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Analysis of the Relationship Between Efficiency and Fairness in a Supply Chain

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Abstract: In addition to efficiency, supply chain members' fairness concerns cannot be ignored in supply chain management. Without certain fairness, the supply chain is likely to be unstable. This paper aims to analyze the relationship between fairness and efficiency in a supply chain through an incentive contract with revenue sharing. When determining contract parameters, the contract designer (supplier) should not only focus on her own interests, but should also consider the fairness of the distribution of the supply chain profits. In this model, the fairness concerns of the retailer are reflected with a profit distribution fairness constraint. A numerical example shows that the retailer's fairness concerns have an important impact on the efficiency of the supply chain and the distribution of supply chain profits. The supply chain's and the retailer's profits increase with the retailer's fairness concerns, whereas the supplier's profit decreases with the retailer's fairness concerns. In both cases where the profit distribution of the supply chain is very fair and unfair, respectively, the efficiency of the supply chain may be very high. But the second situation will cause retailer dissatisfaction. This will affect the stable operation of the supply chain, and also will have a negative influence on the supplier. Therefore, the supplier should pay attention to the retailer's fairness concerns in designing the incentive contract.

Keywords: Efficiency, Fairness, Profit Distribution, Revenue Sharing Contract, Supply Chain

1. Introduction

From the perspective of efficiency, coordination is an optimal state of supply chain operation. This requires the supply chain members to adopt precisely coordinated actions. However, the supply chain members are entities with independent legal personality, and they are primarily concerned with optimizing their own interests. Such self-interested behavior often leads to poor performance. In this case, those members who earn little profit are likely to be not satisfied with the distribution of profits. This situation, in turn, will affect the interests of other members. If so, the supply chain will become unstable. Therefore, in order to keep the supply chain stable and efficient, we should attach importance to the relationship between efficiency and fairness in supply chain management.

Many studies focus on the global objective of the system from a centralized perspective, disregarding the individual goals, which are crucial when dealing with decentralized supply chains, especially when different stakeholders with conflicting objectives are involved. Each stakeholder seeks to optimize his own benefits no matter how the other participating stakeholders' uncertain reactions will be [1].

Economists have examined people's intrinsic preference for fairness through experimentation. In the experiments in which subjects are able to compare their relative payoffs to other subjects, they are willing to forgo absolute payments in order to maintain fairness or equality of payoffs [2]. Stephen et al. found that perceived unfairness directly damaged the channel relationships, aggravated the negative effects of both conflict and opportunism, and undermined the benefits of using contracts to manage channel relationships [3]. Behavioral economics experiments have shown that people are not completely rational and have fairness perceptions. They do not only compare their own incomes to the incomes of others but also concern the fairness of the distribution and motivation [4].

Precisely because supply chain members are entities with independent decision-making rights, they tend to value their own interests in the supply chain. When his own interests conflict with the interests of the entire supply chain, he is likely to choose a decision that is good for him but bad for the supply chain. Therefore, a decentralized supply chain may not always be able to achieve coordination. How supply chain partners cooperate with other related partners and how they establish a stable entity coalition according to their own profits are not only the essential of the supply chain's relationship coordination between partners, but also the key to establishing a stable structure and obtaining optimal profit in a supply chain [5]. Obviously, the fairness of profit distribution is one of the important factors that affect the stability of a supply chain.

Therefore, the organizational structure of supply chain requires that the profit of a supply chain should be fairly distributed among members. In supply chain management, the fairness concerns of the participants should be fully valued. The analysis of supply chain contracts mainly focuses on supply chain coordination, but the fairness concern draws a little attention in the literature of supply chain management.

In this study, we analyze a supply chain composed of two parties and we aim to explore the relationship between the efficiency and fairness in a supply chain. For this study, we build an incentive model. By changing the values of the parameter measuring fairness of the distribution of supply chain's profits, we can show the relations between efficiency and fairness.

In this paper, different from the most literature, we do not specifically look for a coordinating contract but focus on the non-coordinating contracts in order to explore the relations between efficiency and fairness. In addition, in the literature on the supply chain contracts, most of them assume that the supplier's and the retailer's unit costs or marginal costs are constants. The constant marginal cost means that the participants possess unlimited production capacity. That is, the participants have unlimited production resources. In fact, in any supply chains, the resources of members are limited. In this paper, we assume that both of the supplier's and the retailer's marginal costs are variable.

The analysis is based on an incentive contract. The incentive model is designed by the supplier based on revenue sharing contract. In this incentive model, the fairness of profit distribution of the supply chain is regarded as a constraint condition. The supplier must take into account the interests of the retailer while pursuing the maximization of her own profit so as to truly reflect the cooperative relationship between the participants in the supply chain and make the supply chain operate stably and efficiently. In this model, we can analyze how the supply chain efficiency changes with the value of the fairness parameter.

The remainder of this paper is organized as follows. Section 2 presents a brief literature review. Section 3 analyzes coordination of the supply chain. Section 4 introduces the measure of fairness. A supply chain incentive model with constraint of profit distribution fairness is provided in section 5. A numerical example is provided to illustrate the model and each calculation step in section 6. Finally, conclusions and the outline of future research directions are proposed in section 7.

2. Literature Review

There are mainly two categories of literature closely related to this paper. One category is on revenue sharing contracts.

The revenue sharing contract has been widely applied in various industries, such as rental industry [6-8], airline alliances [9, 10], personal computers industry [11], movie industry [12, 13], mobile video industry [14], dairy industry [15], etc.

Cachon and Lariviere [8] studied revenue sharing contracts in a general supply chain model with revenues determined by each retailer's purchase quantity and price. Demand could be deterministic or stochastic and revenue was generated either from rentals or outright sales. They demonstrated that revenue sharing contract could coordinate a supply chain with a single retailer and arbitrarily allocated the supply chain's profit. Giannoccaro and Pontrandolfo [16] proposed a supply chain contract aimed at coordinating a three-stage supply chain, which was based on the revenue sharing mechanism. This model allowed the system efficiency to be achieved as well as it could improve the profits of all the supply chain participants, by tuning the contract parameters. Tiaojun Xiao et al. [17] explored a coordination problem of a supply chain via a revenue-sharing contract, where a product quality assurance policy was provided and the utility of consumer was sensitive to product quality, service quality and retail price. They studied the coordination mechanism and gave the optimal service quality and pricing decisions of the decentralized supply chain. WeiGuo et al. [18] studied how to coordinate a one-manufacturer-two-retailers supply chain with demand disruptions by revenue sharing contracts. This study showed that it was necessary to adjust the original revenue sharing contracts to demand disruptions. Dana and Spier [6] studied the use of revenue sharing contract in a decentralized channel with a perfectly competitive downstream market and stochastic demand. They demonstrated that a revenue sharing contract could induce downstream firms to choose channel optimal actions. Yao et al. [19] investigated a revenue sharing contract for coordinating a supply chain comprising one manufacturer and two competing retailers. The study found that the revenue sharing contract could obtain better performance than a price-only contract. The paper analyzed the impact of demand variability on decisions about optimal retail price, order quantity and profit sharing between the manufacturer and the retailers. It also investigated how the competition factor influenced the decision-making of supply chain members in response to uncertain demand and profit variability. Yunzeng Wang et al. [20] showed that under a consignment contract with revenue sharing, both the total supply chain's profit and each firm's profits depended on the demand price elasticity and the retailer's cost share. The supply chain's profit loss increased with demand price elasticity and decreased with retailer's cost share, while the profit share of the retailer decreased with price elasticity and increased with retailer's cost share. Omkar [13] analyzed two types of revenue sharing contracts: the revenue-dependent revenue sharing contract and the revenue-independent sharing contract. This study showed that the supply chain could be coordinated using the two types of revenue sharing contracts. But, in some cases, the revenue-dependent contract outperformed the revenue-independent contract. The revenue-dependent contract could provide positive surplus to the supply chain members that was not possible under certain situations in the revenue independent contract. Yumei Hou et al. [21] studied the coordination of the decentralized supply chain with the simultaneous move game or the leader-follower game based on a revenue sharing contract. The results showed that the revenue sharing contract could not coordinate the decentralized three-echelon supply chain with the leader-follower game except for a special situation. But, this result provided an opportunity to develop methodology and results that measured the potential improvement in supply chain performance that could be gained from utilizing the revenue sharing contract. Huihui Song and Xuexian Gao [22] established a green supply chain game model with two kinds of revenue-sharing contracts, and then compared the results with the common centralized control game model and the decentralized decision game model's results. By comparing the models' results, they also quantitatively analyzed the impact of the contracts on the internal membership decision variables and the overall performance of the supply chain. Sushil and Bibhas [23] analyzed a three-echelon closed-loop supply chain under sustainability consideration through remanufacturing of waste materials. This article determined the optimal incentives for end-customers and optimal profits of supply chain members in three separate cases, and implemented the revenue sharing contracts in two different settings. ZhenSong Chen et al. [24] built a multi-channel optimal pricing decision model with a revenue-sharing contract in the context of a cross-channel effect, consumers trust utility, and after-sales service utility. The study showed that, in order to obtain maximum profit, the manufacturer and reseller would take different measures for different levels of differences between cross-channel effects of direct seller and reseller, different levels of consumer trust utility, and different levels of after-sales service utility.

Another category of literature closely related to this paper is on fairness. Fairness has been long recognized as one of the most important factors guiding human interactions in everyday life as well as in business activity [25].

Tony Haitao Cui et al. [26] investigated how fairness might affect channel coordination. The results showed that the manufacturer could use a constant wholesale price to align the retailer's interest with the channel's and coordinate the channel with a wholesale price higher than its marginal cost. Elena and Valery [25] designed a sequence of laboratory experiments to separate possible factors of channel inefficiency. The three factors considered in this paper were inequality aversion, bounded rationality, and incomplete information. The experiment results showed that all of the three factors would affect human behavior. Among the three factors, inequality aversion possessed the greatest explanatory power for the retailer's behavior. Incomplete information about the retailer's degree of inequality aversion possessed the greatest explanatory power for the supplier's behavior. Qinghua Li and Bo Li [27] considered a dual-channel supply chain in which the retailer had fairness concerns and could provide value-added services. The study showed that channel efficiency grew with increasing customer loyalty to the retail channel and fell with increases in the retailer's fairness concerns. The study also showed that the supply chain could not be coordinated with the wholesale price contract when the retailer with fairness concerns provided value-added services. Mondal and Giri [28] investigated the effect of recycling activity and the retailer's fairness behavior on pricing, green improvement, and marketing effort in a closed-loop green supply chain. The results revealed that the fairness behavior of the retailer improved its profitability but it diminished the manufacturer's profit. Abhishek and Deepika [29] investigated the impact of fairness concerns of the retailer on the pricing policies of the supply chain partners, their individual profits, and the overall performance of a dual-channel supply chain composed of one manufacturer and one retailer. They found that the retailer's fairness concerns are not always beneficial for its better performance. Zelong Yi et al. [30] investigated how consumers' fairness-seeking behavior affected a manufacturer's distribution channel selection. The study showed that it might be more beneficial for the manufacturer to decentralize its distribution channel by adopting agent selling when the consumer was extremely fairness-minded. However, when the consumer's fairness concern was weak, direct selling was preferred by the manufacturer.

3. Supply Chain Coordination

Consider a supply chain with two risk-neutral firms, a supplier and a retailer. The retailer faces the newsvendor's problem: the retailer must choose an order quantity before the start of a single selling season that has stochastic demand $D\geq 0$ with a fixed retail price p. Let F be the distribution function of demand D: F is differentiable, strictly increasing and $F(0)=0$. With the revenue sharing contract, the supplier charges w per unit purchased, and the retailer gives the supplier a percentage of his revenue. Let k be the fraction of supply chain revenue the retailer keeps, so (1-k) is the fraction the supplier earns. The supplier's cost function is $c_s(q)$, the retailer's cost function is $c_r(q)$, and both of the marginal cost functions are increasing, i.e., $\frac{d^2c_s}{dq^2}>0, \frac{d^2c_r}{dq^2}>0$. For simplicity, salvage revenue for leftover inventory and goodwill penalty costs for lost sales are not included in this model.

We use a two-stage Stackelberg game to model the problem, where the supplier is the game's leader and the retailer is the game's follower.

The sequence of events in this game is as follows: the supplier offers the retailer a contract; the retailer accepts or rejects the contract; assuming the retailer accepts the contract, the retailer submits an order quantity, q, to the supplier; the supplier produces and delivers to the retailer before the selling season; season demand occurs; and finally transfer payments are made between the firms based upon the agreed contract. If the retailer rejects the contract, the game ends and each firm earns a default payoff [31].

The expected sales, denoted by $S(q)$, is

$$S(q) = q - \int_0^q F(x)dx \tag{1}$$

The expected leftover inventory, denoted by $I(q)$, is

$$I(q) = q - S(q) = \int_0^q F(x)dx \tag{2}$$

The retailer's profit function is

$$\pi_r(q, w, k) = kpS(q) - wq - c_r(q) \tag{3}$$

The supplier's profit function is

$$\pi_s(q, w, k) = (1-k)pS(q) + wq - c_s(q) \tag{4}$$

The supply chain's profit function is

$$\pi(q) = pS(q) - c_r(q) - c_s(q) \tag{5}$$

Suppose q^0 is the quantity that maximizes the supply chain's profit $\pi(q)$.

By equation (5), let

$$\frac{d\pi(q)}{dq} = p(1-F(q)) - c_r'(q) - c_s'(q) = 0 \tag{6}$$

According to the previous hypotheses, the order quantity q^0 which maximizes the expected profit of the supply chain is unique from equation (6).

From equation (6), the determination of the optimal order quantity q^0 of the supply chain is only related to the cost functions of supplier and retailer, the market condition (retail price and demand distribution), but is not related to the contract parameters.

The optimal order quantity q^* of the retailer is calculated below.

In equation (3), $kpS(q)$ is the retailer's expected revenue, $wq+c_r(q)$ is the retailer's cost. According to the principle that the marginal revenue is equal to the marginal cost, we can see that the optimal order quantity $q^*(k, w)$ should satisfy the following equation.

$$\frac{d\pi_r(q)}{dq} = kp(1-F(q)) - w - c_r'(q) = 0$$

We can obtain the following equation

$$kp(1-F(q)) = w + c_r'(q) \tag{7}$$

As a function of q, the right hand side of equation (7) is strictly monotonically increasing, while the left-hand side is monotonically decreasing. Therefore, in the case of given k and w, there exists a unique solution q^* in equation (7).

Through a simple calculation, we can see that the relationship between the optimal order quantity q^* and wholesale price w, coefficient k satisfies:

$$\frac{\partial q^*}{\partial w} < 0, \frac{\partial q^*}{\partial k} > 0 \tag{8}$$

where

$$\frac{\partial q^*}{\partial w} = -\frac{1}{c_r''(q^*) + kpf(q^*)} \quad \frac{\partial q^*}{\partial k} = \frac{p(1-F(q))}{c_r''(q^*) + kpf(q^*)} \tag{9}$$

Therefore, the retailer's order quantity decreases with the wholesale price, and increases with the coefficient k.

The determination of the optimal order quantity q^0 is not related to the contract parameters, but the retailer's optimal order quantity q^* is closely related to the contract parameters. From equation (7), the optimal order quantity of the retailer is determined by the contract parameters when the market conditions (i.e., retail price p, $F(x)$) and the cost function of the retailer remain unchanged. Therefore, it is necessary to analyze how the supplier sets the contract parameters in order to achieve the coordination of the supply chain.

By substituting equation (6) into equation (7), we can obtain

$$w = kc_s'(q^0) - (1-k)c_r'(q^0) \tag{10}$$

So, the contract parameters (w and k), determined by the supplier, should satisfy equation (10) in order to coordinate the supply chain when the optimal order quantity q^0 is determined.

It is easy to understand from equation (10) that there exists a positive relationship between wholesale price w and coefficient k.

4. Fairness Analysis of Profit Distribution in a Supply Chain

The literature on supply chain coordination focuses on enhancing network efficiency, and stability issues are largely unexplored [32]. If the supply chain is not stable, its members will not put their superior resources into the supply chain, and the cooperation between members will become more difficult. Because the supply chain members are likely to choose short-term opportunistic behaviors in this situation. Therefore, a certain degree of stability is an important character of a supply chain alliance. Stability is essential to the sustainable and efficient operation of a supply chain [33].

However, in the literature on supply chain coordination, most of them mainly analyze the quantity the retailer should order in order to coordinate the supply chain, and often do not determine the values of contract parameters. So, they do not specify how the supply chain profits should be distributed. Even considering the distribution of profits, usually, the contract designer (principal) obtains most or even all of the profits of the supply chain. Another enterprise (agent) can only get the lowest profit (such as reservation profits). In the case of information asymmetry, agents can get excess profits only because they own private information. The distribution of profits in a supply chain should not be like this, because this can not reflect the cooperative relationship between the supply chain members. It is not conducive to the stable operation of the supply chain, and ultimately is not conducive to the principal himself.

The essence of the supply chain is that it is an organizational form organized by member enterprises to provide a better product or service to the consumers, in which the member enterprises can efficiently exert their own resource advantages and reasonably make use of other member enterprises' resources [34]. This combination of resources often can bring super profits, this will inevitably give rise to the profit distribution problem in the supply chain. Without a relatively fair profit distribution, it is difficult to maintain the cooperative relationship between member enterprises and the stability of the supply chain. Therefore, the distribution of profits in the supply chain should be fair to a certain extent. Here, the profit distribution should take into account not only the willingness of each member enterprise to join the supply chain, but also the fairness of profit distribution.

4.1. Measurement of the Importance of Resources

There are many kinds of resources in the supply chain. Each enterprise has its own core resources. These resources are important to the profitability of the supply chain, but obviously their importance is often different. In this paper, the importance weight of enterprise resources is used to describe the differences in importance of the member enterprises to the supply chain. Here, the expert scoring method is used to determine the importance weight of an enterprise.

Suppose *m* experts evaluate the importance of 2 enterprises in the supply chain, and the following evaluation matrix is obtained.

$$W = \begin{pmatrix} \omega_{11} & \omega_{12} \\ \omega_{21} & \omega_{22} \\ \vdots & \vdots \\ \omega_{m1} & \omega_{m2} \end{pmatrix} \tag{11}$$

Where, ω_{ij} represents expert *i*'s evaluation of the importance of enterprise *j*, which value is one of 9 positive integers of 1~9. The greater the value is, the more important it is. The meanings of these numbers are as follows. 1 indicates unimportance, 3 indicates moderate importance, 5 indicates strong importance, 7 indicates very strong importance, 9 indicates extreme important. 2, 4, 6, 8 are the intermediate values between the two adjacent judgments, which are used when compromise is needed [35].

The average value of the importance scores of enterprise *j* is taken as the importance score of enterprise *j* (denoted by ω_j).

$$\omega_j = \frac{1}{m}\sum_{i=1}^{m}\omega_{ij} \qquad j = 1,2 \tag{12}$$

The importance weight of enterprise j (denoted by α_j) is determined by following formula.

$$\alpha_j = \frac{w_j}{\sum_{j=1}^{n} w_j} \qquad j = 1,2 \tag{13}$$

The importance weight of enterprises also can be determined by using the analytic hierarchy process (AHP) [35, 36].

4.2. Fairness Measurement

In order to maintain the stability of the supply chain, the profit distribution should take into account not only the willingness of each member enterprise to join into the supply chain, but also the fairness of profit distribution. When considering the fairness of profit distribution, we should consider the resource quantity invested in the supply chain by the enterprises (here, costs $c_s(q)$ and $c_r(q)$ are used to represent the supplier's and retailer's input, respectively.), we should also consider the importance of these resources to the profitability of the supply chain. Assume the profits of member enterprise *i* (*i*=*s*, *r*) are π_i^0 and π_i respectively before and after joining the supply chain. Denote member enterprise *i*'s excess profit as $\Delta\pi_i$ (where, $\Delta\pi_i = \pi_i - \pi_i^0$) (so, the excess profit here refers to the profit that exceeds the reservation profit.). Taking into account the importance of the enterprise, the excess profit of unit resource input of the enterprise, denoted by e_i, $e_i = \dfrac{\Delta\pi_i}{(1+\alpha_i)c_i(q)}$. If the distribution of excess profit is absolutely fair, the excess profit margin e_i of unit resource input of each member enterprise should be equal. Therefore, the difference between e_i (*i*=*r*, *s*) reflects the degree of unfair distribution. Obviously, the smaller the difference is, the more equitable the distribution is. So, the difference (denoted by *d*) between e_i (*i*=*r*, *s*) is used as an indicator of fairness in profit distribution.

$$d = | e_s - e_r |$$

Since the absolute value is not easy to calculate, the index is redefined as follows.

$$d = \sqrt{(e_s - e_r)^2} \tag{14}$$

The smaller the value of *d* is, the more equitable the profit distribution is.

4.3. Supply Chain Profit Distribution Fairness Constraint

In order to make the supply chain stable to a certain extent, we must attach importance to the interests of each enterprise in the supply chain so that the distribution of profits has a certain degree of fairness. That is, the value of *d* can not be too large. In practical applications, a threshold can be set to ensure the fairness. Assume that the threshold is d_0. To ensure the stability of the supply chain, the fairness of profit distribution should meet the following requirement

$$d \le d_0 \tag{15}$$

5. Incentive Model Considering Fairness of Profit Distribution

The previous section analyzes the stability of a supply chain from the perspective of the fairness of profit distribution, and the smaller the value of d is, the more stable the supply chain is. In fact, only the fairness of profit distribution can not describe the stability of the supply chain very well. This is because we have not yet considered another important factor: the size of the profit. When the supply chain is in a low efficiency state, the value of d may also be very small. Therefore, in order to make the supply chain run stably and efficiently, we should also consider the size of the profit as an important factor so that the supply chain can achieve a higher profit while the value of d is smaller. To achieve this goal, an incentive model is proposed as follows:

$$\begin{aligned} &\max_{k,w} \pi_s \\ s.t.\quad & \pi_r \ge \pi_{r_0} && (16-1) \\ & q \in \arg\max\{\pi_r\} && (16-2) \\ & 0 \le k \le 1 && (16-3) \\ & d \le d_0 && (16-4) \end{aligned} \quad (16)$$

In this model, π_s and π_r are determined by equations (4) and (3), respectively. Equation (16-1) is a participation constraint. Only when the retailer gets at least the profit π_{r_0}, will he join the supply chain. (16-2) is the incentive-compatibility constraint. After joining the supply chain, a retailer will take action to maximize his own profits. The scope of the contract parameter k should satisfy inequation (16-3). In order to make the supply chain achieve a certain degree of stability, the fairness of profit distribution should satisfy inequation (16-4).

Using incentive model (16), the supplier can induce the retailer to determine an order quantity beneficial to both parties, which also determines the resource inputs of both parties.

According to the previous analyzes, we can see that the model (16) is equivalent to model (17).

$$\begin{aligned} &\max_{w,k}\{(1-k)pS(q)+wq-c_s(q)\} \\ s.t.\quad & kpS(q)-wq-c_r(q) \ge \pi_{r_0} && (17-1) \\ & kp(1-F(q)) = w + c_r'(q) && (17-2) \\ & 0 \le k \le 1 && (17-3) \\ & d \le d_0 && (17-4) \end{aligned} \quad (17)$$

When the supplier pursues her own profit maximization, she considers both the size of her profit and fairness of the profit distribution. If the supplier does not consider the fairness of the profit distribution, the retailer often get very low profits or even get the reservation profit π_{r_0}. Such a supply chain is unstable and does not reflect the cooperative relationship between supply chain partners.

Here, because the incentive model (mainly the expression of fairness constraint) is complex, it is difficult to find the analytical solutions of the model. So the analytical expressions for the contract parameters are not obtained. But as long as we know the relevant data and cost expressions, it is easy to calculate the results using computer software.

6. Numerical Example

This section illustrates how to analyze the relationship between supply chain efficiency and the fairness of profit distribution with a numerical example.

Assume the retail price p=100, the demand follows a continuous uniform distribution between 1000 and 2000. the supplier's and the retailer's cost functions are $c_s=0.01q^2$ and $c_r=0.005q^2$, respectively. The calculation process consists of five steps.

Step 1: supply chain optimal order quantity and profit

The optimal order quantity of the supply chain can be calculated from equation (6). It's value is q^0=1538, and from equation (5), the optimal total profit of the supply chain $\pi(q^0)$=103846.

Step 2: the retailer's optimal order quantity

From equation (7), the retailer's optimal order quantity $q^*(w, k)$ satisfies the following formula.

$$q^*(w,k) = \frac{100(200k-w)}{1+10k} \quad (18)$$

Step 3: the expression of d

Assume that the importance weights of the supplier and retailer are 0.4 and 0.6, respectively. The reservation profits of the supplier and retailer are π_s^0 =12000 and π_r^0 = 8500, respectively.

$$\pi_r(q,w,k) = -(0.05k+0.005)q^2 + (200k-w)q - 50000k \quad (19)$$

$$\pi_s(q,w,k) = -(0.05(1-k)+0.01)q^2 + (200(1-k)+w)q - 50000(1-k) \quad (20)$$

The supply chain's profit function is

$$\pi(q) = -0.065q^2 + 200q - 50000 \quad (21)$$

$$e_s = \frac{\Delta\pi_s}{(1+\alpha_s)c_s(q)} = \frac{-(0.05(1-k)+0.01)q^2 + (200(1-k)+w)q - 50000(1-k) - 12000}{0.014q^2} \quad (22)$$

$$e_r = \frac{\Delta \pi_r}{(1+\alpha_r)c_r(q)} = \frac{-(0.05k+0.005)q^2+(200k-w)q-50000k-8500}{0.008q^2} \tag{23}$$

$$d = \sqrt{(e_s - e_r)^2}$$

Step 4: Incentive model

Substituting related data and expressions into incentive model (17), we can obtain the following model.

$$\begin{aligned} &\max_{w,k}\{100(1-k)(-0.0005q^2+2q-500)+wq-0.01q^2\} \\ s.t.\quad & 100k(-0.0005q^2+2q-500)-wq-0.005q^2 \ge 8500 \\ & 100k(2-0.001q) = w+0.01q \\ & 0 \le k \le 1 \\ & d \le d_0 \end{aligned} \tag{24}$$

Step 5: supply chain's efficiency under different fairness thresholds

The model can be solved under different values of d_0 with Lingo software, and the results are shown in Table 1.

The optimal profit of the supply chain is 103846. The efficiency of the supply chain under different d_0 values can be calculated from the fourth column data in Table 1.

From Table 1 (In Table 1, η represents supply chain efficiency), we can see that with the decrease of d_0, the profit of the retailer is increasing, and the efficiency of the supply chain is also increasing.

It can be seen from Table 1, as the value of d_0 increases (i.e., fairness decreases), the efficiency of the supply chain begins to decline strictly, then increases until the efficiency of coordination is reached. In the course of increasing d_0, the profit of supplier is increasing, and correspondingly, the profit of retailer is decreasing and finally, the retailer can only get reservation profit. It also can be seen from Table 1 that the supply chain efficiency can be very high at very high and very low level of fairness. But in these two cases, their respective profits vary greatly.

Table 1. *Efficiency and fairness under revenue sharing contract.*

d_0	π_s	π_r	π	η
0	65038	38808	103846	100.00
0.05	65645	38196	103840	99.99
0.1	66258	37564	103822	99.98
0.15	66880	36912	103792	99.95
0.2	67509	36239	103748	99.91
0.25	68146	35545	103691	99.85
0.3	68792	34828	103620	99.78
0.35	69446	34089	103534	99.70
0.4	70108	33326	103434	99.60
0.5	71458	31726	103185	99.36
0.6	72845	30023	102868	99.06
0.7	74268	28210	102479	98.68
0.8	75731	26280	102011	98.23
1.0	78779	22037	100816	97.08
1.5	87205	8754	95959	92.41
1.6	88915	8500	97415	93.81
1.75	91033	8500	99533	95.85
2	93516	8500	102016	98.24
3	95346	8500	103846	100.00
3.5	95346	8500	103846	100.00

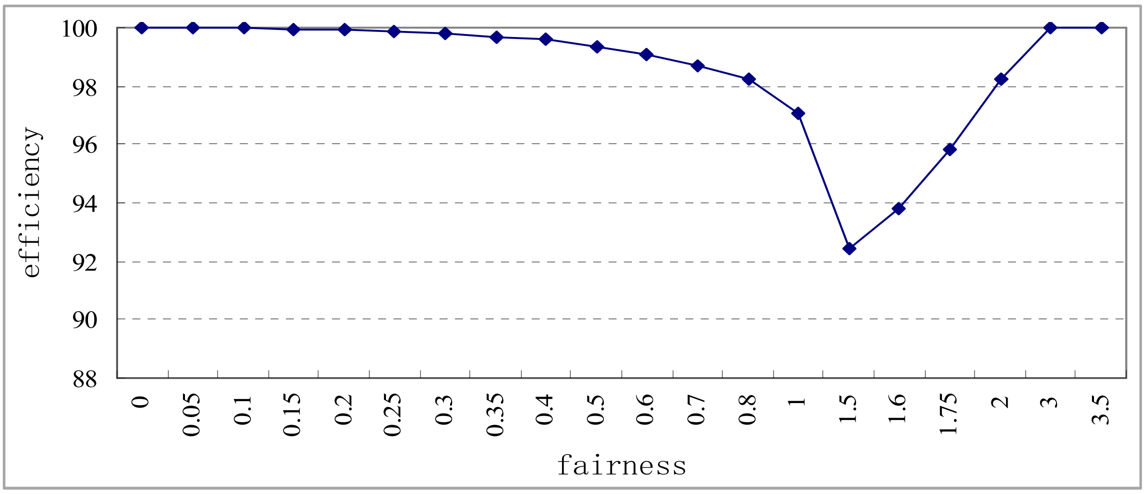

Figure 1. *Relationship between efficiency and fairness.*

Figure 1 shows the relationship between efficiency and fairness more intuitively.

The effects of the change of d_0 on the profits of the supply chain, supplier and retailer are shown in figure 2.

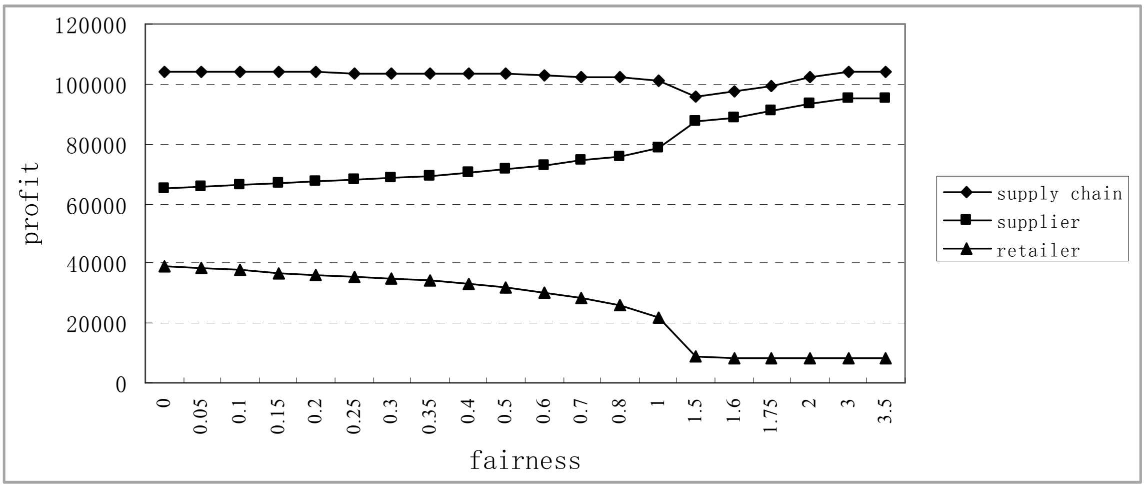

Figure 2. *Effect of fairness on profits.*

7. Conclusions and Future Research

From the analysis of this paper, we can see that fairness concerns have an important effect on supply chain efficiency. From the supplier's point of view, if the model only contains the participation constraint and incentive compatibility constraint, this model is not much different from the general incentive model. Although fairness changes in two opposite directions may increase the efficiency of the supply chain, it is obvious that when the profit distribution of the supply chain is very unfair, although the efficiency may be very high, such a supply chain is very unstable. Such a profit distribution state will cause strong dissatisfaction of the retailer. Especially when the retailer can only get reservation profit, he is more likely to leave the supply chain. This situation is likely to cause the disintegration of supply chains. Therefore, in order to make the supply chain run stably and efficiently, the supplier should carefully consider the fairness concerns of the retailer.

The purpose of establishing a supply chain is to enhance the competitive advantage of enterprise alliance (that is, the supply chain in this paper) through the complementary use of resources of each member enterprise, so as to achieve the goal of win-win, and then realize the stable operation of the supply chain [34]. In order to achieve this goal, the supplier should fully consider the interests of the retailer when designing incentive contracts, and motivate the retailer by fairly distributing the profits of the supply chain to a certain extent. The stronger the fairness of the profit distribution of the supply chain is, the more profits the retailer gets. Thus, the retailer will take the initiative to choose the decision that is beneficial to the whole supply chain.

The model can be extended in several directions. Firstly, the model is proposed based on some strong assumptions, such as complete information and the member enterprises' risk neutral. In future analysis, these assumptions can be relaxed. For example, we can analyze the problem under the condition of one party or two sides' risk aversion, or (and) under the condition of information asymmetry. Secondly, this paper analyzes the relationship between supply chain efficiency and fairness in a static setting. In fact, the relationship between supply chain partners is often a long-term cooperative relationship. So how to analyze the problem in a dynamic setting is also a problem worth studying. Thirdly, how to verify the method proposed in this paper through laboratory experiments is a problem worth studying. If there is a big difference between the results of the laboratory and the theoretical analysis, we need to analyze what causes the difference and how to revise the model in order to make this method provide some useful suggestions for supply chain management practices.

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