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Study of Supplier-led Supply Chain Decision-Making Considered Fairness Concern

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Abstract

In order to study the supply chain decision-making problem considering supplier dominance under the perspective of fairness concern. This paper constructs a supplier-led Stackelberg game model for three scenarios: suppliers with fairness concern preferences, retailers with fairness concern preferences, and risk-neutrality, and solves it by using backward induction, analysing the impact of fairness concerns on the decision-making behaviours and profits of chain members. The results show that the wholesale price is largest when the supplier has a fair concern preference, followed by the risk-neutral, retailer has a fair concern preference scenario; the relationship between the size of the supplier's production effort, the retailer's retail price, and the supplier's expected profit in the three scenarios is more complex and depends on the size of the stochastic output factor and the level of fair concern; furthermore, the retailer's expected profit is smallest when the retailer has a fair concern preference, followed by the risk-neutral, retailer has a fair concern preference scenario. In addition, the retailer's expected profit is smallest when the retailer has a fairness preference, followed by the risk-neutral, supplier-fairness concern scenario.

Keywords

Equity Concerns; Supply Chain Decision-Making; Stackelberg Game; Supplier Dominance.

1. Introduction

In the field of supply chain management, upstream enterprise dominance means that it has the priority of decision-making compared with other members, and it occupies an absolute core position in the whole supply chain system [1,2]. For example, COFCO Corporation in the fresh agricultural products industry; Apple and Huawei in the electronics industry; Pepsi and Coca-Cola in the fast moving consumer goods industry; and Moutai and Wuliangye in the liquor industry.

In addition, in practice, it is easy to find that some decision makers in supply chain enterprises have a preference for fairness, which will not only pay attention to their own benefits, but also compare with the benefits obtained by other enterprises, and once they feel that there is 'unfairness' in the distribution of benefits, they will choose to take irrational decision-making behaviours to cope with it, which will affect the decision-making behaviours of all the enterprises in the supply chain. The decision-making behaviour of all enterprises in the supply chain [3]. For example, Qualcomm decided to stop supplying chips and other raw materials to Huawei in 2019, believing that it did not receive a relatively fair profit, which also put Huawei at risk of insufficient supply of chips [4]; In addition, Changchun FAW decided not to continue to co-operate with the automaker Chrysler because Chrysler maliciously raised the price of the engine, which led to conflicts between the two sides due to the unequal distribution of profits [5], and ultimately made Chrysler miss the Chinese market. Chrysler missed out on the Chinese

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market. Of course, in real life, there are also completely rational corporate decision makers, who always make decisions with the goal of maximising their own interests without being affected by external factors, i.e., they are called risk-neutral [6,7].

Different power structures have an important impact on the benefits of each node firm in the supply chain. For this reason, many scholars have conducted relevant studies around different power structures in supply chains, most of which focus on supply chain coordination [8,9]. For example, Chen Changbin et al [10] pointed out that an effective incentive contract is an important way to achieve coordination. Wen Huo et al [11] considered the optimal decision-making and profitability of a closed-loop supply chain under different power structures and designed two combined contractual mechanisms to coordinate a manufacturer-dominated dual-channel closed-loop supply chain. Huang Ju et al [12] further considered the problem of emission reduction and pricing decisions under different power structures in a two-tier supply chain in the context of green development, and found that supply chain members can gain more benefits in their own positions regardless of their competitive and associative positions. Jin Liang et al [13] considered a supply chain system consisting of an incumbent manufacturer, an entrant manufacturer and a retailer and found that the entrant manufacturer always needs to implement a low price strategy to invade the market under different power structures.

Research on supply chain decision-making under fairness concern preference is also an important concern, and a large number of studies have shown that the degree of importance attached to the fairness of profit distribution by each decision-making body in the supply chain will affect its decision-making behaviour. For example, Huang et al [14] investigated the optimal pricing decisions and coordination strategies of members and the whole system in a closed-loop supply chain considering members' fairness concerns, and analysed the impact of fairness concerns on decision making.Mondal et al [15] investigated the impact of retailer's fairness concerns on the decision making of supply chain members in a closed-loop green supply chain, and proposed a wholesale price contract based on compensation for coordinating the supply chain. Further, Li Xinran et al [16] constructed a closed-loop supply chain consisting of a manufacturer and a retailer based on the government's trade-in subsidy policy, and explored the impact of retailers' service and fairness concern behaviours on decision-making issues in a closed-loop supply chain. Wang Yibao et al [17] and Wang et al [18] incorporated e-commerce platforms into decision making and investigated the impact of retailers' fair concern preferences on decision making and coordination in e-commerce supply chains. In addition, Han Tongyin et al [19] investigated the impact of retailers‘ fairness concerns on supply chain optimal pricing, greenness decisions, and supply chain members’ profits in the context of green supply chains with and without government subsidies.

In summary, this paper introduces the supplier dominance situation of upstream firms and fairness concern preferences into the supply chain in order to study the supply chain decision-making problem considering supplier dominance under fairness concern. Specifically, for a two-tier supply chain system consisting of a single dominant supplier and a single follower retailer, firstly, a demand function model is constructed in which the stochastic output depends on the production effort, and the retail price depends on the stochastic output and the production effort; then three models are constructed in which the supplier has fairness concern preference, the retailer has fairness concern preference, and the risk-neutral model are constructed, and the equilibrium solutions are analysed by using the inverse induction method. Finally, the effects of changes in the level of fairness concern of decision makers on the decisions and profits of supply chain members are investigated, and the equilibrium solutions of the three models are compared and analysed.

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2. Problem Description and Assumptions

As shown in Figure 1, in a two-tier supply chain consisting of a dominant supplier and a follower retailer, at the onset of the production season, the supplier first decides on the size of its production effort e and the wholesale price of the product w based on the retailer's order quantity q , and the retailer decides on the retail price p based on the supplier's decision to sell the purchased product $uq+e$ to the market, so that demand is realised. At the same time, this chapter also considers three scenarios, namely the supplier's fairness preference, the retailer's fairness preference and bilateral risk neutrality, and explores the impact of their fairness preference on their own decision-making behaviour and profits, and compares the equilibrium solutions of the game under the three scenarios.

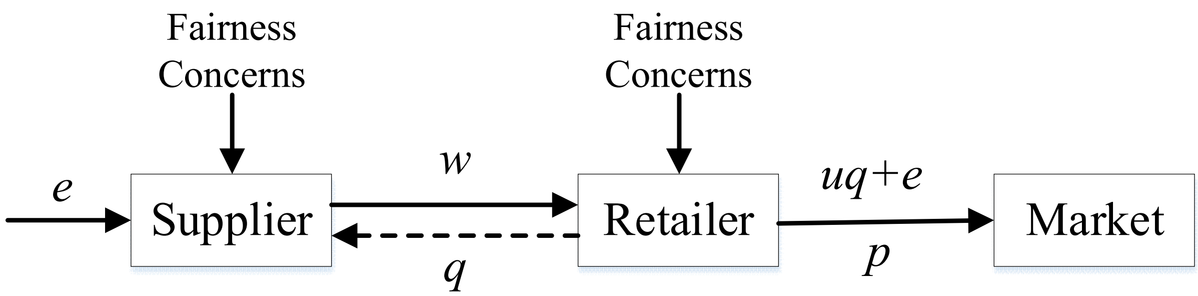

Figure 1. The structure diagram

The model construction in this paper is based on the following assumptions:

Assumption 1: The supplier's product output is subject to uncertainty and product output is affected by production effort (e.g., labour inputs, production equipment, production environment), i.e., actual output is $(uq+e)$. Where u is a stochastic factor, q is the amount of production inputs, and e is the production effort. The cost of production effort is $C(e)=e^2$ [20,26], and the expectation and mean squared error are $E(u)=\mu$, $V(u)=\delta$ [21,26,27], respectively.

Assumption 2:The market price p of the product is inversely proportional to the product quantity and directly proportional to the production effort e . This is because under normal circumstances, the input level of production effort is positively correlated with product quality, and product quality is also positively correlated with product price. Drawing on the models of Cachon[21] and Qin[25], the retail price function of the product is assumed to be as shown in the following equation, where A is a constant.

$$p = A-(uq+e)+ke \quad (1)$$

Assumption 3: In order to simplify the model, without prejudice to the conclusions set the supplier's production cost of the product as $c=0$ [21,26].

The symbols and meanings involved in this paper are shown in Table 1.

Table 1. Symbols and their meanings

Symbols	Meaning	Symbols	Meaning
A	Market saturation of the product	p	retail price
u	stochastic factor	q	order quantity
μ	expected value	π_S^j	Manufacturer's profit
δ	variances	π_R^j	Retailer's profit
k	Coefficient of elasticity of production effort	SN	risk-neutral
λ	Coefficient of preference for equity concerns	SS	Vendor equity concerns
w	wholesale prices	SR	Retailer equity concerns
e	Production effort inputs		$j \in \{SN, SS, SR\}$

3. Analysis of the Stackelberg Game Model under Supplier Dominance

Under supplier dominance, this section constructs a game model based on both suppliers and retailers being risk-neutral, suppliers‘ fair concern preferences, and retailers’ fair concern preferences, followed by the analysis of the equilibrium solutions of the three game models using backward induction.

3.1. Risk-neutral Models (SN Models)

If both the supplier and the retailer are risk-neutral, the order of the Stackelberg game for the supply chain is as follows: 1) the supplier first decides on the level of its production effort inputs e and the wholesale price of the product w; and 2) the retailer then decides on its firm ordering quantity q based on the supplier's decision. the profit functions of the supplier and the retailer are, respectively:

$$\begin{cases} \pi_S^{SN}(e,w) = E(wQ - e^2) = w(\mu q + e) - e^2 \\ \pi_R^{SN}(q) = E[(p-w)Q] = E[A - uq - e + ke - w)(uq + e)] \\ = (A - e + ke - w)(\mu q + e) - \mu q e - (\mu^2 + \delta^2) q^2 \end{cases} \tag{2}$$

Under the SN model, the optimal wholesale price, level of production effort input, order quantity, retail price and expected profit for the supplier and retailer can be found by using backward induction, thus, Proposition 1 can be obtained.

Proposition 1 Under the SN model, when $4\delta^4 + 4(k-2)\delta^2\mu^2 + (k^2-8)\mu^4 < 0$, i.e., $\mu > 0$, $1 < k < 2$, and $0 < \delta < \frac{\sqrt{2\mu^2 - k\mu^2}}{\sqrt{2}}$, the optimal decisions for the supplier and the retailer are:

$$\begin{cases} e^{SN*} = -\dfrac{A\mu^2(2\delta^2 + k\mu^2)}{4\delta^4 + 4(k-2)\delta^2\mu^2 + (k^2-8)\mu^4} \\ w^{SN*} = -\dfrac{4A\mu^2(\delta^2 + \mu^2)}{4\delta^4 + 4(k-2)\delta^2\mu^2 + (k^2-8)\mu^4} \\ q^{SN*} = \dfrac{A\mu[2\delta^2 + (k-2)\mu^2]}{4\delta^4 + 4(k-2)\delta^2\mu^2 + (k^2-8)\mu^4} \\ p^{SN*} = \dfrac{2A\mu^2[2\delta^4 + (k-4)\delta^2\mu^2 - 3\mu^4]}{4\delta^4 + 4(k-2)\delta^2\mu^2 + (k^2-8)\mu^4} \end{cases} \tag{3}$$

At this point, the optimal expected profits of the retailer and supplier are:

$$\begin{cases} \pi_R^{SN*} = \dfrac{A^2\mu^2[-4\delta^6 - 4k\delta^4\mu^2 - (k^2-4)\delta^2\mu^4 + 4\mu^6]}{[4\delta^4 + 4(k-2)\delta^2\mu^2 + (k^2-8)\mu^4]^2} \\ \pi_S^{SN*} = -\dfrac{A^2\mu^4}{4\delta^4 + 4(k-2)\delta^2\mu^2 + (k^2-8)\mu^4} \end{cases} \tag{4}$$

3.2. Supplier Fairness Concern Preference Model (SS Model)

If the supplier has fair concern preferences and the retailer is risk neutral, the supplier will not only be concerned about its own returns, but also the returns of other members. At this point, the order of the Stackelberg game for the supply chain is: 1) the supplier first decides its production effort input level e and the wholesale price of the product w; 2) the retailer then decides its ordering quantity based on the supplier's decision q. Drawing on Du Shaofu et al [22], the supplier fair concern preference coefficient λ_S is introduced, which leads to the supplier's expected utility function U_S^{SS}, the supplier's expected profit function π_S^{SS} and the retailer's expected profit function π_R^{SS} respectively:

$$\begin{cases} U_S^{SS}(e,w) = \pi_S^{SN} - \lambda_S(\pi_R^{SN} - \pi_S^{SN}) \\ \qquad\qquad = (1+\lambda_S)[w(\mu q+e) - e^2] - \lambda_S[(A-e+ke-w)(\mu q+e) - \mu qe - (\mu^2+\delta^2)q^2] \\ \pi_S^{SS}(e,w) = E(wQ - e^2) = w(\mu q+e) - e^2 \\ \pi_R^{SS}(q) = E[(p-w)(uq+e)] = (A-e+ke-w)(\mu q+e) - \mu qe - (\mu^2+\delta^2)q^2 \end{cases} \tag{5}$$

Under the SS model, the optimal wholesale prices, production effort inputs, order quantities, retail prices and expected profits of suppliers and retailers can be found using backward induction, thus leading to Proposition 2.

Proposition 2 Under the SS model, the optimal decisions of suppliers and retailers are when $\Lambda_0 < 0$:

$$\begin{cases} e^{SS*} = -\dfrac{A\mu^2(1+\lambda_S)^2(2\delta^2+k\mu^2)}{\Lambda_0} \\ w^{SS*} = \dfrac{4A(1+2\lambda_S)(\delta^2+\mu^2)[\delta^2\lambda_S - (1+\lambda_S)\mu^2]}{\Lambda_0} \\ q^{SS*} = \dfrac{A(1+\lambda_S)\mu[\delta^2(2+4\lambda_S) + (-2+k)(1+\lambda_S)\mu^2]}{\Lambda_0} \\ p^{SS*} = \dfrac{2A\left\{2\delta^4(1+2\lambda_S)^2 + \delta^2[-4-7\lambda_S-\lambda_S{}^2+k(1+\lambda_S)^2]\mu^2 - (3+8\lambda_S+5\lambda_S{}^2)\mu^4\right\}}{\Lambda_0} \end{cases} \tag{6}$$

At this point, the optimal expected profits of the supplier and the retailer are:

$$\begin{cases} \pi_R^{SS*} = -\dfrac{A^2\mu^2(1+\lambda_S)^2\begin{bmatrix}4\delta^6(1+2\lambda_S)+4\delta^4\mu^2[k(1+\lambda_S)^2+\lambda_S(2+\lambda_S)] \\ +\delta^2(1+\lambda_S)\mu^4[4(-1+\lambda_S)+k^2(1+\lambda_S)]-4(1+\lambda_S)^2\mu^6\end{bmatrix}}{{\Lambda_0}^2} \\ \pi_S^{SS*} = \dfrac{\begin{bmatrix}8\delta^6{\lambda_S}^2A^2\mu^2(1+\lambda_S)(1+2\lambda_S)-4\delta^4\mu^2(1+7\lambda_S+13{\lambda_S}^2+5{\lambda_S}^3) \\ -A^2\mu^2(1+\lambda_S)4\delta^2(1+\lambda_S)\mu^4[-2-2\lambda_S+4{\lambda_S}^2+k(1+\lambda_S)^2] \\ -A^2\mu^2(1+\lambda_S)(1+\lambda_S)^2\mu^6[k^2(1+\lambda_S)-8(1+2\lambda_S)]\end{bmatrix}}{{\Lambda_0}^2} \end{cases} \tag{7}$$

where $\Lambda_0 = 4\delta^4(1+2\lambda_S)^2+4\delta^2\mu^2[-2-3\lambda_S+k(1+\lambda_S)^2]+(1+\lambda_S)[k^2(1+\lambda_S)-4(2+3\lambda_S)]\mu^4$.

Proposition 3 Under the SS model: 1) $q^{SS*}, e^{SS*}, \pi_S^{SS*}, \pi_R^{SS*}$ are decreasing functions with respect to λ_S, and w^{SS*} is an increasing function with respect to λ_S. 2) The relationship between p^{SS*} and λ_S depends on $L_3(\lambda_S,\delta,\mu,k)$,if $L_3(\lambda_S,\delta,\mu,k)>0$, then p^{SS*} is an increasing function of λ_S; otherwise, it is a decreasing function of λ_S.

Here, $L_3(\lambda_S,\delta,\mu,k)=\begin{bmatrix}4\delta^6(1+2\lambda_S)\mu^2[-1+2k(1+\lambda_S)]-2(-2+k^2)(1+\lambda_S)^2\mu^8 \\ +4\delta^4\mu^4[2k\lambda_S(1+\lambda_S)-\lambda_S(2+\lambda_S)+k^2(1+3\lambda_S+2{\lambda_S}^2)] \\ +\delta^2\mu^6(1+\lambda_S)[4-4\lambda_S-4k(1+\lambda_S)+k^2(1+5\lambda_S)]\end{bmatrix}$.

Proposition 3 states that a supplier's equity concern λ_S leads to impaired profitability for itself and the retailer, as well as a reduction in the level of its own production effort inputs and in the retailer's ordering, but leads to an increase in the supplier's wholesale price; the relationship between the retailer's retail price p^{SS*} and the supplier's equity concern λ_S depends on the parameter $L_3(\lambda_S,\delta,\mu,k)$, and is positively correlated when the parameter satisfies $L_3(\lambda_S,\delta,\mu,k)>0$, and conversely the two are inversely correlated. This is shown in figures 2 to 4.

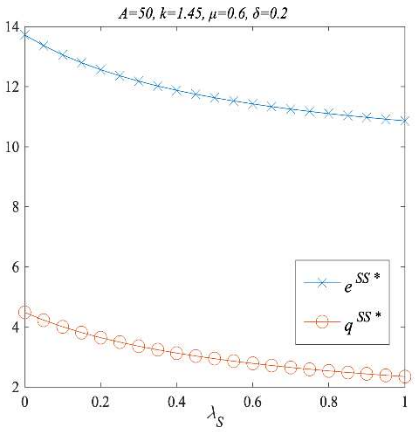

Figure 2. Effect of λ_S on q^{SS*} and e^{SS*}

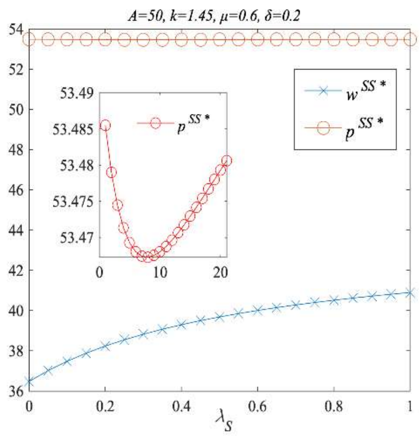

Figure 3. Effect of λ_S on w^{SS*} and p^{SS*}

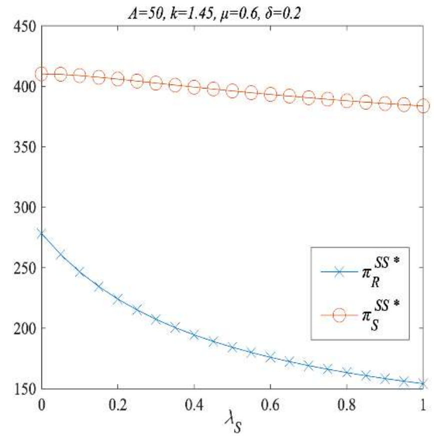

Figure 4. Effect of λ_S on π_S^{SS*} and π_R^{SS*}

3.3. Retailer Fairness Concerns Preference Model (SR Model)

If the retailer has fair concern preferences and the supplier is risk-neutral, the retailer will be concerned not only with its own returns but also with the returns of other members. At this point, the order of the Stackelberg game in the supply chain is: 1) the supplier first decides its production effort input level e and the wholesale price of the product w; 2) the retailer then decides its ordering quantity q according to the supplier's decision. Drawing on the coefficient of the retailer's fairness concern preference λ_R introduced by Zhong Yuanguang et al. [23,24], the supplier's expected profit function π_S^{SR} and the retailer's expected utility function U_R^{SR} and the retailer's expected profit function π_R^{SR}, respectively:

$$\begin{cases} \pi_S^{SR}(e,w) = w(\mu q + e) - e^2 \\ U_R^{SR}(q) = \pi_R^{SN} - \lambda_R(\pi_S^{SN} - \pi_R^{SN}) \\ \qquad = (1+\lambda_R)[(A - e + ke - w)(\mu q + e) - \mu q e - (\delta^2 + \mu^2)q^2 - \lambda_R[w(\mu q + e) - e^2] \\ \pi_R^{SR}(q) = (A - e + ke - w)(\mu q + e) - \mu q e - (\mu^2 + \delta^2)q^2 \end{cases} \tag{8}$$

Under the SR model, the optimal wholesale prices, production effort inputs, order quantities, retail prices and expected profits of the suppliers and retailers can be found using backward induction, which leads to Proposition 4.

Proposition 4 Under the SR model, the optimal decisions of suppliers and retailers are when $\Lambda_1 < 0$:

$$\begin{cases} w^{SR*} = -\dfrac{4A\mu^2(1+\lambda_R)(\delta^2+\mu^2)}{\Lambda_1} \\ e^{SR*} = -\dfrac{A\mu^2(1+\lambda_R)(2\delta^2+k\mu^2)}{\Lambda_1} \\ q^{SR*} = \dfrac{A\mu[2\delta^2(1+\lambda_R)+(-2+k-4\lambda_R+k\lambda_R)\mu^2]}{\Lambda_1} \\ p^{SR*} = \dfrac{2A[2\delta^4(1+\lambda_R)+\delta^2(-4+k-8\lambda_R+k\lambda_R)\mu^2-3(1+2\lambda_R)\mu^4]}{\Lambda_1} \end{cases} \tag{9}$$

At this point, the optimal expected profits of the supplier and the retailer are:

$$\begin{cases} \pi_S^{SR*} = -\dfrac{A^2(1+\lambda_R)\mu^4}{\Lambda_1} \\ \pi_R^{SR*} = \dfrac{A^2\mu^2\begin{bmatrix} 4(1+6\lambda_R+8\lambda_R^{\ 2})\mu^6 - 4\delta^6(1+\lambda_R)^2 - 4k\delta^4(1+\lambda_R)^2\mu^2 \\ -\delta^2\mu^4[k^2(1+\lambda_R)^2 - 4(1+6\lambda_R+8\lambda_R^{\ 2})] \end{bmatrix}}{\Lambda_1^{\ 2}} \end{cases} \tag{10}$$

where $\Lambda_1 = 4\delta^4(1+\lambda_R) + 4\delta^2\mu^2(-2+k-4\lambda_R+k\lambda_R) + \mu^4[k^2(1+\lambda_R) - 8(1+2\lambda_R)]$.

Based on the optimal decision result given in Proposition 4 and $\Lambda_1 < 0$, Proposition 5 discusses the sensitivity analysis of the optimal decision variables and the expected profits of both parties with respect to the retailer's fair concern preference λ_R.

Proposition 5 Under the SR model :1) w^{SR*}, e^{SR*}, p^{SR*} and π_S^{SR*} are decreasing functions with respect to λ_R and q^{SR*} is an increasing function with respect to λ_R;2) The relationship between π_R^{SR*} and its coefficient of fairness concern, λ_R, depends on the parameter $L_5(\lambda_R,\delta,\mu,k)$. When $L_5(\lambda_R,\delta,\mu,k)>0$, π_R^{SR*} is an increasing function with respect to λ_R, and when $L_5(\lambda_R,\delta,\mu,k)<0$, π_R^{SR*} is a decreasing function with respect to λ_R.

where $L_5(\lambda_R,\delta,\mu,k) = \begin{bmatrix} 8\delta^6(1+\lambda_R) + [8+16\lambda_R - k^2(2+5\lambda_R)]\mu^6 \\ +4\delta^4\mu^2[-2-5\lambda_R+2k(1+\lambda_R)] \\ +2\delta^2\mu^4[4+8\lambda_R+k^2(1+\lambda_R)-2k(2+5\lambda_R)] \end{bmatrix}$.

Proposition 5 states that the retailer's fairness concern preference λ_R will lead to an impairment of the supplier's expected profit, as well as a reduction in the supplier's input of production effort, the wholesale price, and the retailer's retail price, but it will lead to an increase in the retailer's ordering volume; the relationship between the retailer's expected profit π_R^{SR*} and the retailer's fairness concern preference λ_R depends on the parameter $L_5(\lambda_R,\delta,\mu,k)$, and when the parameter is satisfied with $L_5(\lambda_R,\delta,\mu,k)>0$ the two are positively correlated, and vice versa the two are are positively correlated when the parameter e is satisfied, and vice versa. This is shown in figures 5 to 7.

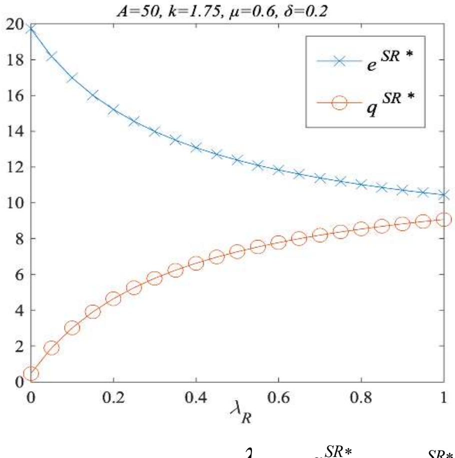

Figure 5. Effect of λ_S on q^{SR*} and e^{SR*}

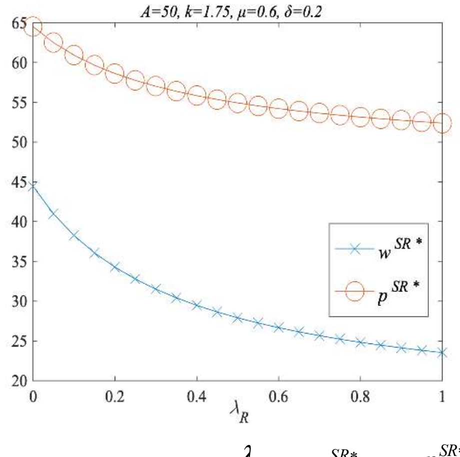

Figure 6. Effect of λ_R on w^{SR*} and p^{SR*}

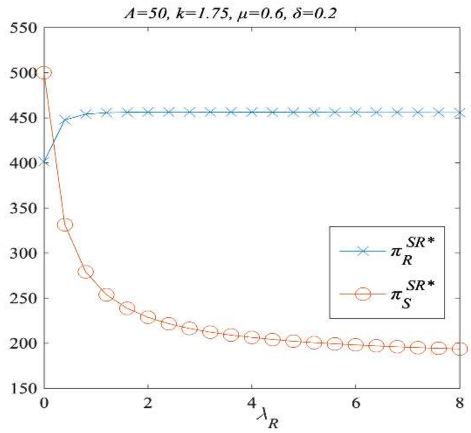

Figure 7. Effect of λ_R on π_S^{SR*} and π_R^{SR*}

4. Comparative Analysis of Models

Based on the equilibrium results obtained from the above three game structures, the following propositions can be obtained by comparing the optimal wholesale price, order quantity, level of production effort input, wholesale price, and the magnitude of expected profit.

Proposition 6 Comparison of optimal wholesale prices and order quantities under the SN, SS, and SR models yields: $w^{SR*} < w^{SN*} < w^{SS*}$ and $q^{SS*} < q^{SN*} < q^{SR*}$.

Proposition 6 shows that the supplier's wholesale price is largest when it has a fairness concern preference, followed by the risk-neutral case, and the case where the retailer has a fairness concern preference. This is due to the fact that when the supplier is dominant and concerned about fairness, it will retaliate by raising the wholesale price by setting a higher price when it feels unfair. The retailer orders the most when it has a fairness concern preference, followed by the risk-neutral scenario, and the scenario where the supplier has a fairness concern preference. This is shown in Figure 8.

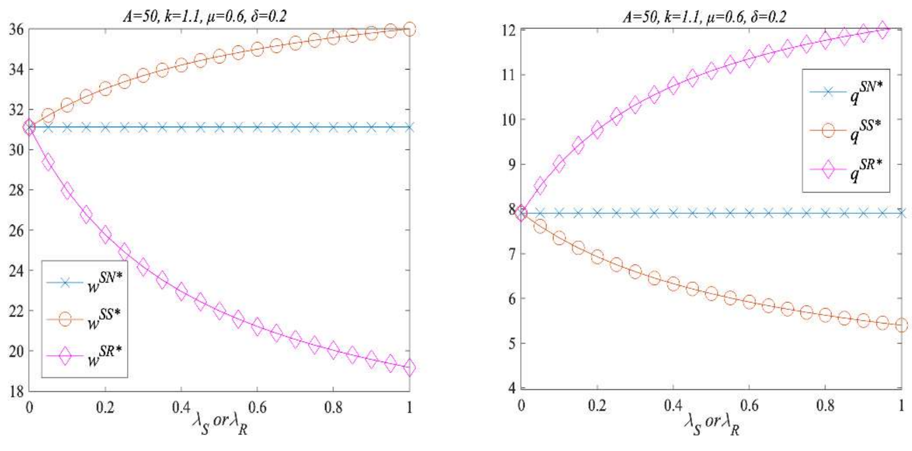

Figure 8. Effect of λ_S or λ_R on wholesale price, order quantity in three scenarios

Proposition 7 A comparison of the optimal production effort inputs under the SN, SS and SR models can be obtained:

1) When $\lambda_S^0 < 0$, $e^{SN*} > e^{SS*} > e^{SR*}$.

2) When $\lambda_S > \lambda_S^0 > 0$, $e^{SS*} > e^{SN*} > e^{SR*}$.

3) When $\lambda_S^0 > \lambda_S > \lambda_S^1(\lambda_S^0 > 0)$, $e^{SN*} > e^{SS*} > e^{SR*}$.

4) When $\lambda_S < \lambda_S^1(\lambda_S^0 > 0)$, $e^{SN*} > e^{SR*} > e^{SS*}$.

Where $\lambda_S^0 = \dfrac{-2\delta^2 + \mu^2}{3\delta^2 - \mu^2}$, satisfies $\delta^2\lambda_S(2+3\lambda_S)(1+\lambda_R) + (1+\lambda_S)\mu^2[\lambda_S(\lambda_R - 1) + 2\lambda_R] = 0$.

By Proposition 7, it is known that if parameter $\{\lambda_S, \delta, \mu, k\}$ satisfies $\lambda_S^0 < 0$ or the supplier's fair concern preference is generally $\lambda_S^0 > \lambda_S > \lambda_S^1(\lambda_S^0 > 0)$, the supplier's production effort is greatest when it is risk neutral, then in order of priority the supplier has a fair concern preference, the retailer has a fair concern preference; if the supplier's fair concern preference is large, i.e., $\lambda_S > \lambda_S^0 > 0$, then the supplier's production effort is greatest when it has a fair concern preference, and then in order of priority it is the risk-neutral case, retailer has a fair concern preference; if the supplier has a small fair concern preference, i.e., $\lambda_S < \lambda_S^1(\lambda_S^0 > 0)$, the supplier invests the most in production effort when it is risk neutral, and then in the order of the retailer has a fair concern preference, and the supplier has a fair concern preference. This is shown in Figure 9.

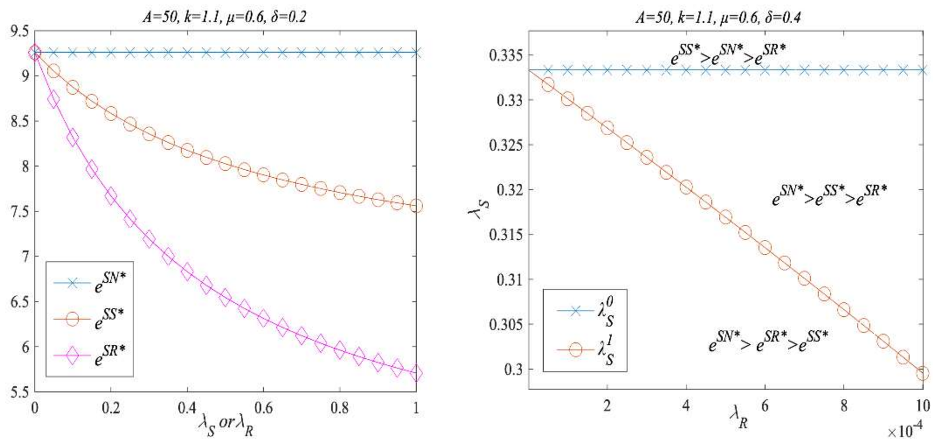

Figure 9. Effect of λ_S or λ_R on productive effort in the three scenarios

Proposition 8 A comparison of the optimal retail prices under the SN, SS and SR models is obtained:

1) When $\lambda_S^2 < 0$, $p^{SS*} > p^{SN*} > p^{SR*}$.

2) When $\lambda_S > \lambda_S^2 > 0$, $p^{SS*} > p^{SN*} > p^{SR*}$.

3) When $\lambda_S^2 > \lambda_S > \lambda_S^3(\lambda_S^2 > 0)$, $p^{SN*} > p^{SS*} > p^{SR*}$.

4) When $\lambda_S < \lambda_S^3(\lambda_S^2 > 0)$, $p^{SN*} > p^{SR*} > p^{SS*}$.

where $\lambda_S^2 = \dfrac{(4-8k)\delta^6 - 4k^2\delta^4\mu^2 - (-2+k)^2\delta^2\mu^4 + 2(-2+k^2)\mu^6}{4(3k-1)\delta^6 + 2(-2+2k+3k^2)\delta^4\mu^2 + k(-4+3k)\delta^2\mu^4 - 2(k^2-2)\mu^6}$, λ_S^3 satisfy

$$\begin{bmatrix} \Lambda_1\{2\delta^4(1+2\lambda_S)^2 + \delta^2\mu^2[-4+k(1+\lambda_S)^2 - \lambda_S(7+\lambda_S)] - (1+\lambda_S)(3+5\lambda_S)\mu^4\} \\ -\Lambda_0\{2\delta^4(1+\lambda_R) + \delta^2\mu^2(-4+k-8\lambda_R+k\lambda_R) - 3\mu^4(1+2\lambda_R)\} \end{bmatrix} = 0 \cdot$$

By Proposition 8, it follows that if parameter $\{\lambda_S, \delta, \mu, k\}$ satisfies $\lambda_S^2 < 0$ or the supplier's fair concern preference is large $\lambda_S > \lambda_S^2 > 0$, the supplier's retail price is largest when it has a fair concern preference, and then in the order of the risk-neutral case, the case where the retailer has a fair concern preference; if the supplier's fair concern preference is average, i.e.,

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$\lambda_S^2 > \lambda_S > \lambda_S^3(\lambda_S^2 > 0)$, the retail price is largest when it is risk-neutral, and then in the order of the supplier's fair concern preference If the supplier's fairness concern preference is small, i.e., $\lambda_S < \lambda_S^3(\lambda_S^2 > 0)$, the retail price is largest when risk neutral, followed by the scenario where the retailer has a fairness concern preference, and the scenario where the supplier has a fairness concern preference, in that order. This is illustrated in figure 10.

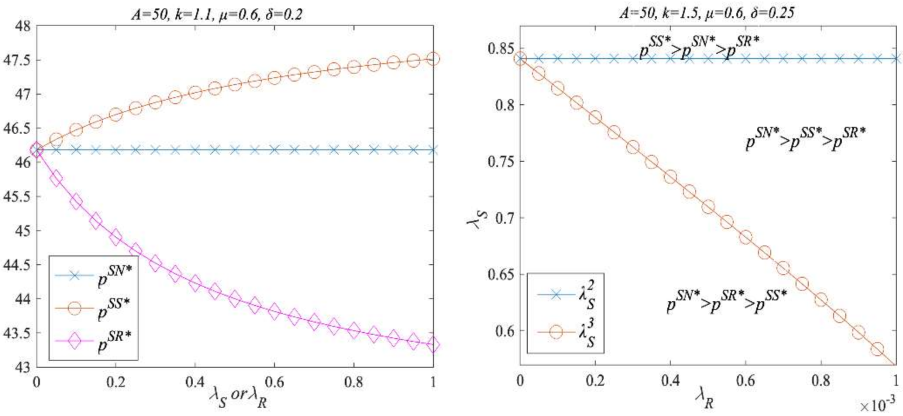

Figure 10. λ_S or λ_R on retail prices in three scenarios

Proposition 9 A comparison of the expected profits of suppliers and retailers under the SN, SS and SR models can be obtained:

1)When $0 < \lambda_S < \lambda_S^4$, $\pi_S^{SS*} > \pi_S^{SN*} > \pi_S^{SR*}$; when $\lambda_S^4 < \lambda_S$, $\pi_S^{SN*} > \pi_S^{SS*} > \pi_S^{SR*}$.

2) $\pi_R^{SR*} > \pi_R^{SN*} > \pi_R^{SS*}$.

Proposition 9 states that (i) when the supplier's fairness concern preference is generally large, i.e., $0 < \lambda_S < \lambda_S^4$, the supplier's expected profit is largest when it has a fairness concern preference, followed in order by the fairness-neutral situation, the retailer has a fairness concern preference, i.e., $\pi_S^{SS*} > \pi_S^{SN*} > \pi_S^{SR*}$. If the supplier's fairness concern preference is large, i.e., $\lambda_S^4 < \lambda_S$, the supplier's expected profit is largest when it is fairness-neutral, followed in order by the supplier having a fairness concern, the retailer having a fairness concern situation, i.e., $\pi_S^{SN*} > \pi_S^{SS*} > \pi_S^{SR*}$. ② The retailer's expected profit is greatest when it has a fair concern situation, followed by a risk-neutral situation and a situation in which the supplier has a fair concern, i.e., $\pi_R^{SR*} > \pi_R^{SN*} > \pi_R^{SS*}$. As shown in Figure 11.

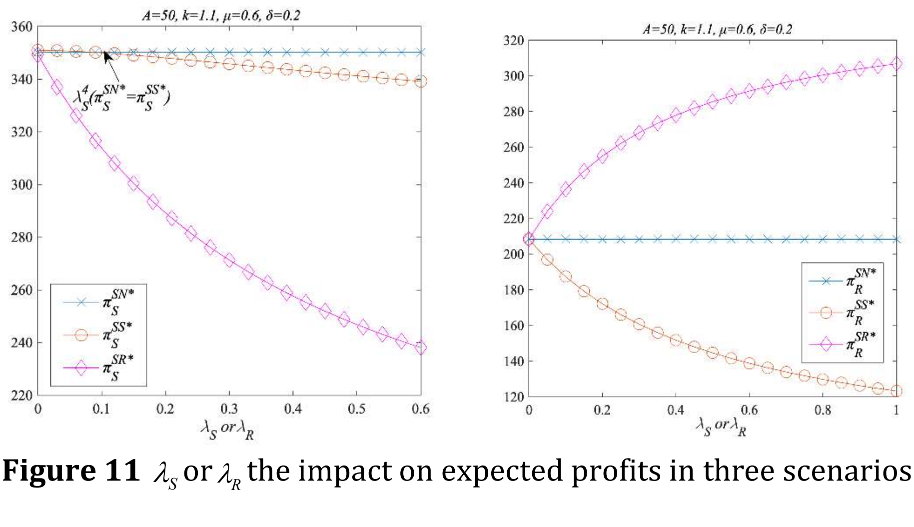

Figure 11 λ_S or λ_R the impact on expected profits in three scenarios

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5. Conclusion

In a two-tier supply chain consisting of a single-following retailer and a single-dominant supplier, three scenarios such as suppliers with fair concern preferences, retailers with fair concern preferences, and bilateral risk neutrality are considered. Meanwhile, a demand function model with stochastic output dependent on production effort and retail price dependent on stochastic output and production effort is constructed. The effects of suppliers‘ and retailers’ fairness concern preferences on their own decision-making behaviour and profits are investigated, and the equilibrium solutions of the game under the three scenarios are compared and analysed, and the conclusions are as follows:

1) In the more risk-neutral scenario, the supplier's fairness preference will lead to an increase in its own wholesale price, but it will lead to an erosion of its own and the retailer's expected profits, as well as a reduction in the level of its own production effort inputs and in the retailer's ordering volume, and, moreover, the effect of the supplier's fairness preference on the retailer's retail price is more complex and depends on the magnitude of parameter $\{\lambda_S, \delta, \mu, k\}$.

2) In the more risk-neutral scenario, the retailer's fairness preference will result in an erosion of the supplier's expected profit, as well as reductions in the supplier's wholesale price, production effort inputs and the retailer's retail price, but an increase in the retailer's order quantity. In addition, the correlation between the retailer's fairness preference and its own expected profit is more complex, depending on the parameter $\{\lambda_S, \delta, \mu, k\}$.

3) when the supplier's fairness concern is generally large, the supplier's expected profit is largest when it has a fairness concern, and the supplier's expected profit is largest when it has a fairness concern.Then in order of fairness neutral situation, the retailer has a fair concern; if the supplier fair concern is large, the supplier expects the largest profit when it is fair neutral, then in order of supplier has a fair concern preference, the retailer has a fair concern situation; and the retailer expects the largest profit when it has a fair concern situation, then in order of risk-neutral, the supplier has a fair concern situation.

4) If parameter $\{\lambda_S, \delta, \mu, k\}$ satisfies $\lambda_S^0 < 0$ or the supplier's fairness concern is general, the supplier's production effort is greatest when it is risk neutral, followed by the case where the supplier has fairness concerns, and the case where the retailer has fairness concerns; if the supplier's fairness concern is large, then the supplier's production effort is greatest when it has fairness concerns, followed by the case where it is risk neutral, and the case where the retailer has fairness concerns; If the supplier's equity concern preference is small, the supplier's productive effort input is greatest when it is risk-neutral, followed by the scenario in which the retailer has equity concerns, and the scenario in which the supplier has equity concerns.

5) If parameter $\{\lambda_S, \delta, \mu, k\}$ satisfies $\lambda_S^2 < 0$ or the supplier's fairness concerns are large, the supplier's retail price is largest when it has fairness concerns, followed by the risk-neutral scenario, and the retailer has fairness concerns; if the supplier's fairness concerns are fair, the retail price is largest when it is risk-neutral, followed by the supplier has fairness concerns, and the retailer has fairness concerns; and if the supplier's fairness concerns are small, the retail price is largest when it is risk-neutral, and the retailer has fairness concerns. If the supplier's equity concerns are small, the retail price is greatest when risk neutral, followed by the scenario where the retailer has equity concerns and the scenario where the supplier has equity concerns.

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