{2 + \lambda_m + \lambda_r}\pi$$
$$\overline{\pi}_r = \frac{1 + \lambda_r}{2 + \lambda_m + \lambda_r}\pi$$

The manufacturer's and retailer's fairness utility functions can therefore be expressed as follows:

$$u_m = \left(1 + \lambda_m\right)\pi_m - \frac{\lambda_m \left(1 + \lambda_m\right)}{2 + \lambda_m + \lambda_r}\pi \tag{4}$$

$$u_r = \left(1 + \lambda_r\right)\pi_r - \frac{\lambda_r \left(1 + \lambda_r\right)}{2 + \lambda_m + \lambda_r}\pi \tag{5}$$

GAME MODELS UNDER THREE POWER STRUCTURES

Manufacturer-dominated Stackelberg Game

For the manufacturer-dominated Stackelberg game, the retailer is a follower at a disadvantage, and so the retailer develops a sense of unfairness. Assume that the manufacturer is fairness-neutral, and the retailer has fairness concerns: $\lambda_m = 0, \lambda_r = \lambda > 0$. Therefore, the manufacturer's and retailer's utility functions become the following:

$$u_m = \pi_m \tag{6}$$

$$u_r = \left(1+\lambda\right)\pi_r - \frac{\lambda\left(1+\lambda\right)}{2+\lambda}\pi \tag{7}$$

In a manufacturer-dominated game model, the manufacturer determines wholesale price and product greenness, and the retailer determines retail price accordingly. The dynamic game model can be solved through backward induction.

According to Equation (7), calculate the first and second derivatives concerning the wholesale price *p*, giving the result $\frac{\partial^2 \pi_r}{\partial p^2} = -\frac{4\left(1+\lambda\right)}{2+\lambda} < 0$. π_r is the concave function regarding retail price, so an optimal value is available. Let its first derivative be 0, and then obtain the optimal retail price p_m under the manufacturer-dominated game:

$$p_m = \frac{1}{4}\left[2w + 2a + 2\alpha g + \lambda\left(w-c\right)\right] \tag{8}$$

Substituting Equation (8) into Equation (6), it then becomes easy to prove that when $8\beta + 4\beta\lambda - \alpha^2 > 0$, u_m is the joint concave function regarding the wholesale price *w* and product greenness *g*. Therefore, an optimal value is available. Let the first derivative of u_m be 0 with respect to *w* and *g*. We then obtain the optimal values of w_m and g_m:

$$w_m = \frac{-c\alpha^2 + 4a\beta + 4c\beta + 4c\beta\lambda}{8\beta + 4\beta\lambda - \alpha^2} \tag{9}$$

$$g_m = \frac{\left(a-c\right)\alpha}{8\beta + 4\beta\lambda - \alpha^2} \tag{10}$$

Substitute Equations (9) and (10) into Equation (8), and then obtain the optimal retail price p_m:

$$p_m = \frac{6a\beta + 3a\beta\lambda + 2\beta c + \beta c\lambda - c\alpha^2}{8\beta + 4\beta\lambda - \alpha^2}. \tag{11}$$

Substitute Equations (9), (10), and (11) into Equations (1), (2), (3), (6), and (7) . Then, obtain the retailer's profit π_{mr}, the mafacturer's profit π_{mm}, the total profit π_{mT} of the supply chain, the manufacturer's fairness utility u_{mm}, and the retailer's fairness utility u_{mr} under the manufacturer-dominated game:

$$\pi_{mm} = \frac{\beta\left(a-c\right)^2}{8\beta + 4\beta\lambda - \alpha^2} \tag{12}$$

$$\pi_{mr} = \frac{\beta^2 \left(a-c\right)^2 \left(2+\lambda\right)\left(2+3\lambda\right)}{\left(8\beta+4\beta\lambda-\alpha^2\right)^2} \tag{13}$$

$$\pi_{mT} = \frac{\beta\left(a-c\right)^2 \left[3\beta\left(\lambda+2\right)^2-\alpha^2\right]}{\left(8\beta+4\beta\lambda-\alpha^2\right)^2} \tag{14}$$

$$u_{mr} = \frac{\beta\left(1+\lambda\right)\left(a-c\right)^2 \left(8\beta\lambda+8\beta+2\beta\lambda^2+\lambda\alpha^2\right)}{\left(\lambda+2\right)\left(8\beta+4\beta\lambda-\alpha^2\right)^2} \tag{15}$$

$$u_{mm} = \pi_{mm} = \frac{\beta\left(a-c\right)^2}{8\beta+4\beta\lambda-\alpha^2} \tag{16}$$

Proposition 1: In the manufacturer-dominated game model, retail price, wholesale price, and product greenness will decline when the retailer's fairness concerns increase.

Proof: We calculate the fairness concern coefficient λ according to Equations (9), (10), and (11):

$$\frac{\partial p_m}{\partial \lambda} = \frac{-3\beta\alpha^2\left(a-c\right)}{\left(8\beta+4\beta\lambda-\alpha^2\right)^2} < 0$$

$$\frac{\partial w_m}{\partial \lambda} = \frac{-16\beta^2\left(a-c\right)}{\left(8\beta+2\beta\lambda-\alpha^2\right)^2} < 0$$

$$\frac{\partial g_m}{\partial \lambda} = \frac{-4\beta}{\left(8\beta+2\beta\lambda-\alpha^2\right)^2} < 0$$

Therefore, Proposition 1 is true.

According to Proposition 1, an increase in the retailer's fairness concerns will cause a decline in wholesale price and product greenness. In the manufacturer-dominated game, the retailer has higher fairness concerns, so the manufacturer reduces wholesale price; to earn a higher profit, the manufacturer will reduce green investment, thereby reducing product greenness. To earn a higher profit, the retailer will try to win a greater market share by reducing the sales price. Therefore, in the manufacturer-dominated game, the retailer's fairness concerns have a more significant impact on the manufacturer and retailer than the manufacturer's dominance.

Retailer-Dominated Stackelberg Game

In the retailer-dominated Stackelberg game, the manufacturer is a follower at a disadvantage. There, the manufacturer develops fairness concerns and the retailer is fairness-neutral. Hence, it can be seen as follows:

Given $\lambda_m = \lambda > 0, \lambda_r = 0$, obtain the manufacturer's and the retailer's utility functions:

$$u_m = \left(1+\lambda\right)\pi_m - \frac{\lambda\left(1+\lambda\right)}{2+\lambda}\pi \tag{17}$$

$$u_r = \pi_r \tag{18}$$

As specified by Shi (2013), Chen (2016), and Song (2018), we set the retailer's profit *m* to $m = p - w$ and substitute $p = w + m$ into Equation (17). It is easy to prove that when $2\beta - \alpha^2 > 0$, u_m is a joint concave function with respect to *w* and *g*; therefore, *w* and *g* have their optimal values. Let the first derivative of u_r be 0 with respect to *w* and *g*. Then, calculate the optimal values for wholesale price and product greenness.

$$w_r = \frac{4\beta\left(a+c\right) + 2\beta\lambda p - 2c\alpha^2 - 4\beta p - \lambda p\alpha^2}{\left(2\beta - \alpha^2\right)\left(\lambda + 2\right)} \tag{19}$$

$$g_r = \frac{\alpha\left(a - p\right)}{2\beta - \alpha^2} \tag{20}$$

We substitute Equations (19) and (20) into Equation (18). It is easy to prove that π_r is a concave function with respect to *p*; the wholesale price has its optimal value. Let its first derivative be 0, then obtain the optimal retail price under the retailer-dominated game:

$$p_r = \frac{\left(a+c\right)\left(2\beta - \alpha^2\right) + 4\beta a}{2\left(4\beta - \alpha^2\right)} \tag{21}$$

We substitute p_r into Equations (19) and (20), and obtain the optimal wholesale price and product greenness under the retailer-dominated game:

$$w_r = \frac{\lambda\left(a+c\right)\left(2\beta - \alpha^2\right) + 4\beta\lambda a + 4\beta a + 12\beta c - 4c\alpha^2}{2\left(4\beta - \alpha^2\right)\left(\lambda + 2\right)} \tag{22}$$

$$g_r = \frac{\alpha\left(a - c\right)}{2\left(4\beta - \alpha^2\right)} \tag{23}$$

We substitute p_r, w_r, and g_r into Equations (1), (2), (3), (17), and (18) . We then obtain the retailer's profit π_{rr}, the manufacturer's profit π_{rm}, the total profit π_{rT} of the supply chain, the manufacturer's fairness utility u_{rm}, and the retailer's fairness utility u_{rr}:

$$\pi_{rr} = \frac{\beta\left(a-c\right)^2}{\left(4\beta-\alpha^2\right)\left(\lambda+2\right)} \tag{24}$$

$$\pi_{rm} = \frac{\beta\left(3\lambda+2\right)\left(a-c\right)^2}{4\left(4\beta-\alpha^2\right)\left(\lambda+2\right)} \tag{25}$$

$$\pi_{rT} = \frac{3\beta\left(a-c\right)^2}{4\left(4\beta-\alpha^2\right)} \tag{26}$$

$$u_{rm} = \frac{\beta\left(\lambda+1\right)\left(a-c\right)^2}{2\left(4\beta-\alpha^2\right)\left(\lambda+2\right)} \tag{27}$$

$$u_{rr} = \pi_{rr} = \frac{\beta\left(a-c\right)^2}{\left(4\beta-\alpha^2\right)\left(\lambda+2\right)} \tag{28}$$

Proposition 2: In the retailer-dominated game, wholesale price and product greenness rise superior to the manufacturer's fairness concerns, and wholesale price increases when the manufacturer's fairness concerns increase.

Proof: According to Equations (21) and (23), in the retailer-dominated game, retail price and product greenness are not correlated with the manufacturer's fairness concerns:

$$\frac{\partial p_r}{\partial \lambda} = 0$$

$$\frac{\partial g_r}{\partial \lambda} = 0$$

Therefore, the manufacturer's fairness concerns have no impact on retail price and product greenness.

We then calculate the derivative of the fairness concern coefficient λ according to Equation (22):

$$\frac{\partial w_r}{\partial \lambda} = \frac{2\left(a-c\right)\left(4\beta-\alpha^2\right)+4\beta\lambda a}{2\left(4\beta-\alpha^2\right)\left(\lambda+2\right)^2} > 0$$

Therefore, Proposition 2 is true.

According to Proposition 2, when the retailer is at an advantage, retail price and product greenness rise superior to the manufacturer's fairness concerns. In the retailer-dominated game, the retailer determines retail price first; the manufacturer then determines wholesale price and product greenness. If the greenness of like products declines, their retail price will lose its competitive advantage, thereby causing a profit decline; this is not acceptable to the retailer. When the manufacturer has fairness concerns, green investment brings about an increase in total cost; to gain more fairness, the manufacturer can only raise the wholesale price.

Nash Equilibrium Game Model

In the Nash equilibrium game, the manufacturer and the retailer are equipollent, and none of the participants has fairness concerns ($\lambda_m = \lambda_r = 0$). The manufacturer's and the retailer's utility functions are as follows:

$$u_m = \pi_m \tag{29}$$

$$u_r = \pi_r \tag{30}$$

The retailer determines the retail price while the manufacturer determines the wholesale price and product greenness (simultaneous decision-making).

As specified in Shi (2013), Chen (2016), and Song (2018)[3,29-30], we substitute $p = w + m$ into Equation (29). It is easy to prove that u_m is a joint concave function with respect to *w* and *g*; *w* and *g* have their optimal values. Let its first derivative be 0. We then obtain the following results:

$$a - w - p + \alpha g = 0 \tag{31}$$

$$\alpha\left(w - c\right) - 2\beta g = 0 \tag{32}$$

We calculate the second derivative of *p* according to Equation (29). It is easy to prove that The manufacturer's utility function is a concave function with respect to *p*. Let its first derivative be 0; we then obtain the following result:

$$2p - w - \alpha g - a = 0 \tag{33}$$

We calculate the retail price p_n , wholesale price w_n , and product greenness g_n in the Nash equilibrium game according to the combination of Equations (31), (32), and (33).

$$p_n = \frac{4a\beta + 2c\beta - c\alpha^2}{6\beta - \alpha^2} \tag{34}$$

$$w_n = \frac{2a\beta + 4c\beta - c\alpha^2}{6\beta - \alpha^2} \tag{35}$$

$$g_n = \frac{\left(a - c\right)\alpha}{6\beta - \alpha^2} \tag{36}$$

Hence, we obtain the retailer's profit π_{nr}, manufacturer's profit π_{nm}, total profit π_{nT} of the supply chain, manufacturer's fairness utility u_{nm}, and retailer's fairness utility u_{nr} in the Nash equilibrium game.

$$\pi_{nr} = \frac{4\beta^2 \left(a-c\right)^2}{\left(6\beta-\alpha^2\right)^2} \tag{37}$$

$$\pi_{nm} = \frac{\beta\left(a-c\right)^2 \left(4\beta-\alpha^2\right)}{\left(6\beta-\alpha^2\right)^2} \tag{38}$$

$$\pi_{nT} = \frac{\beta\left(a-c\right)^2 \left(8\beta-\alpha^2\right)}{\left(6\beta-\alpha^2\right)^2} \tag{39}$$

$$u_{nm} = \pi_{nm} = \frac{\beta\left(a-c\right)^2 \left(4\beta-\alpha^2\right)}{\left(6\beta-\alpha^2\right)^2} \tag{40}$$

$$u_{nr} = \pi_{nr} = \frac{4\beta^2 \left(a-c\right)^2}{\left(6\beta-\alpha^2\right)^2} \tag{41}$$

Proposition 3: In the Nash equilibrium game, retail price, wholesale price, and product greenness rise superior to fairness concerns.

Proof: In the Nash equilibrium game, the manufacturer and the retailer are equipollent, and neither of them has fairness concerns. We calculate the first derivative of the fairness concern coefficient λ according to Equations (33), (34), and (35):

$$\frac{\partial p_n}{\partial \lambda} = 0$$

$$\frac{\partial w_n}{\partial \lambda} = 0$$

$$\frac{\partial g_n}{\partial \lambda} = 0$$

As evidenced by the foregoing, Proposition 3 is true.

According to Proposition 3, the related results are the same as those under the decentralized model of supply chains when the manufacturer and retailer are equipollent. Hence, there is a conflict of interest between the manufacturer and retailer in the Nash equilibrium game. It is therefore necessary to coordinate interests, to better protect the interests of the supply chain and promote the development of the green supply chain.

COMPARISON OF DECISIONS UNDER DIFFERENT POWER STRUCTURES

Proposition 4: If fairness concerns exist in the green supply chain, 1) when $2\beta\lambda - 2\beta + \alpha^2 > 0$, then $p_r > p_m > p_n$; 2) when $4\beta\lambda\text{-}4\beta + \alpha^2 > 0$, then $w_r > w_n > w_m$; and 3) when $2\beta - \alpha^2 > 0$, then $g_n > g_r > g_m$.

Proof: 1) Given $2\beta\lambda - 2\beta + \alpha^2 > 0$, we obtain the following results according to Equations (21) and (11):

$$p_r - p_m = \frac{\left(a-c\right)\alpha^2\left(2\beta\lambda - 2\beta + \alpha^2\right)}{2\left(8\beta + 2\beta\lambda - \alpha^2\right)\left(4\beta - \alpha^2\right)} > 0$$

Likewise, we obtain the following result according to Equations (11) and (33):

$$\begin{aligned} p_m - p_n &= \frac{\beta\left(a-c\right)\left(2\beta - \alpha^2\right)\left(4\beta - 2\alpha^2 + 2\beta\lambda - 3\lambda\alpha^2\right)}{\left(6\beta - \alpha^2\right)\left(8\beta + 4\beta\lambda - \alpha^2\right)} \\ &> \frac{3\left(a-c\right)\left(2\beta - \alpha^2\right)^2}{2\left(6\beta - \alpha^2\right)\left(8\beta + 4\beta\lambda - \alpha^2\right)} > 0 \end{aligned}$$

Therefore, $p_r > p_m > p_n$.

2) When $4\beta\lambda\text{-}4\beta + \alpha^2 > 0$, we obtain the following results according to Equations (34), (9), and (22):

$$w_n - w_m = \frac{2\beta\left(a-c\right)\left(4\beta\lambda - 4\beta + \alpha^2\right)}{\left(8\beta + 4\beta\lambda - \alpha^2\right)\left(6\beta - \alpha^2\right)} > 0$$

$$\begin{aligned} w_r - w_n &= \frac{4\beta\left(a-c\right)\left(2\beta - \alpha^2\right)\left(2\lambda - 1\right)}{2\left(\lambda + 2\right)\left(4\beta - \alpha^2\right)\left(6\beta - \alpha^2\right)} \\ &> \frac{2\beta\left(a-c\right)\left(2\beta - \alpha^2\right)^2}{2\left(\lambda + 2\right)\left(4\beta - \alpha^2\right)\left(6\beta - \alpha^2\right)} > 0 \end{aligned}$$

Then, $w_r > w_n > w_m$.

3) When $2\beta - \alpha^2 > 0$, we obtain the following results according to Equations (35), (23), and (10):

$$g_n - g_r = \frac{\alpha\left(a-c\right)\left(2\beta-\alpha^2\right)}{2\left(4\beta-\alpha^2\right)\left(6\beta-\alpha^2\right)} > 0$$

$$g_r - g_m = \frac{\alpha\left(a-c\right)\left(4\beta\lambda+\alpha^2\right)}{2\left(4\beta-\alpha^2\right)\left(8\beta+4\beta\lambda-\alpha^2\right)} > 0$$

Therefore, $g_n > g_r > g_m$.

Proposition 4 reveals that if fairness concerns exist in the supply chain, then 1) in the retailer-dominated game, both retail price and wholesale price are maximized; 2) in the manufacturer-dominated game, both wholesale price and product greenness are minimized; and 3) in the Nash equilibrium game, retail price is minimized, product greenness is maximized, and wholesale price lies in between. Evidently, the impact on the manufacturer's and retailer's decisions varies under different fairness concerns.

Proposition 5: When $4\beta\lambda - 4\beta + \alpha^2 > 0$ and $2\beta - \alpha^2 > 0$, the retailer's profit satisfies the relational expression $\pi_{mr} > \pi_{nr} > \pi_{rr}$.

Proof: 1) We obtain the following result according to Equations (36) and (13):

$$\begin{aligned}\pi_{mr} - \pi_{nr} &= \frac{\beta^2\left(a-c\right)^2\left(\lambda+2\right)\left(2+3\lambda\right)}{\left(8\beta+4\beta\lambda-\alpha^2\right)^2} - \frac{4\beta^2\left(a-c\right)^2}{\left(6\beta-\alpha^2\right)^2} \\ &= \frac{\beta^2\left(a-c\right)^2\left(\lambda+2\right)\left[8\beta\left(5\beta-\alpha^2\right)+\beta\lambda\left(92\beta-36\alpha^2\right)+3\lambda\alpha^2+2\lambda\left(\lambda+2\right)\alpha^4\right]}{\left(8\beta+4\beta\lambda-\alpha^2\right)^2\left(6\beta-\alpha^2\right)^2} > 0\end{aligned}$$

Therefore, $\pi_{mr} > \pi_{nr}$.

2) We obtain the following result according to Equations (36) and (24):

$$\begin{aligned}\pi_{nr} - \pi_{rr} &= \frac{4\beta^2\left(a-c\right)^2}{\left(6\beta-\alpha^2\right)^2} - \frac{\beta\left(a-c\right)^2}{\left(4\beta-\alpha^2\right)\left(\lambda+2\right)} \\ &= \frac{\beta\left(a-c\right)^2\left[4\beta\lambda\left(4\beta-\alpha^2\right)-4\beta^2+4\beta\alpha^2-\alpha^4\right]}{\left(\lambda+2\right)\left(4\beta-\alpha^2\right)\left(6\beta-\alpha^2\right)^2} \\ &> \frac{4\beta^2\left(a-c\right)^2\left(3\beta-\alpha^2\right)}{\left(\lambda+2\right)\left(4\beta-\alpha^2\right)\left(6\beta-\alpha^2\right)^2} > 0\end{aligned}$$

Therefore, $\pi_{nr} > \pi_{rr}$.

Based on the results in 1) and 2) above, Proposition 5 is true.

Proposition 5 reveals that when fairness concerns exist in the supply chain, the retailer's profit is maximized in the manufacturer-dominated game but minimized in the retailer-dominated game. This implies that fairness concerns under Different power Structures have very significant impacts on the dominator of the supply chain; specifically, the dominator of the supply chain sacrifices its own interests to ensure fairness to the follower. In the Nash equilibrium game, the dominator and follower are equipollent, and neither of them has fairness concerns. Therefore, the manufacturer's profit in the Nash equilibrium game lies in between the others.

Proposition 6: Under the three structures of rights, the manufacturer's profit meets the following condition: when $4\beta\lambda - 4\beta + \alpha^2 > 0$, $\pi_{rm} > \pi_{nm} > \pi_{mm}$.

Proof: When $4\beta\lambda - 4\beta + \alpha^2 > 0$, we obtain the following result according to Equations (12) and (37):

$$\begin{aligned}\pi_{nm} - \pi_{mm} &= \frac{\beta\left(4\beta-\alpha^2\right)\left(a-c\right)^2}{\left(6\beta-\alpha^2\right)^2} - \frac{\beta\left(a-c\right)^2}{8\beta+2\beta\lambda-\alpha^2} \\ &= \frac{\beta\left(a-c\right)^2\left[4\beta\lambda\left(4\beta-\alpha^2\right)-4\beta^2\right]}{\left(6\beta-\alpha^2\right)^2\left(8\beta+2\beta\lambda-\alpha^2\right)} \\ &> \frac{\beta\left(a-c\right)^2\left(2\beta-\alpha^2\right)\left(6\beta-\alpha^2\right)}{\left(6\beta-\alpha^2\right)^2\left(8\beta+2\beta\lambda-\alpha^2\right)} > 0\end{aligned}$$

Therefore, $\pi_{nm} > \pi_{mm}$.

When $\beta\lambda\text{-}2\beta + \alpha^2 > 0$, we obtain the following result according to Equations (25) and (37):

$$\begin{aligned}\pi_{rm} - \pi_{nm} &= \frac{\beta\left(3\lambda+2\right)\left(a-c\right)^2}{4\left(\lambda+2\right)\left(4\beta-\alpha^2\right)} - \frac{\beta\left(4\beta-\alpha^2\right)\left(a-c\right)^2}{\left(6\beta-\alpha^2\right)^2} \\ &= \frac{\beta\left(a-c\right)^2\left(44\beta^2\lambda\text{-}4\beta\lambda\alpha^2\text{-}\lambda\alpha^4\text{-}56\beta^2\text{-}6\alpha^4\right)}{\left(\lambda+2\right)\left(4\beta-\alpha^2\right)\left(6\beta-\alpha^2\right)^2} \\ &> \frac{\left(a-c\right)^2\alpha^2\left(2\beta\text{-}\alpha^2\right)^2}{\left(\lambda+2\right)\left(4\beta-\alpha^2\right)\left(6\beta-\alpha^2\right)^2} > 0\end{aligned}$$

Therefore, Proposition 6 is true.

Proposition 6 reveals that the green manufacturer's profit is maximized in the retailer-dominated game, is minimized in the manufacturer-dominated game, and maintains an equilibrium level in the Nash equilibrium game. Evidently, under structures with different fairness concerns, the dominator of the supply chain sacrifices its own interests for fairness. In Proposition 6, the impact of fairness concerns on the dominator is similar to that in Proposition 5.

Proposition 7: When $2\beta - \alpha^2 > 0$, the total profit of the supply chain meets the following condition: $\pi_{nT} > \pi_{rT} > \pi_{mT}$.

Proof: 1) When $2\beta - \alpha^2 > 0$, we obtain the following result according to Equations (38) and (26):

Therefore, $\pi_{nT} > \pi_{rT}$.

2) We obtain the following result according to Equations (26) and (14):

Therefore, $\pi_{rT} > \pi_{mT}$ and Proposition 7 is true.

Proposition 7 reveals that, owing to fairness concerns, the total profit of the supply chain is maximized in the Nash equilibrium game, thereby largely coordinating the overall interests of the supply chain. In the manufacturer-dominated and retailer-dominated games, owing to fairness concerns, the follower seeks more fairness and the dominator has to sacrifice more profit, thereby impairing the overall interests of the supply chain. In the manufacturer-dominated game, the total profit of the supply chain is minimized, indicating that total profit is affected most significantly by fairness concerns in this structure.

CALCULATION EXAMPLE ANALYSIS

To corroborate the above conclusions and conduct a more in-depth study, this study conducts numerical simulation analysis using the Matlab 7.1 software and analyzes the conclusions of the three models comparatively. To meet all propositional hypotheses, we first set the related parameters ($a = 100, c = 10, \alpha = 2, \beta = 20, \lambda = 4$), then substitute the parameter values into the above models for simulation and analysis purposes.

Comparative Analysis of Green Supply Chain Equilibrium Decisions under Different Power Structures

According to Table 2, in the retailer-dominated game, retail price, wholesale price, and manufacturer's profit are maximized; in the manufacturer-dominated game, wholesale price, product greenness, and the manufacturer's profit and utility function are minimized, whereas the retailer's profit is maximized. In the Nash equilibrium game, the total profit of the supply chain, manufacturer's utility function, and retailer's utility function are maximized, the retailer's profit is minimized, and wholesale price, the retailer's profit, and the manufacturer's profit lie in between.

Moreover, in the Nash equilibrium game, the difference between the retailer's profit and manufacturer's profit is minimized, and the total profit of the supply chain is maximized (Table 2). This implies that in the Nash equilibrium model, the interest relationship of the supply chain attains the highest equilibrium; in other words, the relationship between all participants is well-coordinated. In the manufacturer-dominated and retailer-dominated games, the tension between participants is aggravated by the significant impact of fairness concerns, thereby reducing the total profit of the supply chain. To some extent, this has a negative impact on product greenness, thereby hindering the development of the green supply chain.

The Impact of Fairness Concerns on Green Supply Chain Decisions

1. The impact of fairness concerns on pricing decisions

Table 2. Supply chain decisions under three power structures

	Manufacturer Dominated	Retailer Dominated	Nash Equilibrium
p	77.3	78.68	72.07
w	25.13	63.68	41.03
g	0.38	1.18	1.55
π_r	1201.19	355.26	963.14
π_m	340.34	1243.42	914.98
π_T	1541.53	1598.68	1878.12
u_m	340.34	888.16	914.98
u_r	867.52	355.26	963.14

As shown in Figure 2, retail price is affected by fairness concerns only in the manufacturer-dominated game, and declines when fairness concerns increase. This is consistent with Proposition 1. Moreover, the manufacturer-dominated retail price is lower than the retailer-dominated retail price when fairness concerns increase and other parameters remain unchanged; that is, when $\lambda > 34.03$, $p_m < p_r$. In the Nash equilibrium game, retail price is not correlated with fairness concerns, and is minimized.

As shown in Figure 3, in the retailer-dominated game, wholesale price increases when fairness concerns increase, and is maximized; in the manufacturer-dominated game, wholesale price declines when fairness concerns increase, and is minimized; in the Nash equilibrium game, wholesale price rises superior to fairness concerns, and lies in between the two.

As shown in Figures 2 and 3, in the manufacturer-dominated game, both retail price and wholesale price are negatively correlated with fairness concerns. Evidently, the higher fairness concerns are, the lower retail price and wholesale price are. In the retailer-dominated game, retail price rises superior to fairness concerns and wholesale price increases. This implies that fairness concerns have a more significant impact on the supply chain than the retailer's dominance. Fairness concerns have a significant impact due to the manufacturer's cost of green investment.

2. The impact of fairness concerns on product greenness

As shown in Figure 4, in the retailer-dominated and Nash equilibrium games, product greenness rises superior to the fairness concerns in the supply chain; in the manufacturer-dominated game, product greenness declines with the increase in fairness concerns. Under the effect of the retailer's fairness concerns, the manufacturer can only reduce green investment to seek fairness and interest maximization, thereby reducing product greenness. Moreover, product greenness is maximized in the Nash equilibrium game, but minimized in the manufacturer-dominated game.

The conclusions from Figures 2, 3, and 4 are consistent with Propositions 1, 2, and 3. This also implies that fairness concerns have a more significant impact on supply-chain decisions than the structures of rights.

Figure 2. The impact of fairness concerns on retail price

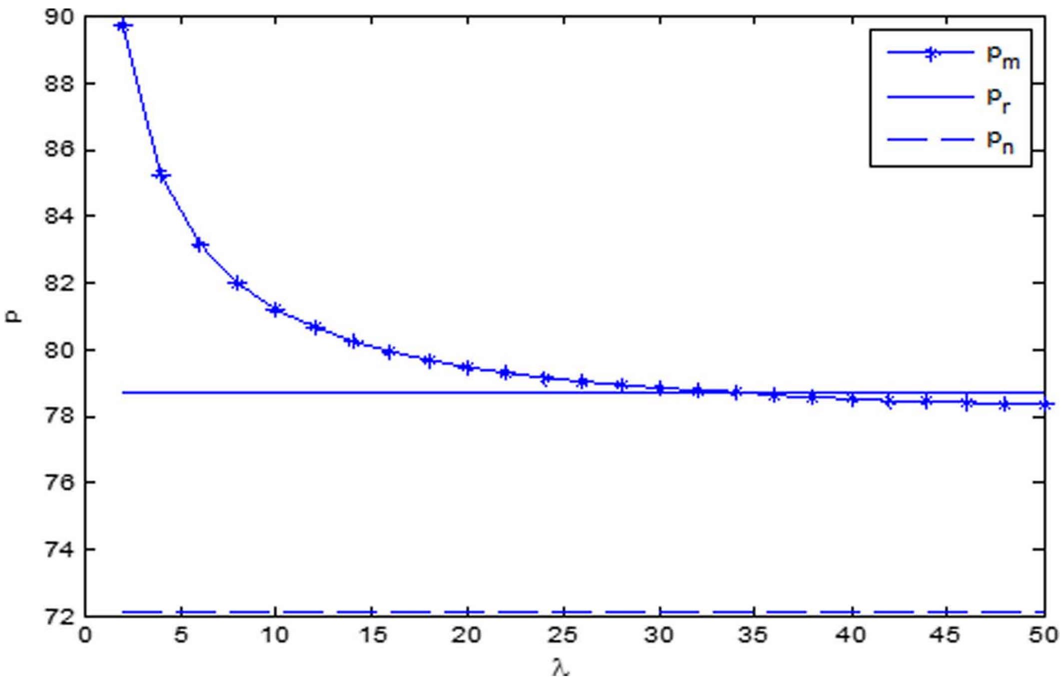


Figure 3. The impact of fairness concerns on wholesale price

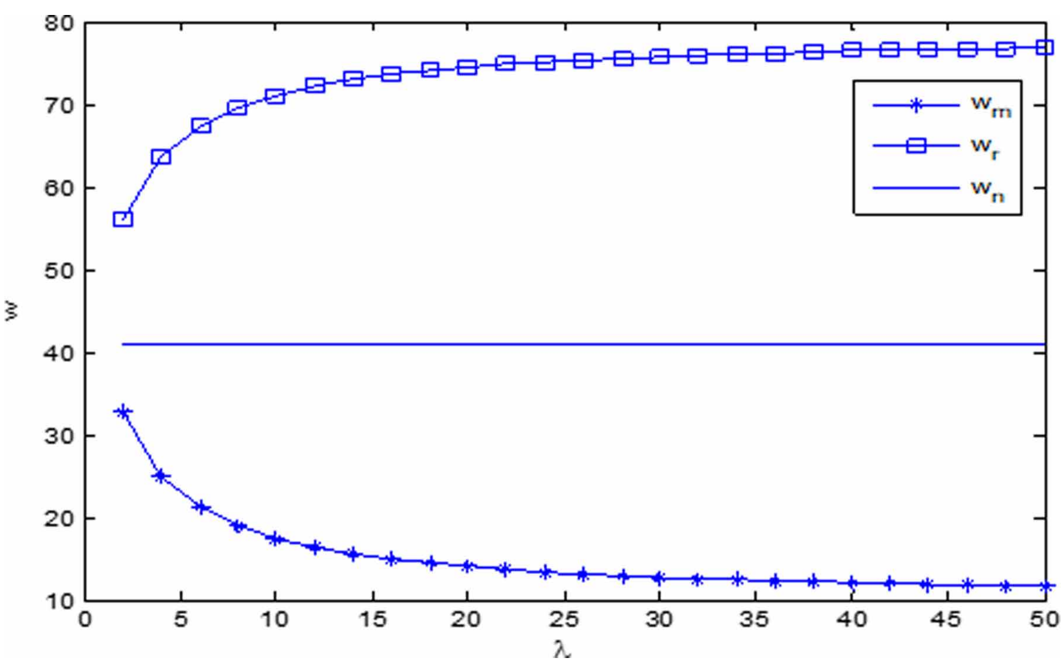
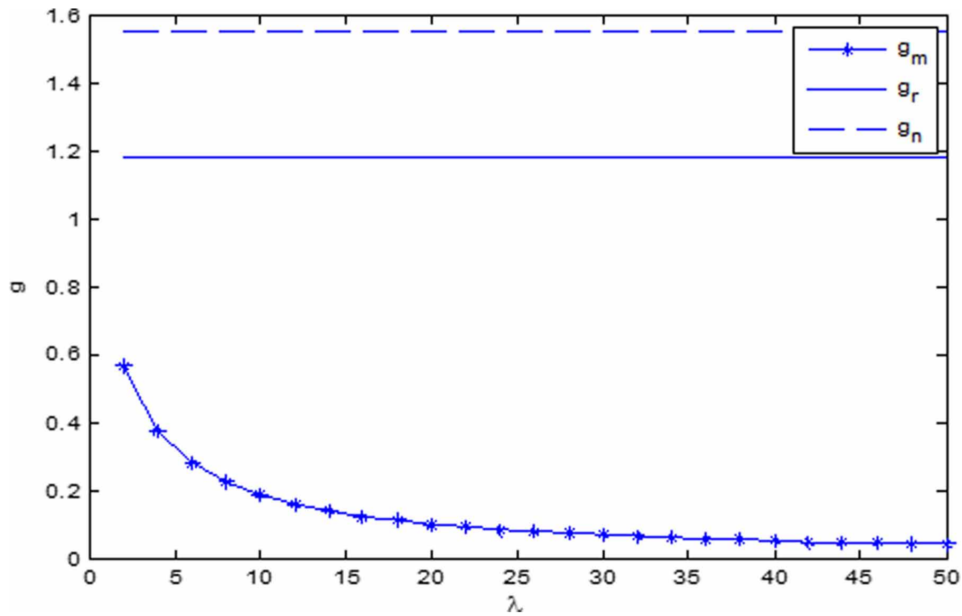


Figure 4. The impact of fairness concerns on product greenness



3. The impact of fairness concerns on the total profit of the supply chain

As shown in Figure 5, fairness concerns under different power structures have a varying impact on the manufacturer's profit. Specifically, the manufacturer's profit is reduced by the retailer's fairness concerns in the manufacturer-dominated game, is improved by the manufacturer's fairness concerns in the retailer-dominated game, and rises superior to fairness concerns in the Nash equilibrium game. Moreover, the manufacturer's profit is minimized in the manufacturer-dominated game but is maximized in the retailer-dominated game. This is consistent with Proposition 6.

As shown in Figure 6, the retailer's profit is positively correlated with fairness concerns in the manufacturer-dominated game, is negatively correlated with fairness concerns in the retailer-dominated game, but rises superior to fairness concerns in the Nash equilibrium game. Figures 5 and 6 indicate that the impact of fairness concerns on the manufacturer's profit and retailer's profit in the manufacturer-dominated game is contrary to that in the retailer-dominated game.

As shown in Figure 7, the total profit of the supply chain is affected by fairness concerns only in the manufacturer-dominated game, declines when fairness concerns increase, and is minimized. The total profit of the supply chain rises superior to fairness concerns in the retailer-dominated game and the Nash equilibrium game and is maximized in the Nash equilibrium game. This is consistent with Proposition 7, implying that the Nash equilibrium can coordinate the supply chain well when no fairness concerns exist.

As shown in Figure 8, in the retailer-dominated game, the manufacturer's utility function increases when fairness concerns increase and is maximized within a certain range; in the manufacturer-dominated game, the manufacturer's utility function declines when fairness concerns increase and is minimized. This implies that fairness concerns have a varying impact on the manufacturer's utility under Different power Structures.

As shown in Figure 9, in the manufacturer-dominated and retailer-dominated games, the retailer's fairness utility declines when fairness concerns increase; specifically, the retailer's fairness utility is maximized in the manufacturer-dominated game but is minimized in the retailer-dominated game.

Figure 5. The impact of fairness concerns on the manufacturer's profit

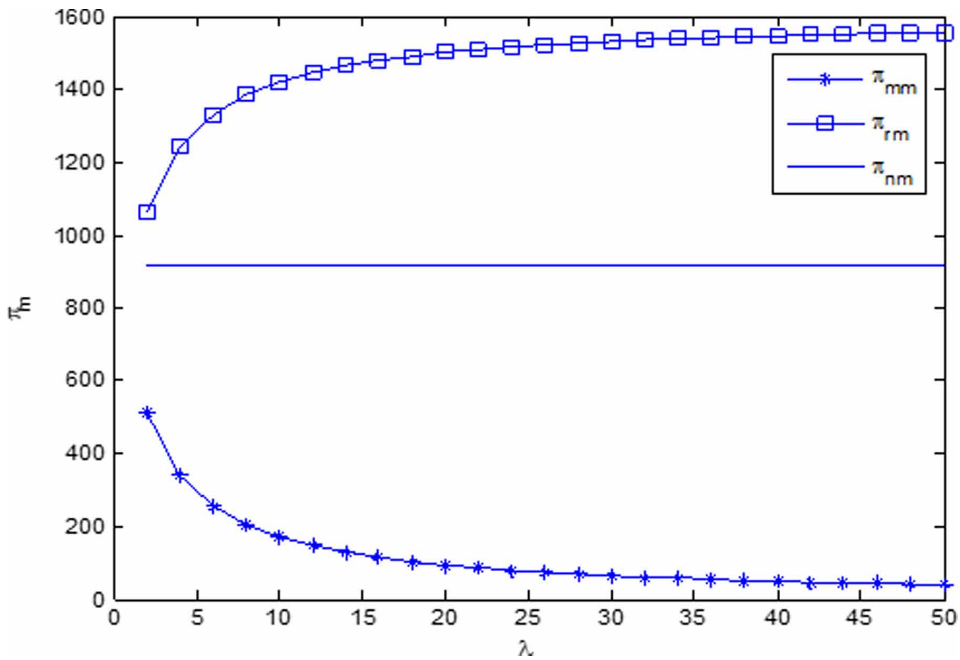


Figure 6. The impact of fairness concerns on the retailer's profit

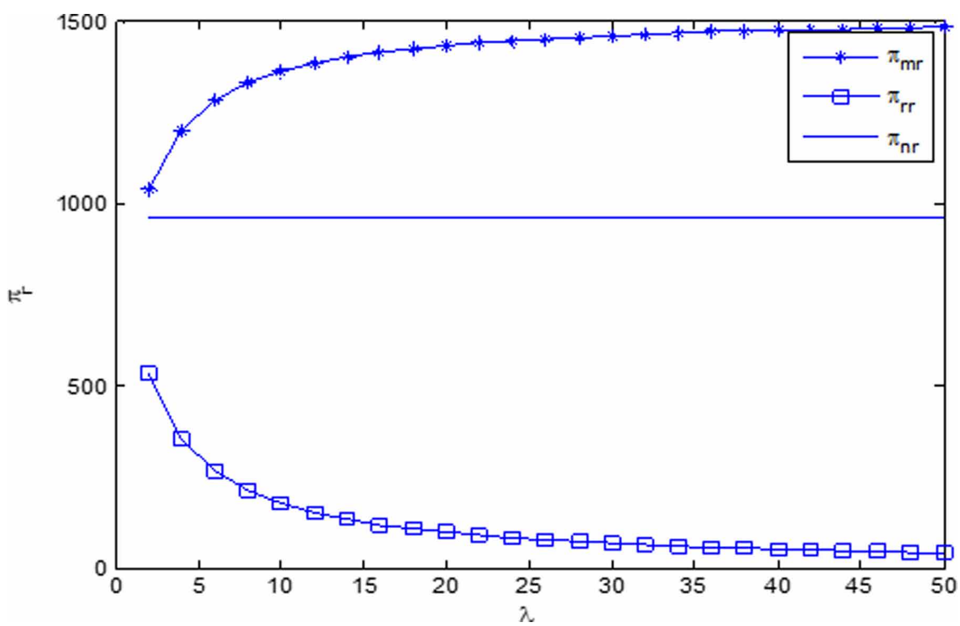
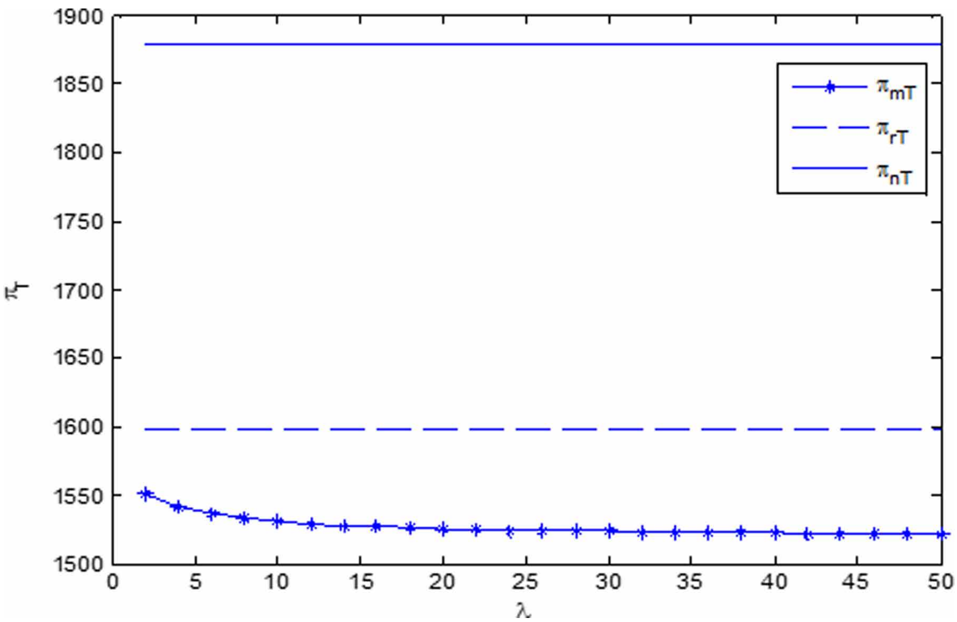


Figure 7. The impact of fairness concerns on the total profit of the supply chain



In the Nash equilibrium game, the retailer's fairness utility rises superior to fairness concerns and lies in between the two.

Figures 2 to 9, when considered together with Propositions 1 to 7, indicate that fairness concerns have a varying impact on supply-chain decisions under Different power Structures. Therefore, it is important to make an optimal decision regarding the balance between fairness and the overall interest

Figure 8. The impact of fairness concerns on the manufacturer's fairness utility

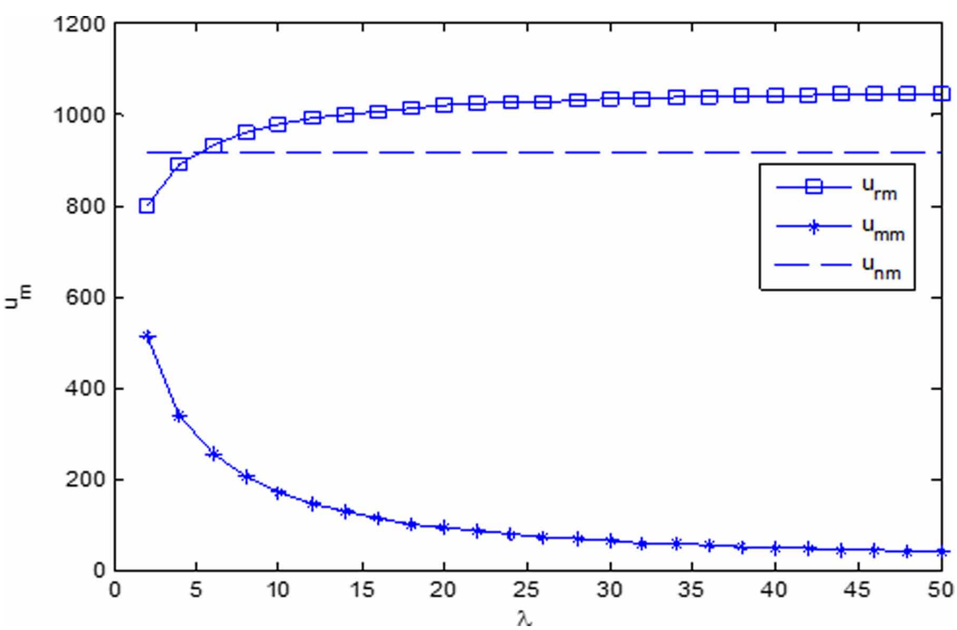
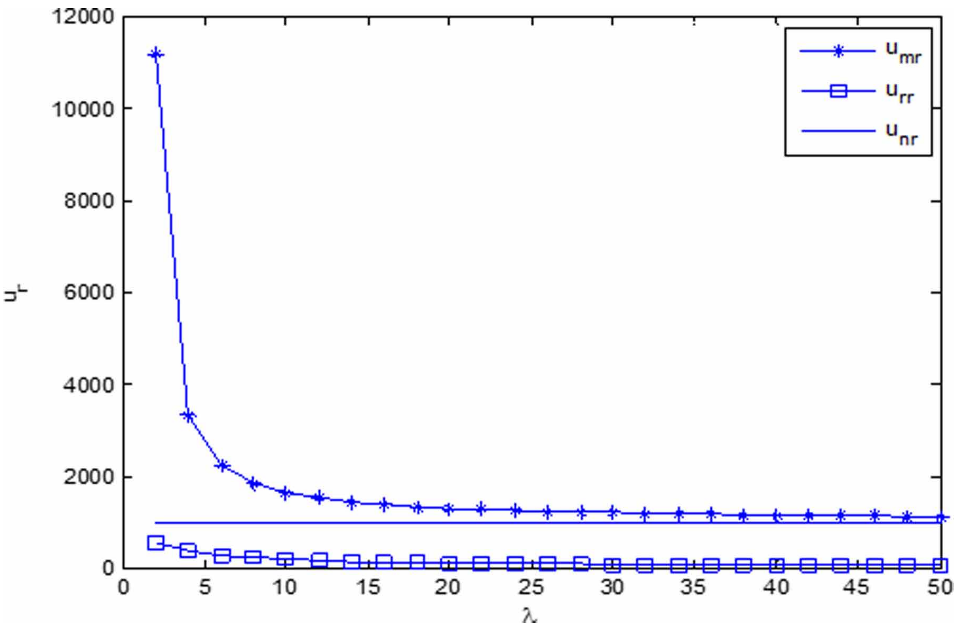


Figure 9. The impact of fairness concerns on the retailer's fairness utility



of the supply chain, to promote the development of the green supply chain, and provide support for the sustainability of the supply chain. For supply chain management personnel, this study provides good evidence for seeking a fair solution to coordinate the interests of the members of the supply chain.

CONCLUSION

In this study, we built a green supply chain comprising one risk-neutral manufacturer and one retailer, used Nash bargaining as the reference point of fairness, and created the manufacturer's and retailer's fairness utility functions under the manufacturer-dominated, retailer-dominated, and Nash equilibrium structures. Accordingly, this study explores the impact of fairness concerns on the pricing of the green supply chain and product greenness and compares the green supply chain decisions under Different power Structures. Finally, this study reaches the following conclusions.

First, in the manufacturer-dominated game, retail price, wholesale price, and product greenness decline when fairness concerns increase; this implies that the retailer seeks more fairness by bargaining with the manufacturer and reducing the retail price, thereby reducing wholesale price and product greenness. In the Nash equilibrium game, retail price, wholesale price, and product greenness rise superior to fairness concerns; this implies a relatively coordinated relationship between the manufacturer and the retailer. In the retailer-dominated game, wholesale price increases when fairness concerns increase, whereas retail price and product greenness remain unchanged; this implies that the manufacturer seeks higher profit by raising the wholesale price and maintaining the level of green investment, while the retailer seeks to maintain its competitive advantage at the expense of its own interests.

Second, when fairness concerns increase, the trends in the variations in the manufacturer's profit and the retailer's profit in the manufacturer-dominated game are contrary to those in the retailer-dominated game. Specifically, the manufacturer's profit in the retailer-dominated game and the retailer's profit in the manufacturer-dominated game both increase when fairness concerns increase, whereas the manufacturer's profit in the manufacturer-dominated game and the retailer's profit in the retailer-dominated game both decline. This implies that fairness concerns have a significant impact on the performance of the supply chain. For supply chain management personnel, it is a matter of great importance to coordinate the interests of the manufacturer and the retailer when fairness concerns exist in the supply chain. The total profit of the supply chain is maximized in the Nash equilibrium game, implying that the system is at relative equilibrium.

Last, under the effect of fairness concerns, the trend in the variations in the manufacturer's utility in the manufacturer-dominated game is contrary to that in the retailer-dominated game, whereas the trend in the variations in the retailer's utility in the manufacturer-dominated game is the same as that in the retailer-dominated game. The manufacturer's utility in the manufacturer-dominated game and the retailer's utility in the retailer-dominated game are both minimized. In the Nash equilibrium game, the manufacturer's utility and retailer's utility both remain unchanged. This reveals that the manufacturer and the retailer are equipollent and have no fairness concerns.

This study does not consider a scenario in which both the manufacturer and the retailer have fairness concerns. In reality, a green supply chain incurs additional costs in the form of green investment, so the manufacturer tends to develop more fairness concerns, which is a topic for the subsequent study. Moreover, fairness concerns bring about obvious discord to the green supply chain; the manner in which the green supply chain should be coordinated will therefore also be an important topic for the subsequent study. Our intent is to obtain more conclusions aligned with market realities, thereby providing more evidence for supply chain decisions.

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