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# ANALYSIS ON THE STACKELBERG GAME MODEL AND RISK SHARING BASED ON BUYBACK CONTRACT

**JINGMIN WEI, JIAFU TANG**

School of Information Science & Engineering, Northeastern University, Shenyang 110004, Liaoning, China.

**ABSTRACT**

This paper deals with the Stackelberg game model based on the buyback contract predominated by the supplier, and the equilibrium solutions to the model are available when wholesale price and maximum buyback rate are determined by the supplier and the order quantity is determined by the retailer with respect to the stochastic market demand. Coordination of different supply chains and risks shared by supply & demand parties are analyzed. The supply and demand parties share different risks because of their different leading statuses and maximum buyback proportion offered by the supplier to the retailer. When the supplier is in the leading role, he can determine the proportion or relation of risks shared by supply and demand parties. As a constraint condition, the proportion or relation the risk is of guiding significance for determination of maximum buyback proportion.

**Keywords:** *Supply Chain, Buyback Contract, Risk, Stackelberg Game*

## 1. INTRODUCTION

The supply chain is a complex and dynamical system, and its management has become a hot issue of research in the academic circles. As all members are individuals in supply chain, the non-cooperative decision mode is more popular than the cooperative one. In non-cooperative decision mode, how to coordinate the supply chain has become an important issue in the study on supply chain. In the chain, every node is the supplier in next node, and is also the customer in the front node, so that their supply and demand relation is built by contract. Uncertain market demand will result in discordance of supply chain. So, how to improve the coordination of supply chain is an important point in this paper.

The types of supply chain contract mainly are: wholesale price contracts, buyback contracts, revenue sharing contracts, and quantity discount contracts. The coordination of supply-demand is one of the most important issues in supply chain [1]. For earlier overviews on supply chain coordination with contacts, see [2]. The effective supply chain contracts change traditional locally-optimizing strategy only for individuals into the globally-optimizing one for the maximization of overall interest in the supply chain. Studies on supply chain contracts at home and abroad are summed up and its classification and models are analyzed [3]. The analysis of contract models on coordination in supply chain based on several typical contractual models is involved [4]. Literature [5] offers the newsvendor for co-decision of suppliers and retailers, and defines the concept of buyback. Literature [6] studies coordination of supply and demand chain in order quantity and retail price of decisions made by the retailers at the same time, that is, rationally applying the buyback strategy can relieve the effect of double marginalization and improve coordination of supply and demand chain in specific conditions. Literatures 7 and 8 both deal with the suppliers' interest maximization by determining the buyback price in a leading role. [9] analyzes different risks to suppliers and retailers based on three types of buyback contracts. [10] analyzes coordination of supply chain and risk sharing of node enterprises in the coordination with the increase of their marginal cost.

Aiming at fewer studies on game strategies of supply and demand parties in current buyback contracts, this paper discusses the Stackelberg game predominated by the supplier based on their buyback contract. The supplier offers wholesale price and maximum buyback rate first, then the retailer determines order quantity. The coordination of supply chain is improved with a buyback offered by the supplier to the retailer. In addition, this paper simply analyzes different risks shared by supply and demand parties with both parties' different leading role and maximum buyback proportion offered by the supplier to the retailer. The supplier can offer proportion or relation of risks shared by both parties as their restrict condition. This is of

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guiding significance for evaluation of maximum buyback proportion.

## 2. FUNDAMENTAL NOTATION AND ASSUMPTION

The following notation and assumption are considered to develop the model.

Notation:

- $p$ Retail price per unit item of retailer
- $w$ Selling price per unit item of supplier
- $c$ Cost per unit item of supplier
- $b$ buyback price supplier to retailer
- $R$ buyback proportion, the largest proportion of order quantity to supplier by buyback Price($0 \le R \le 1$)
- $v$ The remaining products value of retailer
- $g_r$ shortage cost of retailer
- $g_s$ shortage cost of supplier
- $g = g_r + g_s$ shortage cost of the supply chain
- $Q'$ retailer's order quantity non-buyback contract
- $Q$ retailer's order quantity with buyback contract
- $\Pi_r'$ retailer's profit non-buyback contract
- $\Pi_r$ retailer's profit with buyback contract
- $\Pi_s'$ supplier's profit non-buyback contract
- $\Pi_s$ supplier's profit with buyback contract
- $\Pi'$ supply chain's profit non-buyback contract
- $\Pi$ supply chain's profit with buyback contract

Assumption:

(1)Consider a supply chain of a product which consists of a single supplier and single buyer.

(2)The demand is assumed to be stochastic, the density function $f(x)$, distribution function $F(x)$, $x \ge 0, f(x) \ge 0$, $R \ne 0$, is continuous, differentiable, increasing and $F(0)=0$, Let $E(X)=\mu$.

(3)Each firm is risk neutral.

(4)The retail price of retailer and buyback price of supplier are constant.

(5)The supplier earns zero per unit buyback product at the end of season.

(6)Supply and demand sides have complete information, which the two sides' profit functions are the common knowledge.

(7) $v < b \le w < p, v < c < w < p$.

## 3. MODEL AND ANALYSIS

### 3.1 Supply and Demand Model without Buyback Contract

In traditional enterprise relation, the members in supply chain can make their own decisions according to their self-interests. In the random demand, the retailer makes the decision of order batch based on his own forecasts to market demands, while the supplier also offers wholesale price according to his self-interest maximization. In this decisions made independently respectively, the supply chain can not be optimized and coordinated so that it is less competitive.

The retailer's profit function is

$$\Pi_r' = \begin{cases} px - wQ' + v(Q' - x) & 0 \le x \le Q', \\ (p-w)Q' - g_r(x - Q') & x > Q'. \end{cases}$$

The supplier's profit function is

$$\Pi_s' = \begin{cases} (w-c)Q' & 0 \le x \le Q', \\ (w-c)Q' - g_s(x - Q') & x > Q'. \end{cases}$$

The retailer's expected profit function is

$$E\Pi_r' = \int_0^{Q'} [px + v(Q'-x)] f(x)dx + \int_{Q'}^{+\infty} \left[ pQ' - (x-Q')g_r \right] f(x)dx - wQ' \quad (1)$$

$$= (p + g_r - w)Q' - g_r\mu - (p + g_r - v)\int_0^{Q'} F(x)dx$$

The supplier's expected profit function is

$$E\Pi_s' = (w-c)Q' - g_s \int_Q^{+\infty} (x - Q') f(x)dx \quad (2)$$

$$= (w - c + g_s)Q' - g_s\mu - g_s \int_0^{Q'} F(x)dx$$

The retailer's order quantity model is

$$\max E\Pi_r' = (p + g_r - w)Q' - g_r\mu - (p + g_r - v)\int_0^{Q'} F(x)dx$$

Because of

$$\frac{dE\Pi_r'}{dQ'} = p + g_r - w - (p + g_r - v)F(Q')$$

$$\frac{d^2E\Pi_r'}{dQ'^2} = -(p + g_r - v) f(Q') \le 0$$

So $E\Pi_r'$ has maximum value.

When $\frac{dE\Pi_r'}{dQ'} = 0$, then $F(Q_r') = \frac{p + g_r - w}{p + g_r - v}$.

The maximum order quantity of profit wished by the retailer can be got.

$$Q_r'^* = F^{-1}\left(\frac{p + g_r - w}{p + g_r - v}\right) \quad (3)$$

The supplier's wholesale price can be solved by substituting Expression (3) to Expression (2), and then the profit wished by supply and demand parties can be got.

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### 3.2 Stackelberg Game Model in Buyback Contract

The order quantity in Expression (3) is not optimal for the retailer, supplier and the supply chain. In order to earn more profits, the supplier hopes the retailer can increase order quantity. Success to increase of order quantity means more profits for the supplier and the supply chain. However, the retailer is subjected to loss of inventory backlog. As a result, the retailer may earn less profit, and he doesn't increase order quantity. In order to inspire the retailer to increase order quantity, the supplier promises to buy back the rest part or all products by a certain price and proportion during product sales to bear parts of risks, so that he wants to increase the profit of the supply chain. The supplier offers the retailer a wholesale price and maximum buyback proportion, while the retailer determines order quantity. However, if the supplier increases wholesale price to reduce the loss in buyback by his own interests, then the retailer may earn less profit compared with non-buyback. For this reason, the retailer doesn't participate in the supply chain. In this situation, the supplier can promise to offer the retailer buyback in the premise of changeless wholesale price in order to inspire the retailer to participate in the supply chain. Because the supplier takes action first, then the retailer puts into practice after the supplier's action. Moreover, both the retailer and supplier should take into account not only their own strategy but also their opposite party when taking action. Thus, this is an issue on dynamic Stackelberg games.

The retailer's profit function is

$$\Pi_r = \begin{cases} px - wQ + RQb + v(Q - x - RQ) & 0 \le x \le Q - QR, \\ px - wQ + (Q - x)b & Q - QR \le x \le Q, \\ (p - w)Q - g_r(x - Q) & x > Q. \end{cases}$$

The supplier's profit function is

$$\Pi_s = \begin{cases} (w - c)Q - RQb & 0 \le x \le Q - QR, \\ (w - c)Q - (Q - x)b & Q - QR \le x \le Q, \\ (w - c)Q - g_s(x - Q) & x > Q. \end{cases}$$

The retailer's expected profit function is

$$E\Pi_r = \int_0^{Q-QR}[px+RQb+v(Q-x-RQ)]f(x)dx + \int_{Q-QR}^{Q}[px+(Q-x)b]f(x)dx \quad (4)$$
$$+\int_Q^{+\infty}[pQ-(x-Q)g_r]f(x)dx - wQ$$
$$=(p-w)Q-g_r(\mu-Q)-(p+g_r-b)\int_0^Q F(x)dx-(b-v)\int_0^{Q-QR}F(x)dx$$

The supplier's expected profit function is

$$E\Pi_s=(w-c)Q-\int_0^{Q-QR}RQbf(x)dx-\int_{Q-QR}^{Q}(Q-x)bf(x)dx-g_s\int_Q^{+\infty}(x-Q)f(x)dx$$
$$=(w-c)Q-g_s(\mu-Q)-(g_s+b)\int_0^Q F(x)dx+b\int_0^{Q-QR}F(x)dx \quad (5)$$

As to the supply chain predominated by the supplier, its Stackelberg game model in buyback contract is:

First floor：

$$\max E\Pi_s = (w-c+g_s)Q - g_s\mu - g_s\int_0^Q F(x)dx - b\int_{Q-QR}^{Q} F(x)dx$$
$$s.t.\quad v < b \le w < p$$
$$v < c < w < p$$
$$0 \le R \le 1$$

Second floor：

$$\max E\Pi_r = (p-w+g_r)Q - g_r\mu - (p+g_r)\int_0^Q F(x)dx + b\int_{Q-QR}^{Q}F(x)dx$$
$$+v\int_0^{Q-QR}F(x)dx$$
$$s.t.\quad 0 \le Q$$

Two situations should be taken into account with solution of the model by the Backwards Induction: one is that the wholesale price is a decision variable, and the other one is that the wholesale price is a constant value. Another decision variable for the supplier is the maximum buyback proportion, and the retailer's decision variable is the order batch.

The wholesale price is a decision variable.

With respect to $w$ and $R$ given, the retailer's issue is

$$\max E\Pi_r = (p-w+g_r)Q - g_r\mu - (p+g_r)\int_0^Q F(x)dx + b\int_{Q-QR}^{Q}F(x)dx$$
$$+v\int_0^{Q-QR}F(x)dx$$

The optimizing issue in above expression is solved:

$$\frac{dE\Pi_r}{dQ} = p + g_r - w - (p + g_r - b)F(Q) - (b - v)(1 - R)F(Q - QR)$$

$$\frac{d^2 E\Pi_r}{dQ^2} = -(p + g_r - b) f(Q) - (b - v)(1 - R)^2 f(Q - QR) \le 0$$

So, $E\Pi_r$ has maximum value.

When $\frac{dE\Pi_r}{dQ} = 0$, i.e. Expression (6) is solved for unique solution $Q^*$.

$$p + g_r - w - (p + g_r - b)F(Q) - (b - v)(1 - R)F(Q - QR) = 0 \quad (6)$$

Through calculation and derivation for Expression (6), the relation between the retailer's optimal order quantity $Q^*$ and the wholesale price & buyback proportion satisfies

$$\frac{\partial Q^*}{\partial w} = \frac{-1}{(p+g_r-b)f(Q)+(b-v)(1-R)^2 f(Q-QR)} < 0$$

$$\frac{\partial Q^*}{\partial R} = \frac{bF(Q-QR)+Qb(1-R)f(Q-QR)}{(p+g_r-b)f(Q)+(b-v)(1-R)^2 f(Q-QR)} \ge 0$$

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$\frac{\partial Q^*}{\partial w} < 0$, the retailer's order quantity reduces with the increase of the supplier's wholesale price. $\frac{\partial Q^*}{\partial R} \geq 0$, the supplier bears more risks with increase of buyback proportion, and the retailer can increase order quantity.

If the wholesale price is a constant value, the solution is similar to above said case, and more simple.

**Proposition1.** When the wholesale price is a constant in buyback contract, i.e. $R \neq 0$, then $E\Pi_r^* > E\Pi_r^{'*}$.

**Proof**. Because $\frac{dE\Pi_r}{dR} = (b-v)QF(Q-QR)$, where $b > v$, and *F(x)* is continuous, derivable and strictly increasing, then $\frac{dE\Pi_r}{dR} \geq 0$, that is, $E\Pi_r$ is an increasing function of $R$. Additionally, $R \in [0,1]$, so $R = 0$ is the minimum point of profit. Thus, $E\Pi_r^*(R \neq 0) > E\Pi_r^*(R = 0) = E\Pi_r^{'*}$. The proof is done.

Proposition 1 also verifies that in the premise of changeless wholesale price, the profit of the retailer in the buyback contract is larger than the profit in non-buyback contract.

As both parties' information is symmetrical, the supplier forecasts that the retailer determines the order quantity ($Q$) based on Expression (6); the supplier considers the wholesale price and maximum buyback proportion offered by the retailer should be the expected profit maximization. Thus, the supplier should deal with the following issues in the game predominated by them:

$$\max E\Pi_s = (w-c+g_s)Q - g_s\mu - g_s\int_0^Q F(x)dx - b\int_{Q-QR}^Q F(x)dx$$

$$\begin{aligned} s.t.\quad & p+g_r-w-(p+g_r-b)F(Q)-(b-v)(1-R)F(Q-QR)=0 \\ & v<b\leq w<p \\ & v<c<w<p \\ & 0\leq R\leq 1 \end{aligned} \tag{7}$$

It is seen from the target function in Expression (7) that the bigger the whole price $w$ is, the more the supplier's profit is. As the decision condition, can get $w=p+g_r-(p+g_r-b)F(Q)-(b-v)(1-R)F(Q-QR)$, and when $R^*=1$, $w$ is taken as maximum value $w^*=p+g_r-(p+g_r-b)F(Q)$. So, it is concluded that in the buyback contract predominated by the supplier, the optimal value is taken when the supplier promises the retailer by a certain buyback price to buy back the surplus commodities in 100% order quantity in the end of sales.

Finally, the Nash equilibrium solution of supply chain predominated by the supplier is ($Q^*$, $w^*$, $R^*$).

**Proposition2.** In the buyback contract, i.e. $R \neq 0$, then, $E\Pi_s^* \geq E\Pi_s^{'*}$. That is to say, the supplier's profit is not lost because he supplies buyback to the retailer.

**Proof**. Because the feasible solution of the model is not greater than optimal solution in any maximizing planning issues, where $R$=0, is the feasible solution of $E\Pi_s$, so

$$\max E\Pi_s(R\neq 0) \geq E\Pi_s(R=0).$$

And because

$E\Pi_s(R=0) = (w-c+g_s)Q - g_s\mu - g_s\int_0^Q F(Q)dx = E\Pi_s^{'}$,

so $E\Pi_s^* \geq E\Pi_s^{'*}$, The proof is completed.

The expected profit of the supply chain in buyback is

$$E\Pi = E\Pi_r + E\Pi_s = (p-c)Q - \int_Q^{+\infty}(x-Q)gf(x)dx + v\int_0^{Q-QR}(Q-x-QR)f(x)dx \tag{8}$$

In the buyback contract, supply and demand parties' total expected profit is the sum of their profits when they make decisions separately, i.e. $E\Pi^* = E\Pi_r^* + E\Pi_s^*$. It is known from Propositions (1) and (2) that $E\Pi^* > E\Pi^{'*}$, that is, the expected profit of the supply chain in buyback contract is greater than that of non-buyback contract. The supply chain is improved in coordination with a buyback offered by the supplier to the retailer.

### 3.3 Cooperative Games in the Buyback Condition

The cooperative game emphasizes the reasonable and optimal decision of an organization. In the cooperative game theory, how to establish the cooperation for reasonable individuals is omitted, while the result and profit distribution are discussed directly.

In the cooperation, total expected profit of the supply chain can be got from Expression 8. So, it is got that:

$$\begin{aligned} E\Pi &= E\Pi_r + E\Pi_s = (p-c)Q - \int_Q^{+\infty}(x-Q)gf(x)dx + v\int_0^{Q-QR}(Q-x-QR)f(x)dx \\ &= (p-c)Q - (p+g)\int_0^Q F(x)dx - g(\mu - Q) + v\int_0^{Q-QR}F(x)dx \end{aligned} \tag{9}$$

As a whole, the supplier and retailer can make decision from profit maximization in the whole supply chain.

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$$\frac{\partial E\Pi}{\partial Q} = p + g - c - (p+g)F(Q) + v(1-R)F(Q-QR) = 0$$

$$\frac{\partial E\Pi}{\partial R} = -vQF(Q-QR) = 0$$

So, the systematical optimal solution is

$$(F^{-1}(\frac{p+g-c}{p+g}),1).$$

As a whole, order quantity in supply chain is optimal, but it involves how to distribute the profit earned by both the supplier and retailer in cooperation. This will be explored in other papers.

## 4. RISK ANALYSIS

According to Expression (4), (5) and (8), the uncertain market demands result in expected risk loss of the supply chain and supply & demand parties. One part of loss is the stockout risk loss caused by random demands, the other part is the risk loss caused by buyback. The expected risk loss for the supply chain is

$$r = g(\mu - Q) + (p+g)\int_0^Q F(x)dx - v\int_0^{Q-QR} F(x)dx,$$

Where, the risk loss borne by the retailer is

$$r_r = g_r(\mu - Q) + (p + g_r - b)\int_0^Q F(x)dx + (b-v)\int_0^{Q-QR} F(x)dx,$$

and the risk loss borne by the supplier is

$$r_s = g_s(\mu - Q) + (g_s + b)\int_0^Q F(x)dx - b\int_0^{Q-QR} F(x)dx.$$

In a certain total risk of the supply chain and stockout loss of the supply and demand parties, the risk loss borne by supply and demand parties is determined by the maximum buyback proportion offered by the supplier to the retailer.

$$\frac{dr_r}{dR} = -(b-v)QF(Q-QR) \le 0 \qquad (10)$$

$$\frac{dr_s}{dR} = (b-v)QF(Q-QR) \ge 0$$

(11)

According to Expression (10) and (11), the risk borne by the retailer decreases with maximum buyback proportion ( $R$ ) borne by the retailer, that is, the more the maximum buyback proportion is, the less the risk borne by the retailer. The risk borne by the supplier increases with maximum buyback proportion, that is, the more the maximum buyback proportion is, the more the risk borne by the supplier is.

Because of different maximum buyback proportion ( $R$ ) offered by the supplier to the retailer in a leading role, the risks shared by supply and demand parties are different. When the supplier is in a lead role, he can offer proportion or relations between or borne by both parties. As a restriction condition by this, it decides the maximum buyback proportion ( $R$ ). In order to indicate the relation between risk and $R$, it is supposed that $g_r = g_s$, and $f(x)$ is distributed uniformly at $[0,n]$, then,

$$r_r = g_r(\frac{n}{2} - Q) + \frac{p + g_r - 2bR + bR^2 - v(1-R)^2}{2n}Q^2$$

$$r_s = g_s(\frac{n}{2} - Q) + \frac{g_s + 2bR - bR^2}{2n}$$

**Proposition3.** When the supplier offers the retailer buyback price and retail price meeting $b \ge \frac{p}{2}$, i.e. the buyback price for surplus products is not less than one half of the wholesale price, then, the risks borne by both supply and demand parties are the same, and the maximum buyback proportion is $1 - \sqrt{\frac{2b-p}{2b-v}}$.

**Proof**. If supply and demand parties are required to share the same risks, i.e. $r_r = r_s = \frac{1}{2}r$, then,

$$g_r(\frac{n}{2} - Q) + \frac{p + g_r - 2bR + bR^2 - v(1-R)^2}{2n}Q^2 = g_s(\frac{n}{2} - Q) + \frac{g_s + 2bR - bR^2}{2n}$$

it can easily be verified that $(1-R)^2 = \frac{2b-p}{2b-v}$. If it is true, then, $\frac{2b-p}{2b-v} \ge 0$. It is evident that buyback price and retail price should satisfy $b \ge \frac{p}{2}$, while the known condition has been given. That is, if the supplier wants to share the same risk with the retailer, he offers the retailer buyback price which is not less than a half of sale price. By this way, the retailer can share a half of risks. It is solved by above formula that the maximum buyback proportion $R = 1 - \sqrt{\frac{2b-p}{2b-v}}$ offered by the supplier to the retailer. The proof is done.

The proportional relation of risks taken by both parties is used to decide the maximum buyback proportion ( $R$ ) as a restriction condition.

## 5. NUMBERICAL EXAMPLE ANALYSIS

Take the following parameters for simulation on the foregoing circumstances.

$c = \$20$ per unit, $v = \$10$ per unit, $p = \$200$ per unit, $b = \$50$ per unit, $g_r = \$20$ per unit, $g_s = \$10$ per unit.

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The retailer estimates the market demand for some product complies with the uniform distribution, i.e.

$$f(x)=\begin{cases}\dfrac{1}{200} & x\in[0,200]\\ 0 & x\notin[0,200]\end{cases}$$

Based on above given model, the decision values and expected profit & loss are shown in Table 1 comparing non-buyback and buyback Stackelberg model and cooperative games.

It is shown in Table 1 that the retailer's order quantity increases when the supplier offers the retailer buyback ( $w$ is a decision variable). The supplier and supply chain's expected profit is higher than that of the non-buyback model, so the Stackelberg model with buyback is favorable to the supplier and supply chain. This improves coordination of supply chain. The decrease of the retailer's profit is because the supplier raises the wholesale price. In the changeless wholesale price offered by the supplier to the retailer, the expected profits for the retailer, supplier and supply chain are higher than of the non-buyback model. This proves Proposition 1 and 2. The maximum buyback proportion is 1, which is agreed with the optimal value in the 100% buyback proportion of the order quantity for the surplus commodities by a certain buyback price during sales for the supplier which we have analyzed previously. In the cooperative games, the order quantity is biggest, and profit is most for the supply chain, so that the supply chain is well coordinated.

In addition, it is seen from Table 1 that the uncertain market demands result in expected risk loss of the supply chain and supply & demand parties. The more the order quantity is, the more the risk loss borne by the supply chain is. When the supplier takes a part of risk by offering the retailer buyback contract, the proportion of the risk loss borne by the retailer decreases, so that the risk loss borne by the supplier increases accordingly. This is that the supplier offers the retailer interests in order to encourage the retailer to order more commodities.

*Table 1: Parameters Of Non-Buyback And Buyback Models*

| | Non-buyback model | Buyback model ( $w$ is decision variable) | Buyback model ( $w$ is constant) | Cooperative game model |
|---|---|---|---|---|
| $Q$ | 97.67 | 105 | 120.66 | 182.61 |
| $w$ | 117.44 | 130.75 | 117.44 | — |
| $R$ | — | 1 | 1 | 1 |
| $E\Pi_r / r_r$ | 3008.6 /5055.04 | 2685.6 /4585.65 | 4187.4 /5774.19 | — |
| $E\Pi_s / r_s$ | 9255.8 /261.16 | 10025 /1603.75 | 9779.8 /1977.19 | — |
| $E\Pi / r$ | 12264.4 /5316.2 | 12710.6 /6189.4 | 13967 /7751.38 | 16173.91 /16695.89 |

## 6. CONCLUSION

Non-buyback, buyback and cooperative game models have been established and the Nash equilibrium solutions for the models are obtained in this paper on the background of two-stage supply chain. The coordination of supply chain with buyback and cooperative models is improved. In the buyback contract of the supplier as the leading roles, the optimal value can be made when the supplier promises the retailer by a certain buyback price to buy back the surplus commodities by 100% order quantity. Finally, the relation between risk loss and maximum buyback proportion is discussed simply. The relation can be regarded as a restriction condition to determine the maximum buyback proportion. The issue on profit distribution of supply and demand parties in the cooperative games is not the focus in this paper, and will be discussed in other papers.

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