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Research on incentive mechanism of supply chain based on RFID technology[1]

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Abstract. The changes of the investment behaviors of supply chain members are firstly analyzed, when retailer uses the commitment contract as incentive mechanism. Secondly, based on the retailer's commitment contract and with the supplier's reverse mechanism of price discounts, the incentive effect and optimization function of the factors to supply chain, such as the order quantity of retailer commitment, the supplier price discount coefficient, the inventory loss rate and the identification success rate of RFID technology are studied.

Key words. RFID, applied research, supply chain, incentives..

1. Introduction

The supply chain is a system composed of a large number of enterprises whose goal is to maximize their own interests by cooperation and competition. In the process of cooperation, the decentralized decision of the main body often deviates from the optimal result under the centralized decision. Therefore, the enterprises need to establish a certain mutual binding mechanism to promote the supply chain members to take positive measures to achieve information coordination, mutual incentives, and reasonable distribution of profits and other objectives. Supply chain contract is to provide a reasonable and effective incentive measures to enhance the overall performance of the supply chain, so that the optimal decisions of each subject are the similar to the centralized decision under the optimal solution. The common supply chain contracts include Revenue-sharing Contract, Quantity-discount Contract, Price-discount Sharing Contract and Buyback Contract etc.

Revenue-sharing Contract refers to the contract form that the retailer will transfer

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to the supplier according to a certain proportion, which usually adopts the lower wholesale price when the supplier delivers the goods. In the actual situation, the franchise mode is a typical model of supply chain revenue sharing.

Quantity-discount Contract refers to the difference in the quantity of the buyer's order quantity in the process of the transaction. The greater the number of products ordered by the buyer, the greater the wholesale price discount and the lower the price is. It is a mean of promotion by the seller.

For the above supply chain contract, it has been already formed a more mature research system and application mechanism. However, due to the limited presence of rational people, contract design cannot satisfy all situations and solve all the problems. Then it will rely on the reputation of both sides or others as guarantee mechanism outside the negotiations between the two sides' trade relationship and legal constraints [1]. Thus it puts forward a new contract form of relational contract, and gets further research and development. Williamson combines relational contract and transaction cost theory, and points out that the relational contract has a significant improvement in the investment of proprietary trading partners [2].

Commitment Contract is one form of the contractual relationship. It is a kind of informal agreement or verbal agreement. On the basis of mutual trust between the two sides, it is bound by the credibility of the utility of an individual self-enforcing mechanism to promote the contract implementation. Cachon and Lariviere believe that the information asymmetry between supply chain nodes promotes the formation of the commitment contract. They simulated the game process of the supply chain enterprises: firstly after the manufacturer knows the products demand characteristics, it puts forward contractual commitments about the initial amount of related parts; secondly the supplier visits the income and opportunity cost of the commitment of the contract, in order to determine the production; then the manufacturer determines the final parts of the order quantity with the actual production requirements; finally the supplier organizes production. Although the actual demand for the product is not certain when the contract is concluded, the study shows that under certain conditions, the manufacturer's commitment contract stimulates the production of the supplier with higher production capacity [3]. The manufacturer and customer commitment contract was studied by Durango-Cohen and Yano. Considering the partnership between guarantee punishment mechanism for the implementation of the contract, namely if supplier's commitment to supply is less than the prediction of the customers, or suppliers do not meet the commitment amount in the final delivery, then the supplier needs to burden the linear penalty cost. The results show that the contractual commitments enhance the upstream and downstream information sharing level and reduce operating costs [4]. It can be found that the implementation of contractual commitments effectively promotes the revenue sharing and risk sharing, decrease operation costs and lay a good foundation for long-term cooperation for the partners, when there are many uncertain factors of supply chain decision-making situation. The combination of traditional contract and relational contract can enhance the overall competitiveness of the supply chain system.

2. Research on incentive mechanism of retailer's commitment contract

Considering the incentive measures for the downstream retailer to adopt the commitment contract, the decentralized decision-making supply chain system is introduced, and the decision-making process of the two sides of the game is as follows [5]. First of all, retailers promise the minimum quantity to upstream suppliers in advance. The order quantity is set as λ; secondly, according to the supplier's commitment to downstream, the retailers order quantity, combined with the prediction of market demand and determine the period of the optimal production Q_{c}. Finally, in the beginning of the season, retailers of the actual order quantity meet the $\max\{\lambda, x\}$, where x denotes the products that satisfy actual market demands. In this, the supplier continues to bear the retailer product cost caused by slow-moving inventories of actual order quantity, and has a salvage value of the product. Moreover, if retailer's actual sale is among $(0, \lambda)$, the residual value and inventory cost of unsold products are managed and enjoyed by the retailers. It is assumed that the unit inventory cost and the unit residual value of surplus products stored by retailers are the same as that in suppliers, which are still h and v. On the other hand, if the retailer sells the products, he usually cannot meet the actual needs of customers. Both retailers and suppliers will suffer from the loss of reputation and other aspects, and the unit out of stock losses are g_{R} and g_{S}, because products have loss in the process of suppliers managing inventory, and RFID technology cannot completely eliminate it. Thus, there is still $q_{\mathrm{c}} = (1-\mathrm{e}+\theta\mathrm{e})Q_{\mathrm{c}}$, where q_{c} denotes the amount of products for the normal sales that suppliers can provide when retailers use commitment contract.

In the following text, the choice of different commitments for retailers, the game process and the optimal decision-making of the two sides are discussed.

2.1. Case 1: $\lambda < q_{\mathrm{c}}$

Under the model of suppliers managing inventory, when suppliers know that the committed order quantity of retailers is less than the amount of products that can be offered for normal sales, then after using RFID technology, the expected profit function can be expressed as:

$$\Pi_{\mathrm{S}}^{1} = \omega\left[\int_{0}^{\lambda_1} \lambda_1 f(x)\,\mathrm{d}x + \int_{\lambda_1}^{q_{\mathrm{c}}^{1}} x f(x)\,\mathrm{d}x + \int_{q_{\mathrm{c}}^{1}}^{\infty} q_{\mathrm{c}}^{1} f(x)\,\mathrm{d}x\right] - $$

$$- g_{\mathrm{S}} \int_{q_{\mathrm{c}}^{1}}^{\infty} \left(x - q_{\mathrm{c}}^{1}\right) f(x)\,\mathrm{d}x - (c+t)Q_{\mathrm{c}}^{1} - $$

$$- (h-v)\left[\int_{0}^{\lambda_1} \left(q_{\mathrm{c}}^{1} - \lambda_1\right) f(x)\,\mathrm{d}x + \int_{\lambda_1}^{q_{\mathrm{c}}^{1}} \left(q_{\mathrm{c}}^{1} - x\right) f(x)\,\mathrm{d}x\right], \qquad (1)$$

where λ_1 and q_{c}^1 denote the retailer's commitment to order quantity and the supplier can be used for the normal sales of the product. In the formula, the first retailers use a commitment contract and the supplier can obtain the income. The second, third and fourth retailers indicate the production cost of the supplier of out of stock losses, inventory cost, residual value of products and all products. The retailer's expected return function can be expressed as

$$\begin{aligned}\Pi_{\mathrm{R}}^1 = p\left[\int_0^{q_{\mathrm{c}}^1} xf(x)\,\mathrm{d}x + \int_{q_{\mathrm{c}}^1}^{\infty} q_{\mathrm{c}}^1 f(x)\,\mathrm{d}x\right] - \\ - g_{\mathrm{R}}\int_{q_c^1}^{\infty}\left(x-q_c^1\right)f(x)\,\mathrm{d}x - (h-v)\left[\int_0^{\lambda_1}(\lambda_1 - x)\,f(x)\,\mathrm{d}x\right] - \\ - \omega\left[\int_0^{\lambda_1}\lambda_1 f(x)\,\mathrm{d}x + \int_{\lambda_1}^{q_{\mathrm{c}}^1} xf(x)\,\mathrm{d}x + \int_{q_{\mathrm{c}}^1}^{\infty} q_{\mathrm{c}}^1 f(x)\,\mathrm{d}x\right].\end{aligned} \tag{2}$$

Supplier gets retailer's commits order quantity, understands the relationship between the amount of commitment and amount of production that is available to the market demand. So the supplier's expected profit is given by the condition that the first derivative of the normal product sales volume is 0, in other words

$$\frac{\partial \Pi_{\mathrm{S}}^1}{\partial q_c^1} = -\left(\omega + g_{\mathrm{S}} + h - v\right)\int_0^{q_{\mathrm{c}}^1} f(x)\,\mathrm{d}x + (\omega + g_{\mathrm{S}}) - \frac{c+t}{1-\mathrm{e}+\theta\mathrm{e}} = 0\,.$$

The amount of products for normal sales, that makes the value of the equation (1) maximum under commitment contract, can be obtained, that is $q_{\mathrm{c}}^1 = q_1^*$. Thus, when $\lambda < q_c$, the optimal production of suppliers is still the production without using any incentive mechanism, that is $Q_{\mathrm{c}}^1 = Q_1^*$, which has nothing to do with the amount that retailers committed.

For term Π_{S}^1, its first derivative with respect to λ_1, i.e. $\frac{\partial \Pi_{\mathrm{S}}^1}{\partial \lambda_1} = (\omega + h - v)\int_0^{\lambda_1} f(x)\,\mathrm{d}x > 0$ means that under the promise of the contract, supplier returns, which is accompanied by an increase in the amount of upstream partners committed to increase in the amount. From (2) it can be obtained that when $\frac{\partial \Pi_{\mathrm{R}}^1}{\partial \lambda_1} = -(\omega + h - v)\int_0^{\lambda_1} f(x)\,\mathrm{d}x < 0$, it means that the retailer's revenue with the increase in the amount of commitment reduces, and from the derivative of Π_{R}^1 with respect to q_c^1, i.e. $\frac{\partial \Pi_{\mathrm{R}}^1}{\partial q_c^1} = -(p+g_{\mathrm{R}}-\omega)\left(\int_0^{q_c^1} f(x)\,\mathrm{d}x - 1\right) > 0$ it follows that the retailer revenue is an increasing function of the supplier's sales volume. Therefore, for the retailers, when the committed quantity which is expected to be ordered to the suppliers meets the condition of $\lambda < q_c$, it can be expected that the product quantity that suppliers can sell is q_1^*, so the best decision is $\lambda_1^* = 0$. Because the amount of commitment in this case does not lead to the increase in the amount of suppliers available for normal sales, it will not bring the increase in the revenue of the retailer himself.

Therefore, for the case 1, under the consideration of their own profit to be maximize, the optimal committed amount of the retailer will be $\lambda_1^* = 0$, and the supplier's best output will not change, that is, $Q_c^{1*} = Q_{1*}$. So the maximum expected return of suppliers and retailers is still $\Pi_{\mathrm{S}}^{1*} = \pi_{\mathrm{S}}^{1*}$, $\Pi_{\mathrm{R}}^{1*} = \pi_{\mathrm{R}}^{1*}$.

2.2. Case 2: $\lambda > q_{\mathrm{c}}$

When $\lambda > q_c$, the supplier that should meet the retailer's order as the production target, can achieve its revenue maximization, so the optimal production amount is $Q_c^{2*} = \frac{\lambda_{2*}}{1-e+\theta e}$. Symbols Q_c^2 and λ_2, respectively, denote in this case the supplier's production and the retailer's commitment. If the retailer forecasts that his commitment will be greater than the amount of the product that is available for normal sales, that is, $\lambda > q_c$, the expected payoff function can be expressed as

$$\Pi_{\mathrm{R}}^2 = p\left[\int_0^{\lambda_2} x f(x)\,\mathrm{d}x + \int_{\lambda_2}^{\infty} \lambda_2 f(x)\,\mathrm{d}x\right] - \omega\lambda_2 -$$

$$- g_{\mathrm{R}}\int_{\lambda_2}^{\infty}(x-\lambda_2)f(x)\,\mathrm{d}x - (h-v)\int_0^{\lambda_2}(\lambda_2 - x)f(x)\,\mathrm{d}x\,. \tag{3}$$

Because Π_{R}^2 is the strict concave function about its committed amount λ_2, it can be obtained that the committed order amount λ_2^*, which makes the value of equation (3) the largest, satisfies $F(\lambda_2^*) = \frac{p+g_{\mathrm{R}}-\omega}{p+g_{\mathrm{R}}+h-v}$. Still assuming that the market demand is subject to the uniform distribution of $(0, D)$, then in the case 2, the retailer's best commitment to the amount of $\lambda_2^* = D\frac{p+g_{\mathrm{R}}-\omega}{p+g_{\mathrm{R}}+h-v}$. At this point, the supplier's expected return function is

$$\Pi_{\mathrm{S}}^2 = \omega\lambda_2^* - g_{\mathrm{S}}\int_{\lambda_2^*}^{+\infty}(x-\lambda_2^*)\,f(x)\,\mathrm{d}x - (c+t)\frac{\lambda_2^*}{1-\mathrm{e}+\theta\mathrm{e}}\,. \tag{4}$$

The maximum expected revenue functions of the retailer and supplier are then simplified, respectively:

$$\Pi_{\mathrm{R}}^{2*} = \frac{D}{2}\,(p+g_{\mathrm{R}}+h-v)\left(\frac{p+g_{\mathrm{R}}-\omega}{p+g_{\mathrm{R}}+h-v}\right)^2 - \frac{D}{2}g_{\mathrm{R}}\,, \tag{5}$$

and

$$\Pi_{\mathrm{S}}^{2*} = D\frac{p+g_{\mathrm{R}}-\omega}{p+g_{\mathrm{R}}+h-v}\left(\omega + g_{\mathrm{S}} - \frac{c+t}{1-\mathrm{e}+\theta\mathrm{e}} - \frac{g_{\mathrm{S}}}{2}\times\frac{p+g_{\mathrm{R}}-\omega}{p+g_{\mathrm{R}}+h-v}\right) - \frac{D}{2}g_{\mathrm{S}}\,. \tag{6}$$

Comprehending the analyses of Case 1 and Case 2, the range of the committed order quantity of the retailers is $\{\lambda_2^*, 0\}$. When the committed order quantity of the retailers is 0, the optimal production of the suppliers is $Q_c^{1*} = Q_{1*}$. When the committed order quantity of the retailers is positive, and ordering $\lambda = \lambda_{2*}$, the suppliers organize production to fulfill the orders, and the most optimal production is $Q_c^{2*} = \frac{\lambda_2^*}{1-\mathrm{e}+\theta\mathrm{e}}$. Only when $\lambda_2^* > q_1^*$ and $\Pi_{\mathrm{R}}^{2*} > \pi_{\mathrm{R}}^{1*}$ are both established, the retailer will select the optimal commitment amount of λ_{2*}. To simplify these two inequalities, the condition of the optimal commitment amount of the retailers is λ_2^*

$$\frac{p+g_{\mathrm{R}}-\omega}{p+g_{\mathrm{R}}+h-v} > \frac{(1-\mathrm{e}+\theta\mathrm{e})\,(\omega+g_{\mathrm{S}})-c-t}{(1-\mathrm{e}+\theta\mathrm{e})\,(\omega+g_{\mathrm{S}}+h-v)}\cdot \cdot\left[1+\frac{(1-\mathrm{e}+\theta\mathrm{e})\,(h-v)+c+t}{(1-\mathrm{e}+\theta\mathrm{e})\,(\omega+g_{\mathrm{S}}+h-v)}\right]. \tag{7}$$

If the satisfying parameter set is recorded as $\Re_1$, the values of all variables are within the set. Retailers have the will to forwardly choose the positive commitment amount, and compared with the situation that commitment contract is not imported, the suppliers' expected profit has been improved. Moreover, the profit changes of suppliers increase in most cases.

3. Supplier price discount mechanism based on commitment contract

On the basis of retailers adopting commitment contract, considering the suppliers giving commitment amount a price discount of τ, then the wholesale price of advanced order part is $\tau\omega$. At this time, the members of the supply chain decision-making process [6] are as follows: first, the suppliers that need to determine the commitment ordering products can enjoy the discount coefficient τ; second, retailers reference price discount coefficient determined its commitments to the supplier minimum order quantity λ; then, suppliers according to the commitment ordering quantity to determine the optimal yield Q_{d} (at this time, for the amount of product sales and normal $q_{\mathrm{d}}=(1-\mathrm{e}+\theta\mathrm{e})Q_{\mathrm{d}}$). Finally, after the beginning of selling season, the actual order quantity of retailers should meet $\max\{\lambda,x\}$, x being the actual market demand. According to the following two cases, the expected return of the two parties in the supplier's price discount mechanism is discussed separately.

3.1. Case 3: $\lambda<q_{\mathrm{d}}$

Under VMI model [7], [8], when the supplier learned that the downstream partner's commitment order amount would be within the range, then by using RFID technology, its expected return function is

$$\Pi_{\mathrm{S}}^3=\omega\left[\int_0^{\lambda_3}\lambda_3 f(x)\,\mathrm{d}x+\int_{\lambda_3}^{q_{\mathrm{d}}^1}xf(x)\,\mathrm{d}x+\int_{q_{\mathrm{d}}^1}^{+\infty}q_{\mathrm{d}}^1 f(x)\,\mathrm{d}x\right]- -g_{\mathrm{S}}\int_{q_{\mathrm{d}}^1}^{+\infty}\left(x-q_{\mathrm{d}}^1\right)f(x)\,\mathrm{d}x-\frac{c+t}{1-\mathrm{e}+\theta\mathrm{e}}q_{\mathrm{d}}^1-(1-\tau)\omega\lambda_3- -(h-v)\left[\int_0^{\lambda_3}(q_{\mathrm{d}}^1-\lambda_3)f(x)\,\mathrm{d}x+\int_{\lambda_3}^{q_{\mathrm{d}}^1}(q_{\mathrm{d}}^1-x)f(x)\,\mathrm{d}x\right]. \tag{8}$$

The q_{d}^1 and λ_3, respectively, refer to the amount of products available for sale and retailer's early commitment. For suppliers, because Π_{S}^3 is the strictly concave function of q_{d}^1, so it makes its derivative 0, that is $\frac{\partial \Pi_{\mathrm{S}}^3}{\partial q_{\mathrm{d}}^1} = 0$, it can be obtained that , under the mechanism that retailer using the commitment contract and the supplier using the price discount, the product quantity for the normal sales that making expect profit of the upstream suppliers maximum is $q_{\mathrm{d}}^{1*} = q_1^*$. So when $\lambda < q_{\mathrm{d}}$, the supplier will eventually still choose Q_1^* as the most excellent production of this period, the value of the retailer's commitment to order and supplier price discounts are not related.

On the other hand, for the retailer, when $\lambda < q_{\mathrm{d}}$, its revenue function can be expressed as

$$\Pi_{\mathrm{R}}^3 = p\left[\int_0^{q_{\mathrm{d}}^1} xf(x)\,\mathrm{d}x + \int_{q_{\mathrm{d}}^1}^{+\infty} q_{\mathrm{d}}^1 f(x)\,\mathrm{d}x\right] - g_{\mathrm{R}}\int_{q_{\mathrm{d}}^1}^{+\infty}\left(x - q_{\mathrm{d}}^1\right) f(x)\,\mathrm{d}x +$$
$$+ (1-\tau)\omega\lambda - (h-v)\int_0^{\lambda_3}(\lambda_3 - x)\, f(x)\,\mathrm{d}x -$$
$$- \omega\left[\int_0^{\lambda_3}\lambda_3 f(x)\,\mathrm{d}x + \int_{\lambda_3}^{q_{\mathrm{d}}^1} xf(x)\,\mathrm{d}x + \int_{q_{\mathrm{d}}^1}^{+\infty} q_{\mathrm{d}}^1 f(x)\,\mathrm{d}x\right]. \tag{9}$$

Calculating the first-order derivative of Π_{R}^3 with respect to q_{d}^{1*}, $\frac{\partial \Pi_{\mathrm{R}}^3}{\partial q_{\mathrm{d}}^1} > 0$ can be obtained. It can be seen that the retailer's profit is an increasing function of the product quantity available for sale of the suppliers. Ordering $\frac{\partial \Pi_{\mathrm{R}}^3}{\partial \lambda_3} = -(\omega + h - v)\int_0^{\lambda_3} f(x)\,\mathrm{d}x + (1-\tau)\omega = 0$ it can be got that, that in case 3, the retailer's optimal commitment amount is $\lambda_3^* = F^{-1}\left(\frac{(1-\tau)\omega}{\omega+h-v}\right)$, the commitment amount is also the commitment amount that making the suppliers' expected profit minimum in case 3.

On the basis of $x \sim U(0, D)$, equations (8) and (9) can be simplified as follows

$$\Pi_{\mathrm{R}}^{3*} = q_{1*}(p + g_{\mathrm{R}} - \omega)(1 - \frac{q_{1*}}{2D}) - g_{\mathrm{R}}\frac{D}{2} - (\omega + h - v)\frac{\lambda_{3*}^2}{2D} + (1-\tau)\omega\lambda_3^*, \tag{10}$$

$$\Pi_{\mathrm{S}}^{3*} = \frac{1}{2D}\left(\omega + g_{\mathrm{S}} + h - v\right) q_{1*}^2 - \frac{D}{2} g_{\mathrm{S}} + (\omega + h - v)\frac{\lambda_{3*}^2}{2D} - (1-\tau)\omega\lambda_{3*}. \tag{11}$$

When comparing the retailer's commitment to the quantity of products provided by the supplier can be used for the normal sales quantity, the increase of the supplier's price discount mechanism, the income of the members of the supply chain is changed, as follows

$$\Pi_{\mathrm{R}}^{3*} - \pi_{\mathrm{R}}^{1*} = \frac{\lambda_3^*}{2}(1-\tau)\omega = \frac{D\left[(1-\tau)\omega\right]^2}{2\left(\omega + h - v\right)} > 0,$$

$$\Pi_{\mathrm{S}}^{3*} - \pi_{\mathrm{S}}^{1*} = -\frac{\lambda_3^*}{2}(1-\tau)\omega = -\frac{D\left[(1-\tau)\omega\right]^2}{2\left(\omega + h - v\right)} < 0.$$

Relative to case 1, the incentive mechanism taken by the supplier can increase the retailer maximum expected profit, and decline its own expected revenue. The higher price discount τ takes, the smaller retailers' profit increment is. Therefore, when $\lambda < q_{\mathrm{d}}$, the supplier's optimal decision is not to provide a price discount; and the retailer's optimal decision is $\lambda_3^* = 0$. At the same time the supplier's most excellent production has not changed, is still Q_{1^*}.

3.2. Case 4: $\lambda > q_{\mathrm{d}}$

When the supplier knows the retailer's commitment order quantity is greater than its production which can be used for normal sales, the supplier will make to order, so the optimal production quantity is $Q_{\mathrm{d}}^2 = \lambda_4/(1 - \mathrm{e} + \theta \mathrm{e})$, Q_{d}^2 and λ_4 represent the supplier's production and retailer's commitment order quantity in case 4. When $\lambda > q_{\mathrm{d}}$, the upstream supplier's revenue function is

$$\Pi_{\mathrm{R}}^4 = p\left[\int_0^{\lambda_4} x f(x)\,\mathrm{d}x + \int_{\lambda_4}^{+\infty} \lambda_4 f(x)\,\mathrm{d}x\right] -$$

$$- g_{\mathrm{R}} \int_{\lambda_4}^{+\infty} (x - \lambda_4)\, f(x)\,\mathrm{d}x - (h - v)\int_0^{\lambda_4} (\lambda_4 - x) f(x)\,\mathrm{d}x - \tau\omega\lambda_4\,. \qquad (12)$$

In the same way, when the commitment order quantity λ_4^* meets $F(\lambda_4^*) = (p + g_{\mathrm{R}} - \tau\omega)/(p + g_{\mathrm{R}} + h - v)$, the retailers expect the maximum revenue. Apparently $\lambda_4^* > \lambda_2^*$, which means that the supplier's price discount mechanism can improve the retailer's commitment order quantity relative to case 2. If it is still assumed that the market demand is subject to the uniform distribution of $(0, D)$, then the optimal commitment quantity of the retailer, the maximum expected return of the supplier, and the maximum expected profit of the retailer are, respectively

$$\lambda_4^* = D\frac{p + g_{\mathrm{R}} - \tau\omega}{p + g_{\mathrm{R}} + h - v}\,, \qquad (13)$$

$$\Pi_{\mathrm{S}}^{4*} = D\frac{p + g_{\mathrm{R}} - \tau\omega}{p + g_{\mathrm{R}} + h - v}\left(\tau\omega + g_{\mathrm{S}} - \frac{c + t}{1 - \mathrm{e} + \theta\mathrm{e}} - \frac{g_{\mathrm{S}}}{2}\cdot\frac{p + g_{\mathrm{R}} - \tau\omega}{p + g_{\mathrm{R}} + h - v}\right) - \frac{D}{2} g_{\mathrm{S}}\,, \qquad (14)$$

$$\Pi_{\mathrm{R}}^{4*} = \frac{D}{2}\,(p + g_{\mathrm{R}} + h - v)\left(\frac{p + g_{\mathrm{R}} - \tau\omega}{p + g_{\mathrm{R}} + h - v}\right)^2 - \frac{D}{2} g_{\mathrm{R}}\,. \qquad (15)$$

3.3. Result analysis

3.3.1. Situation 1. Comparison of the price discount mechanism before and after the retailer's maximum expected return changes. From (5) and (15) we get

$$\Pi_{\mathrm{R}}^{4*} - \Pi_{\mathrm{R}}^{2*} = \frac{D\omega}{2\,(p + g_{\mathrm{R}} + h - v)}\left[\omega\tau^2 - 2\,(p + g_{\mathrm{R}})\,\tau - \omega + 2\,(p + g_{\mathrm{R}})\right].$$

Obviously, when $(p+g_{\mathrm{R}})/\omega > 1$, the retailer's expected return decreases with the increase of the supplier's price discount coefficient, so when $\tau < 1$, the maximum expected return of the retailer is increased, which is similar to the conclusion of Case 3.

3.3.2. Situation 2. Compare the maximum expected return of the supplier before and after the use of the price discount mechanism.

By comparing (6) and (14), when the other factors are constant, Π_{S}^{4*} is the function about the price discount coefficient τ function, therefore, Π_{S}^{4*} about τ, and, therefore, its first-order derivative is

$$\frac{\partial \Pi_{\mathrm{S}}^{4*}}{\partial \tau} = \frac{D\omega}{p+g_{\mathrm{R}}+h-v} \cdot$$

$$\cdot \left[-\omega \left(2 + \frac{g_{\mathrm{S}}}{p+g_{\mathrm{R}}+h-v} \right) \tau + p + g_{\mathrm{R}} - g_{\mathrm{S}} + \frac{c+t}{1-\mathrm{e}+\theta \mathrm{e}} + \frac{g_{\mathrm{S}}\,(p+g_{\mathrm{R}})}{p+g_{\mathrm{R}}+h-v} \right].$$

As

$$\frac{\partial^2 \Pi_{\mathrm{S}}^{4*}}{\partial \tau^2} = \frac{-D\omega^2}{p+g_{\mathrm{R}}+h-v}(2+\frac{g_{\mathrm{S}}}{p+g_{\mathrm{R}}+h-v}) < 0\,,$$

put $\frac{\partial \Pi_{\mathrm{S}}^{4*}}{\partial \tau} = 0$, and then we get the maximum price discount below which can make the supplier's expected return Π_{S}^{4*} maximum

$$\tau^* = \frac{p+g_{\mathrm{R}}-g_{\mathrm{S}}+\frac{c+t}{1-\mathrm{e}+\theta\mathrm{e}}+\frac{g_{\mathrm{S}}(p+g_{\mathrm{R}})}{p+g_{\mathrm{R}}+h-v}}{\omega(2+\frac{g_{\mathrm{S}}}{p+g_{\mathrm{R}}+h-v})}\,.$$

When $0 < \tau^* < 1$, then compared to the situation two, the supplier adopts the price discount mechanism and the maximum expected return will be increased.

However, only when $\lambda_4^* > q_1^*$ and $\Pi_{\mathrm{R}}^{4*} > \pi_{\mathrm{R}}^*$ are both established, the retailer will choose λ_4^* for its commitment amount. By simplifying these two inequalities, the condition that the retailer chooses the optimal commitment amount for λ_4^* is:

$$\frac{(p+g_{\mathrm{R}}-\tau\omega)^2}{p+g_{\mathrm{R}}+h-v} > \frac{(1-\mathrm{e}+\theta\mathrm{e})\,(\omega+g_{\mathrm{S}})-c-t}{(1-\mathrm{e}+\theta\mathrm{e})\,(\omega+g_{\mathrm{S}}+h-v)}\,\cdot$$

$$\cdot\,(p+g_{\mathrm{R}}-\omega)\left[1+\frac{(1-\mathrm{e}+\theta\mathrm{e})\,(h-v)+c+t}{(1-\mathrm{e}+\theta\mathrm{e})\,(\omega+g_{\mathrm{S}}+h-v)}\right]. \tag{16}$$

If the parameter set that satisfies (16) is recorded as $\Re_2$, when all the parameters are in the collection, the retailer will take the initiative to select the λ_4^*'s commitment order quantity. Obviously $\Re_2 \supset \Re_1$. Also if

$$0 < \tau^* = \frac{p+g_{\mathrm{R}}-g_{\mathrm{S}}+\frac{c+t}{1-\mathrm{e}+\theta\mathrm{e}}+\frac{g_{\mathrm{S}}(p+g_{\mathrm{R}})}{p+g_{\mathrm{R}}+h-v}}{\omega(2+\frac{g_{\mathrm{S}}}{p+g_{\mathrm{R}}+h-v})} < 1$$

is established, the manufacturer's profit will yield higher than the price discount mechanism is adopted, namely in the retailer commitment contract basis, the supplier adopts reasonable price discount mechanism can realize the downstream of the game on the side of the Pareto improvement [9].

4. Numerical analysis

The method of numerical simulation is used to analyze and explain the investment decision-making of RFID in the supply chain members. Assume that the market demand for the product obeys a uniform distribution $U(0, 2000)$ and the unit cost of wholesale products, value and price, respectively, are $\omega = 26$, $v = 9$ and $p = 35$. The supplier's unit production costs and inventory costs are $c = 16$ and $h = 4$. The two sides of the game out of stock losses are $g_{\mathrm{S}} = 6$ and $g_{\mathrm{R}} = 5$. The RFID tag cost $t = 1$. According to the calculation and analysis, we can see that the inventory loss rate of the supplier needs to meet the $0 < \mathrm{e} < 0.48$ and the cooperation intention of the VMI model can be reached. We can distinguish two cases

4.1. Situation 1

When the retailer uses a commitment contract, the effect of inventory loss rate and RFID technology identification success rate affects the revenue of supply chain members.

From the previous analysis, we can conclude that when retailer takes contractual commitments to encourage suppliers to implement RFID technology, if the commitment amount is small (such as Case 1) to downstream retailers, the choice of the optimal strategy is not the commitment contract [10]. Therefore, this situation cannot be verified numerically. If retailer's commitment ordering quantity satisfies the assumptions in Case 2, it can be shown by the numerical simulation that the retailer's optimal commitment order quantity $\lambda_2^* = 800$, this value is uncorrelated to the rate of supplier' shrinkage and the rate of RFID's identification. Figure 1 shows the impact of the vendor's inventory loss rate and the RFID technology on the identification success rate of the inventory inaccuracy problem on the optimal commitment amount of retailer selection Case 2. As shown in Fig. 1, when the rate of supplier' shrinkage and the rate of RFID's identification are below the curve, the commitment contract used by retailer will increase its maximal expected revenue, and make itself more positive to adopt incentive mechanism to promote the suppliers to implement RFID . Clearly, only the supplier's loss rate is at a high level ($\mathrm{e} > 0.345$), while the RFID technology is at a low level ($\theta < 0.3$) when the recognition success rate is at a low level. But in the actual situation, the recognition success rate of RFID technology is obviously not always at the level of 30 %.

On the other hand, in terms of different RFID identification success rate (order $\theta = 0.3$, $\theta = 0.6$ and $\theta = 0.9$, respectively), the impact of the retailer's commitment to its maximum expected return is shown in Fig. 2. Obviously, the retailer's commitment contract can significantly improve the supplier's maximum expected return, and the supplier's income difference increases with the increase of inventory loss rate, showing a trend of first increasing and then decreasing. With the increase

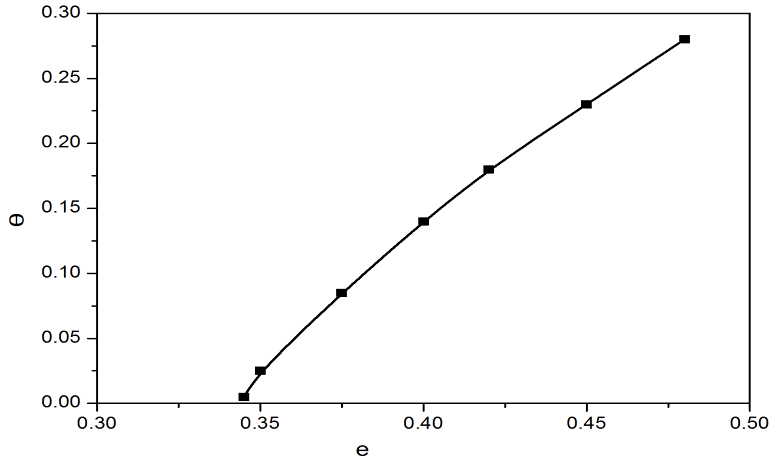

Fig. 1. Conditions for the retailer to select the optimal commitment order quantity in Case 2

of the recognition success rate of the RFID technology, the difference between the maximum expected return and the difference of the maximum expected return of the suppliers is basically a downward trend compared to the situation without using any incentive mechanism. This shows that the higher the recognition success rate of RFID technology is based on the above numerical assumptions, the more stable the retailer's incentive mechanism is to the supplier's effect.

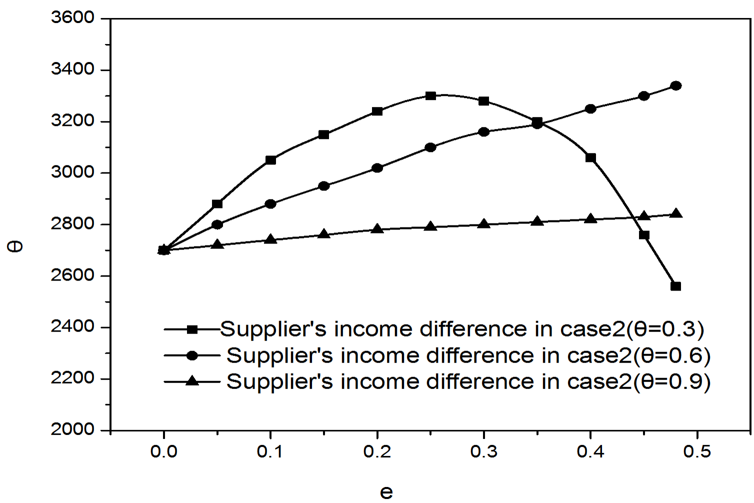

Fig. 2. Effect of different RFID recognition success rate on supplier's benefit in Case 2

It can be seen, based on the above numerical assumptions, that in case 2 retailers can benefit from the promise of the contract conditions being more limited, and in most cases, the supplier can get the expected revenue growth. Therefore, the promotion of RFID technology in the supply chain member enterprises only relies on the incentive contract of the retailer, cannot achieve the expected effect and the dominant side may be the first to abandon the implementation of RFID technology. This is why there is few successful cases that commitment contract or minimum order quantity contract is used by one side.

4.2. Situation 2

We will discuss the effect of the price discount coefficient on the income of the members of the supply chain when the supplier adopts the price discount mechanism in this part.

Case 3 shows that when the supplier uses the mechanism of price discounts, the more discount factor increases, the less retailer's profits increment is, and the less supplier's revenue decrement is. The trend of supplier's revenue decrement is more obvious. So this paper does not carry out numerical analysis for case 3. According to the above numerical simulation, in Case 4 it can be obtained that the supplier's optimal discount coefficient is $\tau* = 1.03 > 1$, which shows that the supplier's optimal decision is not to use the price discount mechanism.Figure 3 shows that the trend of supplier's expected revenue compared with the situation without contract in Case 4. Apparently, combination contract by both sides can increase the supplier's maximal expected revenue, but the changes of income is less than the numerical simulation results in Case 2. When the recognition success rate of RFID technology is maintained at a certain level, the amount of revenue increases with the increase of inventory losses, showing a trend of first increase and then decrease. At the same time, with RFID recognition success rate it continues to increase and income increased steadily, when $\theta = 0.9$ basically shows slowly increasing trend.

4.3. Situation 3

We will discuss the effect of the inventory loss rate and the RFID identification success rate on the retailer's parameter set when the supplier adopts the price discount mechanism.

Order $\tau* = 0.9$, the case 4 shows that, when the other factors are constant, the range of $\Re_1$ is larger than $\Re_2$ obviously, as shown in Fig. 4. It means that adopting price discount mechanism by suppliers can encourage the retailer to order in advance significantly. With the increasing of supplier price discounts, retailer are more willing to commitment contract and make more profit from the cooperation.

It can be seen that, based on the above numerical assumptions, that in Case 4 the value range that the retailer can benefit from the commitment contract significantly, increased. Moreover, in most cases, the supplier can get the growth of expected profit. Therefore, relying on the joint efforts of both sides he can significantly accelerate the implementation and promotion of the RFID technology in the supply

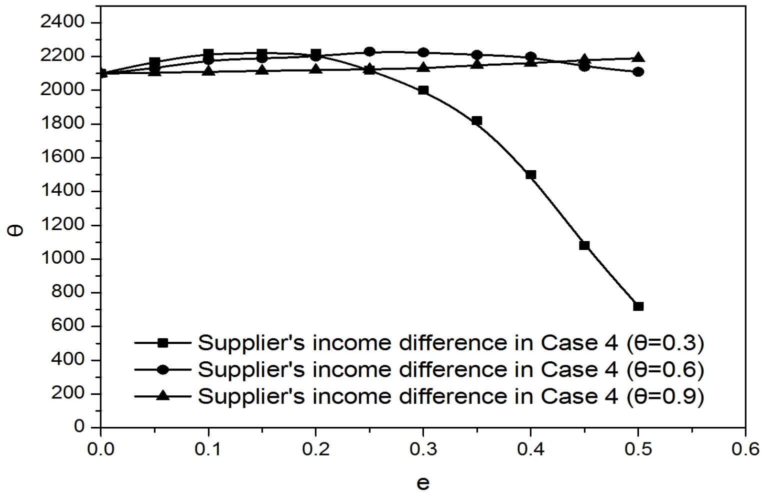

Fig. 3. Effect of different RFID recognition success rate on supplier's revenue in Case 4

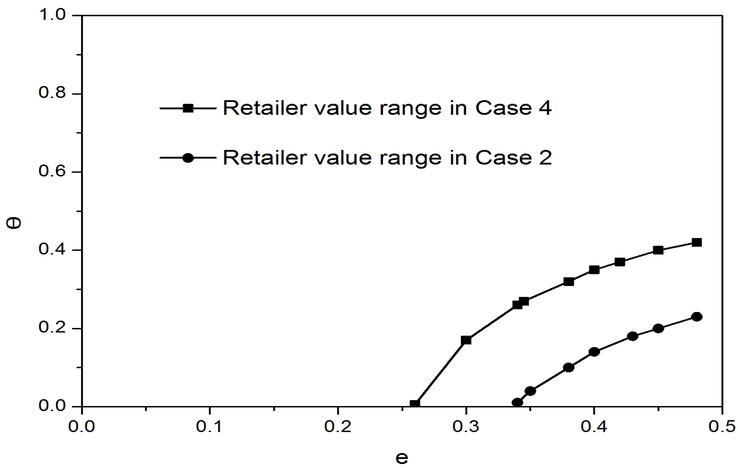

Fig. 4. The conditions for the retailer to adopt the promise contract in Case 4

chain system.

5. Conclusion

This paper studies the incentive mechanism of supply chain members to promote the RFID technology. First of all, retailers consider long-term cooperation to take the commitment to promote the implementation RFID technology of the upstream supplier. Second, the supplier uses the incentive mechanism of price discounts in the amount of retail's commitment in advance. The results of theoretical research and numerical analysis show that when the retailer's commitment is smaller, the maximum expected return of both parties is consistent with that of no contract (case 1 and case 3). When the amount of retail's commitment is large, adopting $\lambda_2^* = D(p + g_{\mathrm{R}} - \omega)/(p + g_{\mathrm{R}} + h - v)$ as the retail's advanced order quantity, and meeting the requirement of $\Re_1$ for all the parameters can realize Pareto improvement for both sides. As well as using $\lambda_4^* = D(p + g_{\mathrm{R}} - \tau\omega)/(p + g_{\mathrm{R}} + h - v)$ as the retail's advanced order quantity, and $\tau*$ $(0 < \tau* < 1)$ as the supplier's optimal discount coefficient, and meeting the requirement of $\Re_2$ for all the parameters can realize Pareto improvement for both sides.

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