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Research on Supply Chain Contract Considering Blockchain input under Fairness Preference

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Abstract: In view of the problems brought by the "excessive pursuit of fairness" to the supply chain, in the secondary supply chain composed of suppliers and retailers, the supplier is the leader in the Stackelberg model. Through numerical models, the impact of suppliers' fair preference coefficients on the level of blockchain input, the utility of each participant in the supply chain and the overall utility under different contract frameworks are analyzed. Under the four decision-making models, the level of supplier blockchain input and the utility of supply chain participants are positively correlated with consumers' preference coefficients and negatively correlated with R&D cost coefficients. Second, the fair preference coefficient of suppliers is negatively correlated with the profits of the supply chain. By comparing the equilibrium results under various contract conditions, the utility of retailers, suppliers, and the entire supply chain is the greatest under the revenue sharing contract and considering the blockchain input.

Keywords: fairness preference; supply chain contracts; Blockchain; consumer preferences;

1. Introduction

In recent years, blockchain has shown great application potential in intelligent manufacturing, agricultural product traceability, and finance due to its decentralization, traceability, and immutability [1,2].. Harnessing the power of blockchain, it is possible to fully track and record all stages from the purchase of raw materials to the delivery of finished products. The use of this technology can not only efficiently store and share important information about the manufacturing process, but also improve customer trust and purchase decisions. However, in practice, there are differences in the acceptance of the technology by different companies, which has led to a series of problems and debates. For example, suppliers can not only make consumers more trust the advantages of blockchain products, but also establish their own brand value, which can not only bring greater benefits to themselves, but also bring huge profits to downstream retailers in the supply chain.

In reality, fairness preference is a widespread phenomenon, and members of the supply chain are concerned not only about their own benefits, but also about the benefits of other members [3].. Therefore, from the perspective of fairness preference, this paper intends to study the complex interaction between retailers and suppliers, and based on this, it is of great significance to minimize the negative impact of "excessive pursuit of fairness" on the supply chain, which is of great significance to ensure the healthy operation of the supply chain. Only when the two sides reach a more balanced and mutually beneficial cooperation can we ensure that all links of the entire supply chain can cooperate with higher efficiency, so as to promote the prosperity of the market and the sustainable development of enterprises.

At present, many researchers have made a series of achievements in the study of supply chain contracts. The revenue sharing contract can not only improve the overall synergy ability of the enterprise, but also efficiently promote the energy conservation and emission reduction work of each enterprise in the industrial chain. Existing studies have shown that collaboration among supply chain members can promote green R&D investment across the entire industry chain, thereby increasing individual income and overall income [4]. Huang et al. [5] constructed the Stackelberg model on the basis of the emission reduction cost-sharing contract to analyze the benefits of enterprises and retailers to achieve Pareto improvement in specific situations. Similarly, Xu et al. [6] studied the differential game between retailers and producers, and proved that under certain conditions, Pareto optimization of the overall benefits of producers, retailers, and the entire supply chain can be achieved through cost-sharing contracts. In terms of revenue sharing contracts, Wang Qinpeng and Zhao Daozhi [7] found that revenue sharing contracts can coordinate the relationship between the two sides of the supply chain, thereby achieving Pareto improvement by studying the optimal order quantity of retailers in the two-tier supply chain and the emission reduction strategies of suppliers. Ying Shanshan and Jiang Chuanhai [8] found that revenue sharing contracts can improve the total revenue of the entire supply chain enterprises, but their impact on the total welfare of consumers and the total welfare of society is uncertain. Yang Shihui and Xiao Daodong [9] argue that for the second-level low-carbon supply chain, only the larger the revenue sharing coefficient, can achieve coordination. In theory, most scholars agree that both cost-sharing and revenue-sharing contracts can achieve the coordination of green supply chains by improving the overall benefits of the supply chain [10,11].

The above supply chain contract model assumes that all participants are rational people. In recent years, some scholars have introduced the concept of fairness preference into the supply chain system, and examined the impact of different fairness preferences on the pricing, order quantity, and overall profit of the supply chain system [12-14]. Yan et al. [15] established a model of reward and punishment contract under the condition of fair preference of retailers based on the quality of products provided by suppliers, and studied the supply chain coordination problem based on this contract. Ma et al. [16] discussed the supply chain operation decision-making under the fair preference behavior based on blockchain, which can provide a reference for enterprises to choose in terms of service input level, pricing, and purchase volume.

The existing research is mainly from the perspective of the fairness preference of the participants, and there is little discussion on how the fairness preference affects the blockchain investment decision of suppliers in different contract environments. To this end, this paper introduces the fair preference theory into the supply chain composed of retailers and suppliers, based on the wholesale price contract and the revenue sharing contract, and considers whether to invest in blockchain to model the decision-making of the supply chain.

On the basis of the above, under the secondary supply chain composed of suppliers and retailers, this paper studies the equilibrium decision-making under different contract frameworks under the consideration of fairness preference, and analyzes the impact of the supplier's fairness preference coefficient on the supplier's blockchain input level, supplier utility, retailer utility and overall utility of the supply chain. It provides a theoretical basis for the contract selection between suppliers and retailers and whether to invest in blockchain.

2. Problem Description

The research object of this paper is the secondary supply chain composed of retailers and suppliers. A supplier records the raw materials or components it sources in the blockchain. After detecting problematic products, it can greatly reduce the difficulty of product traceability, enhance customer trust in the quality of goods, and thus be able to obtain more potential customers. Since the contracts signed between retailers and suppliers are different, suppliers tend to be in a relatively weak position in the supply chain, and when their margins are lower than those of retailers, they can cause jealousy from suppliers. And this jealousy will affect the level of investment in the blockchain. The order of decision between suppliers and retailers is as follows:

T1: The supplier and the retailer decide on the contract structure.

T2: The vendor determines the blockchain input level e based on the contract structure.

T3: The supplier determines the price ω at which the product is wholesaled to the retailer.

T4: The retailer sells it to the consumer at a price p to get a profit.

From the perspectives of wholesale price and profit, this paper constructs two different types of supply chain contracts: wholesale price contract and revenue sharing contract. In the T3 stage of Figure 1, the supplier determines the wholesale price of its products to obtain the maximum profit, and the wholesale price contract is a contract system based on the wholesale price. In the T4 phase, the retailer and the supplier enter into a revenue sharing contract to share the revenue together. On this basis, we will examine how suppliers' fairness preferences affect different equilibrium levels in different types of contracts. For better modeling, the following assumptions are also given.

1)Suppliers determine their wholesale prices ω, It is used to meet the cost of production, logistics, etc. Retailers determine their retail price P to maximize retail profits. This article does not take into account the direct costs paid by each party for the unit of production cost.

2) In the supply chain, suppliers typically determine their investment in blockchain through contracts with retailers. The investment in blockchain will not change the manufacturing cost per unit of product, but there will be corresponding R&D costs $I=\frac{1}{2}be^2$ .where b is the R&D cost coefficient, and e is the blockchain investment level.

3) The final demand for blockchain products is:$d=a-kp+\gamma e$.thereinto, a It is the largest scale of the product without considering other factors, moreover $a-kp>0$； kindicates the consumer's sensitivity to price changes, The γ is the consumer's preference coefficient for blockchain products, which indicates the degree of consumers' preference for products that are added to blockchain technology.

Under the above assumptions, according to Fehr et al. [3] and references [17].To facilitate model analysis, $U(\pi_s)=u(\pi_s)/(1+\hat{\lambda}),\lambda=(1+\hat{\lambda})$.$U(\pi_s)$ is an affine change to$u(\pi_s)$, which involves only dimensional changes and still measures the utility of the supplier.λ is about the increment function of $\hat{\lambda}$ and $\lambda\in[0,1)$, When $\hat{\lambda}=0$, $\lambda=0$ means that the supplier is fair and neutral; When $\hat{\lambda}\to\infty$, $\lambda\to 1$ indicates that the supplier is extremely concerned about fairness preferences. Based on the above transformation, the utility of the supplier can be expressed as:$U(\pi_s)=\pi_s-\lambda\pi_m$.To simplify the description, the subscripts W and S are used to indicate the supply chain strategy under the wholesale price contract and the revenue sharing contract, respectively.

3. Supply chain contract model under fair preference

Wholesale price contract model under fair preference

The wholesale price contract model that does not consider the blockchain input

In the wholesale price contract model, the supplier will set a reasonable wholesale price ω based on the cost level before carrying out production activities, that is, the price of the wholesale transaction. The retailer then decides its own retail price based on this price and then sells the item to the customer. Under the framework of the wholesale price contract, the profit functions of the two are respectively

$$(\pi_m)_{w_1}=(p-\omega)(a-kp) \quad (1)$$

$$(\pi_s)_{w_1}=\omega(a-kp) \quad (2)$$

After considering the fairness preference, the utility of the two is respectively

$$U(\pi_m)_{w_1}=(p-\omega)(a-kp) \quad (3)$$

$$U(\pi_s)_{w_1}=(\pi_s)_{w_1}-\lambda(\pi_m)_{w_1} \quad (4)$$

Using the backward extrapolation method, it can be obtained according to the retailer utility maximum, and the retailer utility function $\frac{\partial^2(\pi_m)_{w_1}}{\partial^2 p}=-2k<0$,So $\pi_m^{w_1}$ has a maximum value with respect to p, then

$$p'=\frac{k\omega+a}{2k} \quad (5)$$

Substituting Eq. (5) into Eq. (4) gives us the partial derivative of ω and making it equal to zero

$$\omega_{w_1}^*=\frac{a(\lambda+1)}{k(\lambda+2)} \quad (6)$$

Substituting Eq. (6) into Eq. (5) obtains

$$p_{w_1}^{*}=\frac{a(2\lambda+3)}{2k(\lambda+2)} \tag{7}$$

Substituting Eq. (6) and Eq. (7) into Eq. (1) and Eq. (2) respectively to obtain the optimal profit of the supplier and retailer

$$U^{*}(\pi_m)_{w_1}=\frac{a^2}{4k(\lambda+2)^2} \tag{8}$$

$$U^{*}(\pi_s)_{w_1}=\frac{a^2(\lambda+1)}{2k(\lambda+2)^2} \tag{9}$$

Wholesale price contract model considering blockchain input

Under the wholesale price contract and considering the blockchain input model, the supplier will pre-determine the level of its input cost for the application of blockchain technology before carrying out production activities. And will set a reasonable wholesale price based on this cost level, that is, the price of the wholesale transaction. The retailer then decides its own retail price based on this price and sells the item to customers. Under the framework of the wholesale price contract, the utility functions of the two are respectively

$$(\pi_m)_{w_2}=(p-\omega)(a-kp+\gamma e) \tag{10}$$

$$(\pi_s)_{w_2}=\omega(a-kp+\gamma e)-\frac{1}{2}be^2 \tag{11}$$

After considering the fairness preference, the utility of the two is respectively

$$U_{w_2}(\pi_m)=(p-\omega)(a-kp+\gamma e) \tag{12}$$

$$U_{w_2}(\pi_s)=(\pi_s)_{w_2}-\lambda(\pi_m)_{w_2} \tag{13}$$

The reverse extrapolation method is used to maximize the utility of retailers

$$p''=\frac{a+\gamma e+k\omega}{2k} \tag{14}$$

Substituting the value of p'' into Eq. (13) gives the Hessian matrix of b with respect to ω and e as

$$H=\begin{bmatrix}-\frac{1}{2}\lambda k-k & \frac{1}{2}\lambda\gamma+\frac{1}{2}\gamma \\ \frac{1}{2}\lambda\gamma+\frac{1}{2}\gamma & -\frac{\lambda\gamma^2}{2k}-b\end{bmatrix}$$

When $|H|=\frac{1}{4}(2bk\hat{\lambda}+4bk-\gamma^2)$,H is negatively fixed, ω and e have maximum values, which are solved

$$e_{w_2}^{*}=\frac{\gamma a}{2bk\lambda+4bk-\gamma^2} \tag{15}$$

$$\omega_{w_2}^{*}=\frac{2ba(\lambda+1)}{2bk\lambda+4bk-\gamma^2} \tag{16}$$

Substituting the value of e_w^*、 ω_w^* into Eq. (12), finding the partial derivative of p and making it zero, we can get it

$$p_{w_2}^{*}=\frac{ba(2\lambda+3)}{2bk\lambda+4bk-\gamma^2} \tag{17}$$

Substituting e_w^*、 ω_w^* and p_w^* substituting Eq. (12) and Eq. (13) gives the utility of both

$$U^*(\pi_m)_{w_2} = \frac{b^2a^2k}{\left(2bk\lambda + 4bk - \gamma^2\right)^2} \tag{18}$$

$$U^*(\pi_s)_{w_2} = \frac{a^2\left(k(\lambda+1)b - \frac{\gamma^2}{4}\right)b}{2\left(k(\lambda+2)b - \frac{\gamma^2}{2}\right)^2} \tag{19}$$

In order to ensure that the optimal solution is meaningful, assurance is required $2bk\lambda + 4bk - \gamma^2 > 0$, $k(\lambda+1)b - \frac{\gamma^2}{4} > 0$.In order to ensure that this formula must be true, Take $\lambda = 0$, so $4bk - \gamma^2 > 0$.

Revenue sharing contract model under fairness preference

The revenue sharing contract model that does not consider the blockchain investment

Under the revenue sharing contract, the supplier determines the wholesale price based on the revenue share ratio d1 agreed by the retailer. Ultimately, the retailer decides on its own retail price P on the basis of a negotiated wholesale price ω to maximize its own profits. Then the profit function of the two is

$$(\pi_m)_{S_1} = \left((1-d_1)p - \omega\right)(a - kp) \tag{20}$$

$$(\pi_s)_{S_1} = (\omega + d_2p)(a - kp) \tag{21}$$

The utility of the two after considering the fairness preference is

$$U(\pi_m)_{S_1} = \left((1-d_2)p - \omega\right)(a - kp) \tag{22}$$

$$U(\pi_s)_{S_1} = (\pi_s)_{S_1} - \lambda(\pi_m)_{S_1} \tag{23}$$

The same can be said

$$p(S_1) = \frac{-ad + k\omega + a}{-2dk + 2k} \text{ e} \tag{24}$$

$$\omega(S_1) = -\frac{a(d-1)^2(\lambda+1)}{\left((d-1)\lambda + d - 2\right)k} \tag{25}$$

Substituting Eq. (24) and (25) into (22) gives us the partial derivative of d_1 so that it is equal to zero

$$d_1 = \frac{\lambda}{\lambda+1} \tag{26}$$

Substituting Eq. (26) into Eq. (24) and (25) obtains

$$p^*_{S_1} = \frac{3a}{4k} \tag{27}$$

$$\omega^*_{S_1} = \frac{a}{2(\lambda+1)k} \tag{28}$$

Substituting Eq. (26), (27) and (28) into Eq. (20) and (21) respectively gives the profit function of them

$$U^*(\pi_m)_{S_1} = \frac{a^2}{16(\lambda+1)k} \tag{29}$$

$$U^*(\pi_s)_{S_1} = \frac{a^2(3\lambda+2)}{16(\lambda+1)k} \tag{30}$$

Consider the revenue sharing contract model invested by the blockchain

Under the framework of the revenue sharing contract, the supplier determines the investment level of its blockchain technology and the corresponding wholesale price ω according to the revenue sharing ratio d2 agreed by the retailer. Ultimately, the retailer decides on its own retail price P on the basis of a negotiated wholesale price ω to maximize its own profits. Then the profit function of the two is

$$(\pi_m)_{S_2} = \left((1\text{-}d_2)p - \omega\right)\left(a - kp + \gamma e\right) \tag{31}$$

$$(\pi_s)_{S_2} = (\omega + d_2 p)\left(a - kp + \gamma e\right) - \frac{1}{2}be^2 \tag{32}$$

After considering the fairness preference, the utility of the two is:

$$U(\pi_m)_{S_2} = \left((1-d_2)p - \omega\right)\left(a - kp + \gamma e\right)\ ; \tag{33}$$

$$U(\pi_s)_{S_2} = (\pi_s)_{S_2} - \lambda(\pi_m)_{S_2}\,. \tag{34}$$

The same can be said

$$p(d_2) = \frac{ab\left(2d_2\lambda + 2d_2 - 2\lambda - 3\right)}{2kb\left((d_2-1)\lambda + d_2 - 2\right) + \gamma^2} \tag{35}$$

$$\omega(d_2) = \frac{2ab\left(1-d_2\right)^2\left(\lambda+1\right)}{2k\left((1-d_2)\lambda + 2 - d_2\right)b + \gamma^2} \tag{36}$$

$$e(d_2) = \frac{a\gamma}{2kb\left((1-d_2)\lambda + 2 - d_2\right) - \gamma^2} \tag{37}$$

Substituting Eq. (35)~(37) into the retailer's decision function Eq. (33), find the partial derivative of d and make it zero

$$d_2 = \frac{2kb\lambda + \gamma^2}{2kb\left(\lambda+1\right)} \tag{38}$$

The same goes for you

$$p^*_{S_2} = \frac{a\left(\gamma^2 - 3bk\right)}{2k\left(\gamma^2 - 2bk\right)} \tag{39}$$

$$\omega^*_{S_2} = \frac{a\left(2bk - \gamma^2\right)}{4k^2 b\left(1+\lambda\right)} \tag{40}$$

$$e^*_{S_2} = \frac{a\gamma}{4bk - 2\gamma^2} \tag{41}$$

$$U^*(\pi_m)_{S_2} = \frac{a^2 b}{8(2bk - \gamma^2)(\lambda+1)} \tag{42}$$

$$U^*(\pi_s)_{S_2} = \frac{a^2 b}{8bk - 4\gamma^2} \tag{43}$$

In order to ensure that the optimal solution is meaningful, it needs to be ensured $2bk-\gamma^2>0$, $4bk-2\gamma^2>0$, $\begin{cases}\gamma^2-3bk>0\\ \gamma^2-2bk>0\end{cases}$ or $\begin{cases}\gamma^2-3bk<0\\ \gamma^2-2bk<0\end{cases}$.In order to ensure that this formula must be true, take $\lambda=0$, so $2bk>\gamma^2$.

Parameter sensitivity analysis

Proposition 1 $\frac{\partial p_{W_1}^*}{\partial k}<0$, $\frac{\partial \omega_{W_1}^*}{\partial k}<0$; $\frac{\partial p_{W_2}^*}{\partial k}<0$, $\frac{\partial e_{W_2}^*}{\partial k}<0$, $\frac{\partial \omega_{W_2}^*}{\partial k}<0$; $\frac{\partial p_{S_1}^*}{\partial k}<0$, $\frac{\partial \omega_{S_1}^*}{\partial k}<0$; $\frac{\partial p_{S_2}^*}{\partial k}<0$, $\frac{\partial e_{S_2}^*}{\partial k}<0$, $\frac{\partial \omega_{S_2}^*}{\partial k}<0$.

Prove: $\frac{\partial p_{W_1}^*}{\partial k}=-\frac{a(2\lambda+3)}{2k^2(\lambda+2)}<0$; $\frac{\partial \omega_{W_1}^*}{\partial k}=-\frac{a(\lambda+1)}{k^2(\lambda+2)}<0$.

Other proofs are similar.

Proposition 1 shows that retail and wholesale prices are inversely correlated with price sensitivity in four cases, suggesting that retailers will lower their retail prices as people become more price-sensitive, and suppliers will lower their wholesale prices in order to gain more benefits when they perceive such situations. In the two cases of considering blockchain investment, the level of blockchain investment is negatively correlated with the price sensitivity coefficient, because when people are more sensitive to price, suppliers will find ways to reduce their own retail price or wholesale price, and in order to reduce the price, they can only reduce their own costs, so they will reduce their own blockchain investment level to reduce costs and get more benefits.

Proposition 2 $\frac{\partial p_{W_2}^*}{\partial \gamma}>0$, $\frac{\partial e_{W_2}^*}{\partial \gamma}>0$, $\frac{\partial \omega_{W_2}^*}{\partial \gamma}>0$; $\frac{\partial p_{S_2}^*}{\partial \gamma}>0$, $\frac{\partial e_{S_2}^*}{\partial \gamma}>0$, $\frac{\partial \omega_{S_2}^*}{\partial \gamma}>0$

Prove: $\frac{\partial p_{W_2}^*}{\partial \gamma}=\frac{2ab(2\lambda+3)\gamma}{\left(-\gamma^2+2k(\lambda+2)b\right)^2}>0$; $\frac{\partial e_{W_2}^*}{\partial \gamma}=\frac{\left(k(\lambda+2)b+\frac{\gamma^2}{2}\right)a}{2\left(k(\lambda+2)b-\frac{\gamma^2}{2}\right)^2}>0$;

$$\frac{\partial \omega_{W_2}^*}{\partial \gamma}=\frac{4ba(\lambda+1)\gamma}{\left(-2kb\lambda-4kb+\gamma^2\right)^2}>0.$$

Other proofs are similar.

Proposition 2 shows that the retail price, wholesale price and blockchain input level are positively correlated with the preference coefficient of blockchain products under the wholesale price contract and revenue sharing contract considering blockchain input. When consumers pay more attention to the traceability of products, that is, the level of investment in the blockchain, suppliers will increase their investment in the blockchain, and their own costs will also increase, suppliers will increase the wholesale price to meet their own best interests, and retailers will also increase their retail prices on the baseline of wholesale prices to ensure their own operation.

Proposition 3 $\frac{\partial p_{w_1}^*}{\partial \lambda} > 0$, $\frac{\partial \omega_{w_1}^*}{\partial \lambda} > 0$; $\frac{\partial p_{w_2}^*}{\partial \lambda} > 0$, $\frac{\partial e_{w_2}^*}{\partial \lambda} < 0$, $\frac{\partial \omega_{w_2}^*}{\partial \lambda} > 0$; $\frac{\partial p_{S_1}^*}{\partial \lambda} = 0$, $\frac{\partial \omega_{S_1}^*}{\partial \lambda} < 0$; $\frac{\partial p_{S_2}^*}{\partial \lambda} = 0$, $\frac{\partial e_{S_2}^*}{\partial \lambda} = 0$, $\frac{\partial \omega_{S_2}^*}{\partial \lambda} < 0$.

Prove: $\frac{\partial p_{w_1}^*}{\partial \lambda} = \frac{a}{2k(\lambda+2)^2} > 0$; $\frac{\partial \omega_{w_1}^*}{\partial \lambda} = \frac{a}{k(\lambda+2)^2} > 0$; $\frac{\partial e_{w_2}^*}{\partial \lambda} = -\frac{2\gamma abk}{\left(-2bk\lambda - 4bk + \gamma^2\right)^2} < 0$.

Other proofs are similar.

Proposition 3 shows that in the first case, wholesale and retail prices increase as the supplier's fair preference coefficient increases. This is because when suppliers focus on retailers' profits, suppliers will have stronger bargaining power, so their wholesale prices will become larger, and retailers will observe that the supplier's behavior will also increase their retail prices. In the second case, the wholesale price and retail price are positively correlated with the supplier's fair preference coefficient, while the blockchain input level is negatively correlated with the fairness preference coefficient, because when the supplier's fair preference is greater, it will want more profits, so it will increase its own wholesale price and reduce its own blockchain investment level at the same time, while retailers will follow the supplier's behavior and increase the retail price to ensure their own profits. In the third case, wholesale prices are negatively correlated with the fair preference coefficient, while retail prices remain unchanged. This is because under the revenue sharing contract, the profit composition of the supplier has changed, and there is more profit shared by the retailer, and when the fairness preference becomes larger, the supplier will reduce its wholesale price to ensure the profit of the retailer, and the retailer will not reduce its own retail price although it observes that the supplier has reduced the wholesale price, but it will also share a part of the profit to the supplier, so it will not reduce its own retail price; In the fourth case, the wholesale price is negatively correlated with the fairness preference coefficient, while the retail price and the blockchain input level remain unchanged. Similar to the third situation, in order to ensure their own profits, they must ensure the profits of retailers, and the profits of retailers are also related to the level of blockchain investment, so when suppliers reduce their wholesale prices, although they ensure the level of blockchain investment, they will not increase blockchain investment, because investing in blockchain also requires costs. The retailer behaves similarly to the third scenario.

Proposition 4 $\frac{\partial (\pi_m)_{w_1}^*}{\partial \lambda} < 0$, $\frac{\partial (\pi_s)_{w_1}^*}{\partial \lambda} < 0$; $\frac{\partial (\pi_m)_{w_2}^*}{\partial \lambda} < 0$, $\frac{\partial (\pi_s)_{w_2}^*}{\partial \lambda} < 0$; $\frac{\partial (\pi_m)_{S_1}^*}{\partial \lambda} < 0$, $\frac{\partial (\pi_s)_{S_1}^*}{\partial \lambda} > 0$; $\frac{\partial (\pi_m)_{S_2}^*}{\partial \lambda} < 0$, $\frac{\partial (\pi_s)_{S_2}^*}{\partial \lambda} > 0$.

Prove: $\frac{\partial (\pi_m)_{w_1}^*}{\partial \lambda} = -\frac{a^2}{2k(\lambda+2)^3} < 0$; $\frac{\partial (\pi_s)_{w_1}^*}{\partial \lambda} = -\frac{a^2\lambda}{2k(\lambda+2)^3} < 0$.

Proposition 4 shows that under the wholesale price contract, the profits of suppliers and retailers will decrease with the increase of the fair preference coefficient, regardless of whether the blockchain is invested or not. This is because as the wholesale price of the supplier increases, the price of the retailer will also increase, and the consumer will reduce the desire to buy because of the increase in price; In the case of blockchain investment, the investment level of the blockchain will decrease with the increase of the fair preference coefficient, and consumers will reduce the sales volume of retailers due to the dual factors of price and blockchain investment level, which will lead to a decrease in profits. Under the revenue-sharing contract, as the supplier's fair preference coefficient increases, the supplier's profit will become larger, while the retailer's profit will become smaller. When the blockchain input is not considered, for suppliers, as the fair preference coefficient increases, the wholesale price decreases but the sales volume does not change, and the retailer will receive a part of the benefits. When considering the investment of blockchain, the supplier's price decreases while the retailer's price remains the same, but because the consumer's preference for blockchain products will increase part of the sales, and then the supplier will get a part of the retailer's shared profit while the sales volume is guaranteed, so the supplier's profit will increase.

Equilibrium solution comparison

Proposition 5 $e_{S_2}^* > e_{w_2}^*$.

Prove: $e_{S_2}^* - e_{w_2}^* = \frac{\gamma a}{4bk - 2\gamma^2} - \frac{\gamma a}{-2bk\lambda - 4bk + \gamma^2} = \frac{\gamma a\left(k(\lambda+4)b - \frac{3\gamma^2}{2}\right)}{4\left(bk - \frac{\gamma^2}{2}\right)\left(k(\lambda+2)b - \frac{\gamma^2}{2}\right)} > 0$.

Because $2bk > \gamma^2$, both the numerator and the denominator are greater than 0. Other proofs are similar.

Proposition 5 indicates that the level of blockchain investment is higher under the revenue sharing contract. Because under the revenue sharing contract, retailers will share a part of the revenue to suppliers, and suppliers will also have a greater incentive to invest in the integration of blockchain and their own products while ensuring their own interests.

Proposition 6 $(\pi_m)_{w_2}^* > (\pi_m)_{w_1}^*$, $(\pi_m)_{s_2}^* > (\pi_m)_{s_1}^*$, $(\pi_m)_{s_2}^* > (\pi_m)_{w_2}^*$, $(\pi_m)_{s_1}^* > (\pi_m)_{w_1}^*$, $\max\left\{(\pi_m)_{w_2}^*, (\pi_m)_{w_1}^*, (\pi_m)_{s_2}^*, (\pi_m)_{s_1}^*\right\} = (\pi_m)_{s_2}^*$.

Prove:

$$(\pi_m)_{w_2}^* - (\pi_m)_{w_1}^* = \frac{b^2a^2k}{\left(-2bk\lambda - 4bk + \gamma^2\right)^2} - \frac{a^2}{4k(\lambda+2)^2} = \frac{\gamma^2 a^2\left(b(\lambda+2)k - \frac{\gamma^2}{4}\right)}{4\left(b(\lambda+2)k - \frac{\gamma^2}{2}\right)^2 k(\lambda+2)^2} > 0$$

Because $2bk > \gamma^2$, the value of the numerator is greater than 0. Other proofs are similar.

Proposition 6 suggests that the retailer is more profitable when investing in the blockchain under the wholesale price contract than if it is not; Under the revenue sharing contract, the retailer's profit is the largest when considering the blockchain input, which indicates that the supplier's decision to invest in the blockchain is beneficial to the development of the entire supply chain under any contract. When the blockchain investment is not considered, the profit of the retailer under the revenue sharing contract is larger; When considering the blockchain investment, the retailer's profit under the revenue sharing contract is larger, indicating that the retailer will do its best to cooperate with the supplier for its own profit regardless of whether it invests in the blockchain or not. In these four cases, the retailer has the largest profit when considering the blockchain investment under the revenue sharing contract.

Proposition 7 $(\pi_r)_{w_2}^* > (\pi_r)_{w_1}^*$, $(\pi_r)_{s_2}^* > (\pi_r)_{s_1}^*$, $(\pi_r)_{s_2}^* > (\pi_r)_{w_2}^*$, $(\pi_r)_{s_1}^* > (\pi_r)_{w_1}^*$. $\max\left\{(\pi_r)_{w_2}^*, (\pi_r)_{w_1}^*, (\pi_r)_{s_2}^*, (\pi_r)_{s_1}^*\right\} = (\pi_r)_{s_2}^*$.

Prove:

$$(\pi_r)^*_{w_2}-(\pi_r)^*_{w_1}=\frac{ba^2\left(b(\lambda+1)k-\frac{\gamma^2}{4}\right)}{2\left(k(\lambda+2)b-\frac{\gamma^2}{2}\right)^2}-\frac{a^2(\lambda+1)}{2k(\lambda+2)^2}=\frac{3\left((\lambda+2)b\left(\lambda+\frac{2}{3}\right)k-\frac{\gamma^2(\lambda+1)}{3}\right)\gamma^2a^2}{8(\lambda+2)^2\left(k(\lambda+2)b-\frac{\gamma^2}{2}\right)^2k}>0$$

Because $2bk>\gamma^2$, the value of the numerator is greater than 0. Other proofs are similar.

Proposition 7 shows that in the case of wholesale price contracts, the supplier is more profitable when investing in the blockchain than if it is not; In the case of a revenue sharing contract, the supplier's profit is the largest when considering the investment in the blockchain, indicating that the supplier will be more inclined to invest in the blockchain technology and integrate with its own products in order to maximize its own profits. Without considering the blockchain investment, the profit of the supplier under the revenue sharing contract is larger; When considering the blockchain investment, the profit of the supplier under the revenue sharing contract is larger, indicating that the supplier will do its best to cooperate with the retailer for its own profit regardless of whether it is invested in the blockchain or not. In these four cases, the profit of the supplier is the largest when the revenue sharing contract and the blockchain investment is considered.

4. Model validation

In order to further verify the correctness of the above conclusions, this paper analyzes the optimal cooperation strategies between retailers and suppliers under different contract methods by establishing a model. The model analyzes in detail the effects of k, γ,b, and λ on each equilibrium value in the supply chain. By precisely setting these parameters, it is possible to gain insight into how they work together to affect the overall economic performance of the supply chain and other equilibriums. Set the corresponding parameters to a=80, b=8, k=2, γ=5. The coefficient λ ranges from [0, 0.5], which focuses on the analysis of the influence of the supplier's fair preference coefficient.

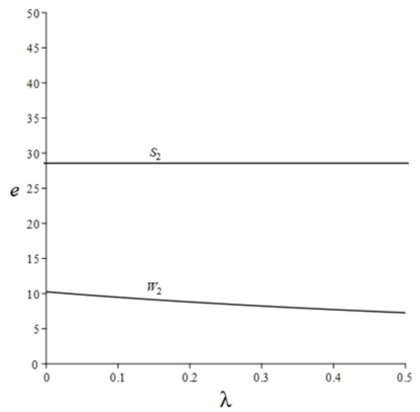

Figure 2: The impact of the supplier's fair preference coefficient on the supplier's blockchain investment level

As can be seen from Figure 2, there has been a significant change in suppliers' attitudes towards blockchain technology investment when it comes to wholesale price contracts. Specifically, when a supplier's fairness preference coefficient rises (i.e., they pay more attention to fairness), the willingness of suppliers to invest more money and resources in blockchain investment decreases. This phenomenon suggests that as suppliers become more aware of fairness, their willingness to invest in blockchain is declining, possibly because they want to ensure their own fairness throughout the transaction process while pursuing maximum benefits.

Under the revenue sharing contract, increasing the fairness preference coefficient will not affect the supplier's investment in blockchain technology. The reason for this is the positive correlation between the revenue sharing ratio and the fairness preference coefficient. That is, if a supplier believes that a higher percentage of the benefits can be obtained by investing in the blockchain, the supplier will still maintain the continued interest and investment level in the blockchain technology even if the fair preference coefficient increases. As a result, vendors tend to continue to invest in blockchain technology to secure their own interests, regardless of the contractual conditions. By comparing the blockchain investment level under the two contracts, the blockchain investment level under the revenue sharing contract will not change with the change of the fairness preference coefficient. However, under the wholesale price contract, when the blockchain investment level is the largest, that is, when the supplier is fair and neutral, it is also smaller than the blockchain investment level in the case of the revenue sharing contract.

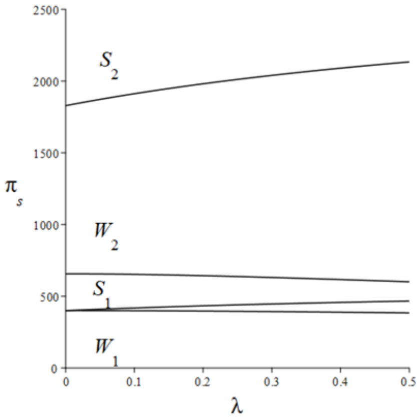

Figure 3: The impact of the supplier fair preference coefficient on supplier utility

Based on the data analysis in Figure 3, it can be found that the vendor's utility shows the highest level under the framework of revenue sharing contracts and considering blockchain inputs. Moreover, in the case of revenue sharing contracts, the supplier's profit is positively correlated with the supplier's fair preference coefficient. This is because under the revenue sharing contract, the higher the supplier's interest in the profits of other members of the supply chain, the higher the proportion of revenue sharing received by the supplier, so the supplier's profit increase is obtained at the expense of the retailer's benefit. However, under the wholesale price contract, the supplier's profit decreases as the fair preference coefficient increases. Suppliers will have more bargaining power and therefore higher wholesale prices, and retailers will observe that their suppliers' behavior will increase their retail prices, but because higher retail prices will lead to lower sales. In addition, it should be pointed out that the profits of suppliers under the blockchain revenue sharing contract will be greater than under the wholesale price contract, regardless of whether they are considered to invest in the blockchain revenue sharing contract. This is because under a revenue-sharing contract, suppliers face a trade-off: in order to maximize their own interests, they may adjust their wholesale offers, resulting in a reduction in their total revenue. But at the same time, due to the increase in the proportion of benefits among retailers, suppliers have to some extent made up for the loss of profits caused by price increases. Therefore, even under the influence of fairness preference, although suppliers feel unfair, their profits are guaranteed and improved to a certain extent.

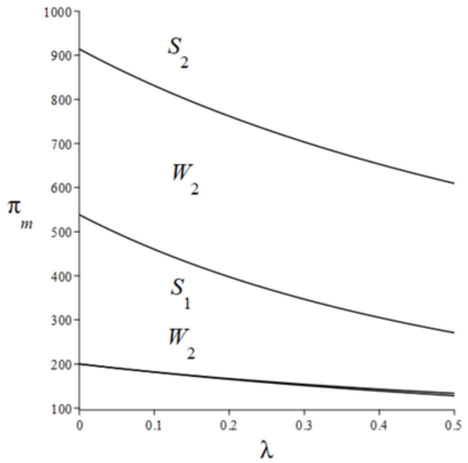

Figure 4: The impact of the supplier fair preference coefficient on retailer utility

As can be seen from Figure 4, there is a negative correlation between the supplier fair preference coefficient and the retailer's profit. This is because, in either case, the supplier's increased focus on profit will increase its bargaining power. In the wholesale price contract, it is mainly reflected in the wholesale price, and in the revenue sharing contract, it is mainly reflected in the revenue sharing ratio. Retailers are most profitable when it comes to revenue-sharing contracts and when blockchain inputs are taken into account. Under the revenue sharing contract model in which the supplier's fair preference coefficient cannot affect the supplier's blockchain investment, the supplier's blockchain technology investment will remain at a relatively stable level, thereby ensuring that the product quality is at a relatively high level. As a result, consumers will have a greater preference for blockchain products, which will increase demand, lower wholesale prices, and lower costs for retailers. At the same time, profit margins have expanded.

5. Conclusion

This paper can draw the following conclusions by studying whether the wholesale price contract model and revenue sharing contract model of blockchain input are considered in the secondary supply chain under the fairness preference:

1) Among the four models, the level of supplier blockchain input and the utility of supply chain participants are positively correlated with consumers' preference coefficients, and negatively correlated with R&D cost coefficients. When consumers prefer blockchain products more or the R&D cost coefficient of suppliers is smaller, the overall benefits of the supply chain will be greater, which requires suppliers to increase their investment in blockchain.

2) Among the four models, the fair preference coefficient of suppliers is negatively correlated with the overall profit of the supply chain. Under the wholesale price contract, when the supplier's fair preference coefficient increases, its profit decreases. The greater the supplier's fair preference factor, the greater the risk for retailers and secondary supply chains. Therefore, when retailers work with suppliers, they should choose suppliers with less fairness preference. Suppliers should also communicate with retailers to adjust the distribution of profits between the two sides, so as to reduce their own fairness preferences and improve overall utility.

3) By comparing the equilibrium results under various contract conditions, it is found that the utility of retailers, suppliers and the entire supply chain is the greatest when the revenue sharing contract is considered and the blockchain input is considered. Regardless of whether blockchain input is taken into account in wholesale prices and revenue-sharing contracts, retailers' earnings depend on the supplier's fair preference coefficient. Among the four models, the revenue sharing contract under the fair preference when considering the blockchain input is better than the wholesale price contract. Therefore, in the cooperation between retailers and suppliers, an appropriate contract structure should be selected to maximize the interests of both parties and achieve mutual benefit and win-win results; Under the wholesale price contract and the revenue sharing contract, the profit of the supply chain is optimal when considering the blockchain input.

The results of this paper have some guiding significance for the contract choice between retailers and suppliers, and whether to add blockchain to the supply chain. In addition, this paper only focuses on individual retailers and individual suppliers, and further research can be carried out in the future on complex supply chain systems with alternative competitiveness**.**

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