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MODELLING RISK COORDINATION OF SUPPLY CHAINS WITH PUT OPTION CONTRACTS AND SELECTIVE RETURN POLICIES

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Abstract
To study risk coordination of supply chains, a two-echelon supply chain with one risk-neutral supplier and one risk-averse retailer is constructed, in which the retailer behaves with waste aversion. The retailer's conservative attitude to order results in poor performance of the supplier and the whole supply chain. A new contract which combines put options and selective return policies is developed. The retailer buys option contracts when he places an order, then decides to exercise part or all of them after the sales season so that he can choose the return quantity selectively. The exercise price is equivalent to the wholesale price of merchandise. The result demonstrates that this contract can coordinate the supply chain well and be carried out normally despite the retailer's risk preference being private because the supplier's pricing policy is independent of retailer's risk aversion. The numerical analysis shows that the retailer's expected utility outperforms that of the expected utility under the classical buyback contract.
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Key Words: Risk-Averse, Put Option, Selective Buyback Contract, Supply Chain Coordination

1. INTRODUCTION

Perishable products have short demand lives, demand uncertainty, low salvage value after sales season (e.g., fashionable dresses, magazines, and newspapers). More and more products are viewed as perishable because of the rapid update rate of technology and consumer's demand for products such as mobile phones, laptops, and digital cameras. The loss caused by overstock is greater than that caused by stockout for retailers who sell perishable products. Excess inventory devalues rapidly, occupies capital and warehouse space which in turn influences the ordering of next cycle. Conversely, stockout may have a good effect on marketing to some extent. For example, the hunger marketing that Apple and Mi-corporation take, attract more fans for them. So the retailers are usually sensitive to overstock and show a preference for waste aversion.

The waste-aversion retailers are conservative in order quantity, and different retailers exhibit different sensitivities to the risk of overstock because of the diversity in their financial strength, marketing levels, and handling capacity to overstock. The more sensitive the retailer is to the risk of overstock, the more conservative he is in order quantity. Such a phenomenon leads to the order quantity being less than the actual demand, which damages the profits of the supplier and the whole supply chain.

In order to solve this problem, we developed a contract which combined put option contracts and selective return policies to help the supplier coordinate the order decisions of a waste-averse retailer. Through such a selective buyback contract, the retailer can purchase option contracts when he places an order and decide to exercise them whether or not it is the end of sales season. This means the retailer can return the excess product to the supplier at the exercise price, which is equivalent to the wholesale price. The supplier can also get risk compensation from the sales of option contracts. We demonstrate that this contract can coordinate the waste-aversion retailer's order decision, and the supplier's pricing policy is independent of the retailer's risk aversion.

The selective buyback contract is different to the partial buyback contract [1] and the option contracts [2] in the sense that the retailer but not the supplier decides the return quantity and the time to adjust return quantity after, instead of before sales season. In this way, it makes up for the potential overstocking problem caused by the inflexible partial buyback contract and the retailer's inaccurate forecasting in option contracts. The supplier transfers more selective rights to the retailer so that the retailer can make decisions depending on his risk aversion. At the same time, the supplier can indirectly obtain the information regarding the retailer's risk preference.

This paper is structured into five sections. The next section, Section 2 reviews the relevant literature. In Section 3 the background of the model is described and assumed, and the meanings of the related parameters are explained. Section 4 constructs, solves and analyses a selective buyback contracts model with put option and return policies whilst considering the retailer's risk aversion. Section 5 analyses the impacts of the waste aversion coefficient on the purchase quantity of put option contracts, optimal order quantity and retailer's expected utility through a numerical study. The selective buyback contracts are also compared with classical buyback contracts and the base model without any incentive in this section. The last section concludes and discusses the preceding sections and studies.

2. LITERATURE REVIEW

Many researchers carry out their studies on the coordination of risks in perishable commodities supply chains. They mainly utilize the methods of supply chain contracts (for example, buyback contracts and option contracts) and production operations (for example, postponement manufacturing) to tackle this problem. We will review the literatures about risk aversion, buyback contracts, and option contracts as follows.

There are two ways to transfer the retailer's risk of loss due to overstock to the supplier, one is return policy and the other is markdown money [3]. Some suppliers prefer to choose return policy in order to safeguard brand equity [4], which is widely applied in computer and garment industries. Return policy may improve the performance of supply chain through encouraging retailers to carry larger stocks. Numerous literatures also study the supply chain coordination with return policies [5-7]. The effects of coordinating by supply chain contracts are different under different conditions, such as demand dependent on sales effort [8], multi-retailer [9, 10], multi-channel [11], etc.

Recently, more researchers have been focusing on the member's risk aversion in supply chains. There are three kinds of risk preferences which are risk neutral, risk seeking and risk aversion. The decision maker's objective is to maximize expected utility instead of expected profit when the members' risk preferences are considered [12]. Schweitzer and Cachon studied the decision maker's ordering in the newsvendor problem. With two experiments, they demonstrated that the newsvendor's decisions were not consistent in six conditions, which were: risk-aversion preference, risk-seeking preference, prospect theory preference, waste aversion, stockout aversion, or the consequences of underestimating opportunity costs [13]. When choosing potential channel partners, a firm needs to consider their relative risk attitudes. For instance, a weak retailer should seek manufacturers who are more sensitive to risk, if they offer return privileges [14]. Yoo identified the relationship between return policy and product quality decisions in a decentralized supply chain [15]. He considered the supplier's different risk attitudes, risk aversion and risk neutral, and demonstrated that the enhancement of product quality needs to precede a generous return policy in the current business environment and supply chain management practices [15]. Sun et al. investigated the closed-loop supply chain (CLSC) network equilibrium with consideration of three practical factors: two complementary types of suppliers; the risk-averse character of the manufacturer; and capacity constraints of the suppliers [16]. They found that with the increase of return rate, the profits of various channel members and the performance of the CLSC system will improve [16].

The significance of improving flexibility of a contract is popular in reducing the risk within the supply chain. Eppen and Iyer demonstrated that an enterprises' expected profit may increase by a backup agreement to improve the upstream flexibility [17]. The common flexible contract is a quantity flexibility (QF) contact [18]. Many researchers extended the study to QF under different conditions [19, 20], and some of them studied the risk management of the supply chain with financial instruments, such as insurance contracts and option contracts. Lin et al. demonstrated that insurance contracts are effective in achieving coordination of the supply chain [21], but the suppliers may incur an administrative cost in monitoring the retailer's sales situation. Dong and Tomlin studied risk management with business interruption insurance, they proved that insurance is never a substitute for operational measures and that insurance may lead to higher inventory investment and/or a larger benefit from emergency sourcing [22].

Cheng et al. found that, compared with non-flexible contracts, the share of profit improvement between members in the supply chain may achieve channel coordination when they studied the supply chain coordination with option contracts [23]. Liang et al. introduced the option contract mechanism into relief material supply chain management and demonstrated that with two delivery steps, there is a feasible price range of option contract which can optimize the availability of relief material of both members in the supply chain and make members willing to conduct the transaction with option contracts [24]. Zhao et al. developed a supply contract with the bidirectional option for a manufacturer-retailer supply chain and examined the feedback effects of the bidirectional option on the retailer's initial order strategy [25]. They found that in addition to the cost parameters of the contract, the convexity and concavity of the demand cumulative distribution function can be a critical determinant of the retailer's decisions [25].

From the literature review above we can determine that, with classical buyback contracts, the ratio of return quantity of the excess inventory is decided by the supplier after sales season [5] and that there is a lack of buyback contracts with which the retailer can decide the return quantity by himself according to his risk preferences. The retailer can decide the return quantity independently with put option contracts [23], while what he adjusts is in fact the order quantity but not excess inventory because such returns happen mainly before the sales season. Therefore the put option contracts can merely prevent the risk of excess inventory and not alleviate the risk when it has occurred. So far no literature has been found using the put option contract to improve the flexibility of return policies after the sales season. The selective buyback contract introduced in this paper, combining the put option with selective return policies, will be the first one which applies put option contracts to coordinate the risk of overstock after sales season.

3. ASSUMPTIONS AND NOTATIONS

We considered a supply chain involving a risk-neutral supplier and a risk-averse retailer. In a single-period sales season, the supplier produces units of product at a cost c. Before the sales season, the retailer places an order with quantity Q, and pays the supplier a wholesale price w. Concurrently, the retailer purchases put option contracts with quantity q at price r per contract. Each put option contract gives the retailer the right to return a surplus product to the supplier after the sales season at the exercise price w which is equivalent to the wholesale price. We assumed that the retail price P is exogenous and the salvage value of unsold product is s, the market demand D is a random variable with density $f(\cdot)$ and distribution $F(\cdot)$. The parameters used in this paper and their meanings are shown in Table I.

Table I: Parameters and meanings.

Parameter	Meaning	Parameter	Meaning
P	Retail price	w	Wholesale price
c	Production cost	s	Salvage value
b	Buyback price	r	Price of unit put option contract
λ	Waste aversion coefficient	Q	Quantity of merchandise ordered by retailer
q	Quantity of put option contracts	D	Market demand
$f(\cdot)$	Density function of demand	$F(\cdot)$	Distribution function of demand
Π	Expected profit	U	Expected utility
R	The retailer	V	The supplier

The parameters above conform to the constraint, $s \le c \le w \le P$.

We used λ to represent the retailer's degree of risk aversion caused by excess inventory, just like the loss aversion coefficient introduced by Schweitzer and Cachon to measure the retailer's degree of stockout risk aversion [10]. We assumed that $\lambda \ge 0$. The retailer is risk-neutral when $\lambda = 0$. The retailer makes decisions by maximizing his expected utility instead of his expected profit since he is risk averse.

We assumed that the retailer's expected loss due to overstock is T, if his risk preference is not considered. Then the expected utility of loss due to overstock is $(1+\lambda)T$, when considering the retailer's risk aversion and λT is the psychological waste due to psychology of waste. Here, the specific expression of T is influenced by a supplier's incentives. For example, $T = (w-s)E(Q-D)^+$, if the supplier does not take any incentive, and $T = (w-b)E(Q-D)^+$, if the supplier employs the classical buyback contract.

4. MODEL

4.1 The base model

First the base model where there is no incentive in the supply chain was considered. The risk-averse retailer purchases product from the risk-neutral supplier before the sales season, and retains the salvage value of unsold product after sales season. In this case, the loss caused by overstock due to retailer's risk aversion is $\lambda T_0 = \lambda(w-s)E(Q-D)^+$.

The retailer's expected utility is:

$$U_R^0(Q) = E_R^0(Q) - \lambda T_0 = PE(Q \wedge D) + sE(Q-D)^+ - wQ - \lambda(w-s)E(Q-D)^+ \tag{1}$$

The optimal order quantity Q_0, under decentralized decision making without incentive can be gotten from eq. (1):

$$Q_0 = F^{-1}\left(\frac{P-c}{P-s+\lambda(w-s)}\right) \tag{2}$$

4.2 The integrated supply chain

Suppose the retailer and the supplier forms an entity, where the leader of the supply chain makes decisions dependent on the optimization of the system. In this case the expected utility of the overall supply chain is:

$$\Pi_{SC}(Q) = PE(Q \wedge D) + sE(Q-D)^+ - cQ \tag{3}$$

In the integrated supply chain the optimal order quantity of merchandise Q_{SC}, can be obtained from eq. (3):

$$Q_{SC} = F^{-1}\left(\frac{P-c}{P-s}\right) \tag{4}$$

Comparing eq. (2) with eq. (4), we can deduce:

$$\frac{P-c}{P-s+\lambda(w-s)} \leq \frac{P-c}{P-s}$$

$F(\cdot)$ is a monotone increasing function and its inverse function $F^{-1}(\cdot)$ has the same monotonicity. Therefore, $Q_{SC} \leq Q_0$, in which $Q_{SC} = Q_0$ when $\lambda = 0$. That is, when the retailer's risk aversion is considered, retailer's order quantity in a decentralized decision making supply chain without incentive is always less than the optimal order quantity in a centralized decision making supply chain. Moreover, the stronger the retailer's degree of risk aversion, the less he orders in a decentralized decision making supply chain. Hence the supplier needs to consider taking some incentive measures to encourage the retailer to order more products in order to make the supply chain achieve optimization.

4.3 The selective buyback contract with put options

Under the selective buyback contracts with put options and selective return policies, the retailer purchases merchandise from the supplier at the price w. Meanwhile he can also purchase put option contracts at the price r. If the retailer has excess inventory after the sales season, he can return part or all of his surplus product which is equal to or less than the quantity of the option contracts he purchases, to the supplier at the exercise price w. The selective buyback contract with put options is shown in Fig. 1.

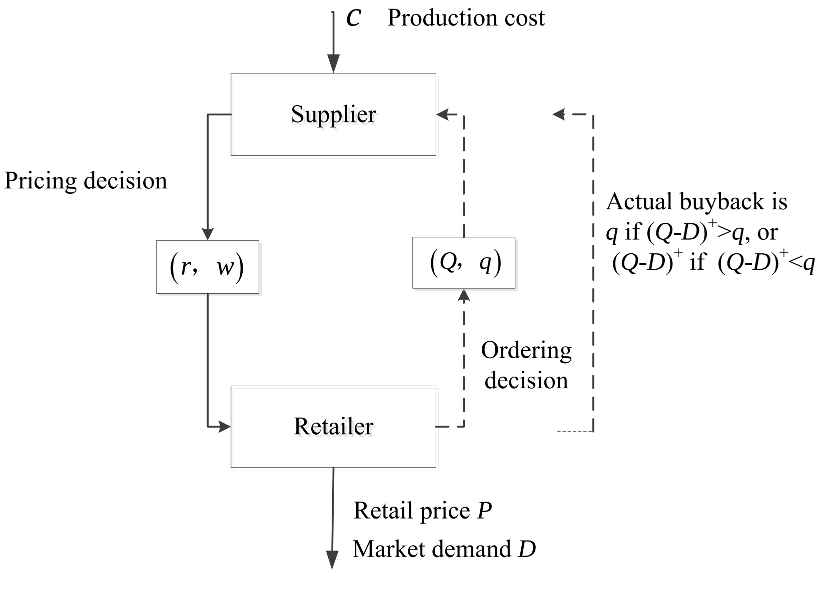

Figure 1: Schematic diagram of flexibility return policies.

Due to part of excess inventory being bought back at the wholesale price under the selective buyback contract, there is no loss of risk on this part of inventory. While the other part of the excess inventory which is not bought back has only salvage value. Therefore, the loss caused by overstock due to retailer's risk aversion is $\lambda T_1 = \lambda(w-s)E(Q-q-D)^+$.

The retailer's utility function under such circumstances is shown by eq. (5):

$$\begin{aligned} U_R^1(Q) &= E_R^1(Q) - \lambda T_1 \\ &= PE(Q\wedge D) + wE[(Q-D)^+ \wedge q] + sE(Q-q-D)^+ - wQ - rq \\ &\quad - \lambda(w-s)E(Q-q-D)^+ \end{aligned} \tag{5}$$

With the selective buyback contract, the retailer decides the order quantity Q and the quantity of put option contracts q to maximize his expected utility. Taking partial derivatives on the objective function in eq. (5) with respect to Q and q, and setting them to zero, following equations can be gotten:

$$\frac{\partial U_R^1(Q,q)}{\partial Q} = (P-w) - (P-w)F(Q) - (1+\lambda)(w-s)F(Q-q) = 0$$

$$\frac{\partial U_R^1(Q,q)}{\partial q} = -r + (1+\lambda)(w-s)F(Q-q) = 0$$

As shown in eqs. (6) and (7), the retailer's optimal order quantity and quantity of put option contracts are achieved by solving the two equations above:

$$Q_1 = F^{-1}\left(\frac{P-w-r}{P-w}\right) \tag{6}$$

$$q = Q_1 - F^{-1}\left(\frac{r}{(1+\lambda)(w-s)}\right) \tag{7}$$

Because the put option contracts chosen by the retailer cannot be more than the order quantity, eq. (7) needs to meet the following inequality:

$$\frac{P-w-r}{P-w} \geq \frac{r}{(1+\lambda)(w-s)}$$

Then we can get eq. (8):

$$r \leq \frac{(1+\lambda)(P-w)(w-s)}{(P-w)+(1+\lambda)(w-s)} \tag{8}$$

Theorem 1: The retailer's optimal order decision (Q,q) with the selective buyback contract has two characteristics.

(1) The retailer's optimal order quantity Q_1 is a decreasing function of the price of the put option contract r and wholesale price w.

(2) The optimal quantity of put option contracts, q is an increasing function of the waste aversion coefficient λ.

Proof: $\frac{P-w-r}{P-w}$ is a decreasing function of r due to:

$$\frac{\partial\left(\frac{P-w-r}{P-w}\right)}{\partial r} = -\frac{1}{P-w} < 0$$

$F(\cdot)$ is an increasing function and its inverse function $F^{-1}(\cdot)$ has the same monotonicity with $F(\cdot)$ so that the composite function $F^{-1}\left(\frac{P-w-r}{P-w}\right)$ is a decreasing function of r. Therefore, Q_1 is a decreasing function of r. In the same way it can also be proven that Q_1 is a decreasing function of w and that q is an increasing function of λ.

The supplier sets appropriate (w,r) to match the retailer's optimal order quantity under the selective buyback contract to that of the centralized decision making supply chain. Thus the parameters of the selective buyback contract (w,r) are the optimal pricing decisions of the supplier. Let eq. (6) equal eq. (2), the supplier's pricing decision which optimizes the whole supply chain under the coordination of the selective buyback contract can be achieved:

$$r = \frac{(P-w)(c-s)}{(P-s)} \tag{9}$$

Theorem 2: The supplier's optimal decision making (w,r) has the following characteristics.

(1) The supplier's pricing decision is irrelevant to the retailer's waste aversion coefficient.

(2) The unit price of put option contract r is a monotone decreasing function of the wholesale price w.

Proof: We can deduce through eq. (9) that there is no parameter related to the retailer's waste aversion coefficient in the supplier's function of pricing decision. So the supplier does not need to consider the retailer's risk aversion when making pricing decisions.

$\frac{\partial r}{\partial w} = -\frac{c-s}{P-s} < 0$, because of $c - s > 0$ and $P - s > 0$. That is, r is a monotone decreasing function of w.

Theorem 3: Compared with the contract without any incentive, the selective buyback contract can improve the retailer's expected utility. Therefore, the retailer would like to accept this contract.

Proof: With any order quantity, subtract the retailer's expected utility without any incentive from that under the selective buyback contract as follows.

$$U_R^1(Q,q) - U_R^0(Q) = (1+\lambda)(w-s)\int_{Q-q}^{Q} F(x)dx - rq$$

Because $q = \int_{Q-q}^{Q} 1dx \geq \int_{Q-q}^{Q} F(x)dx$, the equation above will achieve the minimum when $F(x) = 1$:

$$min\{U_R^1(Q,q) - U_R^0(Q)\} = [(w-s-r) + \lambda(w-s)]q \quad (10)$$

$min\{U_R^1(Q,q) - U_R^0(Q)\} > 0$ can be found according to the constraint relationships between parameters. This means that if the retailer's risk aversion is considered, no matter the order quantity, the retailer's expected utility with the selective buyback contract will always exceed that of those without incentives.

5. NUMERICAL STUDIES

In this section, the impacts of the waste aversion coefficient λ on the supply chain performance are studied and the selective buyback contract is compared with the classical buyback contract. Assume that $P = 100$, $c = 30$, $w = 50$, $s = 10$, and the market demand follows a uniform distribution $U(50, 100)$.

With a classical buyback contract, the supplier gives a contract with wholesale price w and buyback price b to the retailer. The supplier repurchases all the excess inventory with buyback price b at the end of sales season and the supplier gets the unit salvage value s of the unsold product ($s \leq b \leq w$). In this case the loss caused by overstock due to retailer's risk aversion is $\lambda T_2 = \lambda(w-b)E(Q-D)^+$, and his expected utility is as follows:

$$U_R^2(Q) = E_R^2(Q) - \lambda T_2 = PE(Q \wedge D) + bE(Q-D)^+ - wQ - \lambda(w-b)E(Q-D)^+ \quad (11)$$

The retailer decides the order quantity according to eq. (11) based on maximizing his expected utility. The retailer's optimal order quantity Q_2 with classical buyback contract can be achieved using eq. (11):

$$Q_2 = F^{-1}\left(\frac{P-w}{P-b+\lambda(w-b)}\right) \quad (12)$$

5.1 Impact of the waste aversion coefficient λ on option contracts quantity q

In this subsection, the impact of the waste aversion coefficient λ on the quantity of option contracts q is analysed by increasing λ from 0 to 20.

As shown in Fig. 2, the retailer purchases more put option contracts with the increase of the waste aversion coefficient λ when demand follows a uniform distribution. The purchase quantity of put option contracts represents the retailer's degree of overstock risk aversion; therefore the supplier can obtain vital information about a retailer's risk preference indirectly according to the purchase quantity of put option contracts.

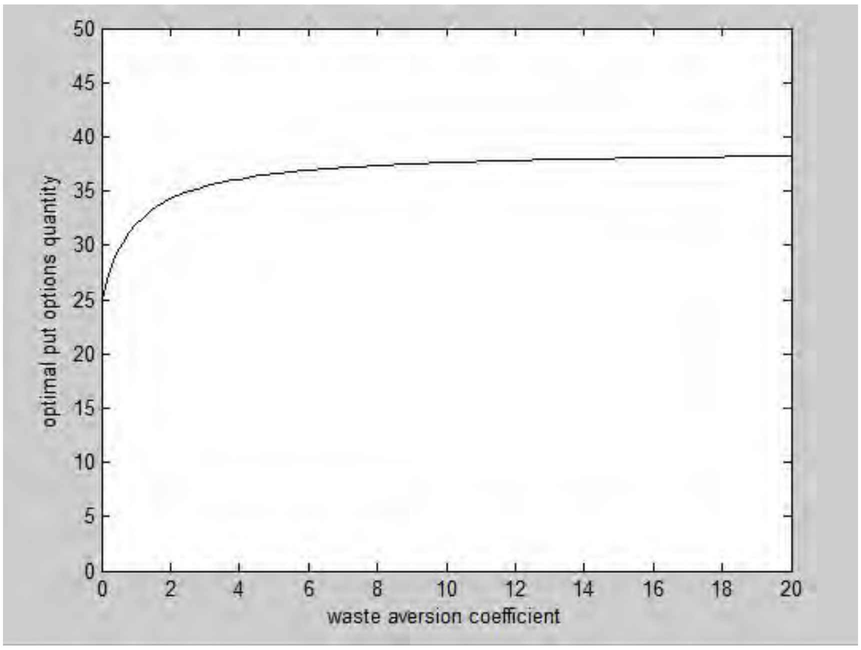

Figure 2: The impact of changing λ on the optimal quantity of put option contracts.

5.2 Impact of the whole price *w* on the price of units of put option contract *r*

The impact of the wholesale price *w* on the price of units of put option contract *r* under the coordination of the selective buyback contracts is shown in Fig. 3 by increasing *w* from 30 to 100.

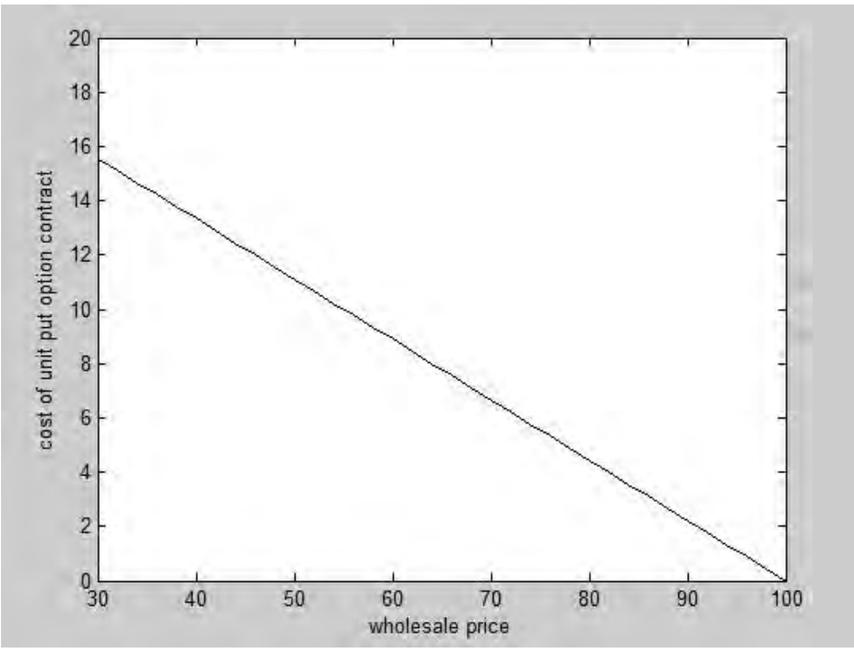

Figure 3: The impact of changing w on the member's expected profit.

Fig. 3 shows that with the increase of the wholesale price *w*, the optimal price of option contracts decreases gradually with the coordination of selective buyback contracts. The supplier has to increase the retailer's buyback compensation indirectly through lower priced option contracts when the wholesale price is high so that the negative effects caused by the increase of wholesale price can be offset.

5.3 Impact of the waste aversion coefficient λ on order quantity *Q*

In Fig. 4, by increasing λ from 0 to 20 the impact of the waste aversion coefficient λ on the order quantity *Q* can be seen.

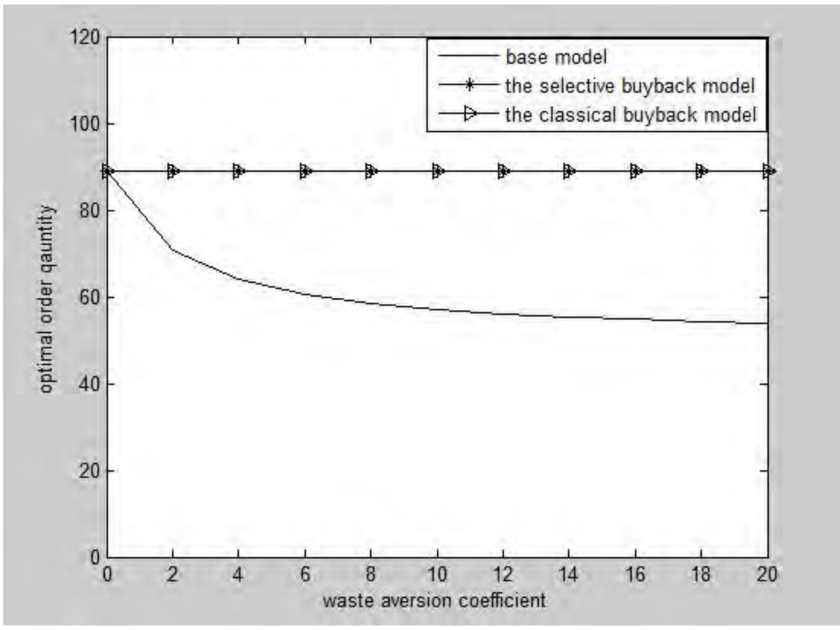

Figure 4: The impact of changing λ on the optimal order quantity.

It can be inferred from Fig. 4 that the retailer's optimal order quantity *Q* under the coordination of selective buy back contracts is unchanged with the increase of the waste aversion coefficient λ and that it is identical to *Q* under the coordination of classical buyback contracts. This shows that both selective and classical buyback contracts can achieve perfect coordination of the supply chain, while the retailer's optimal order quantity *Q* decreases with the increase of λ so that the retailer prefers to accept the selective buyback contract.

5.4 Impact of the waste aversion coefficient λ on expected utility

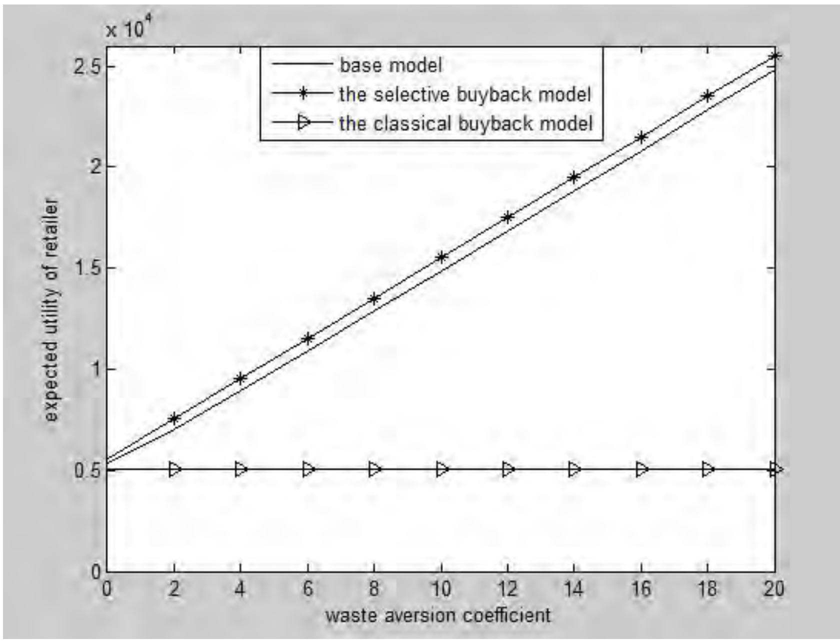

Figure 5: The impact of changing λ on retailer's expected utility.

The impact of the waste aversion coefficient λ on a retailer's expected utility is analysed in this subsection by increasing λ from 0 to 20.

Fig. 5 shows that the retailer's expected utility increases with the increase of waste aversion coefficient λ for both contracts with selective buyback policies and those without an incentive. For the classical buyback contracts, the retailer's expected utility remains unchanged. The retailer's expected utility with the selective buyback contracts is always more than those of classical buyback contracts and those without any incentive, illustrating that the retailer prefers to choose selective buyback contracts when the other parameters are the same.

5.5 Contrast of supplier's and retailer's expected profits

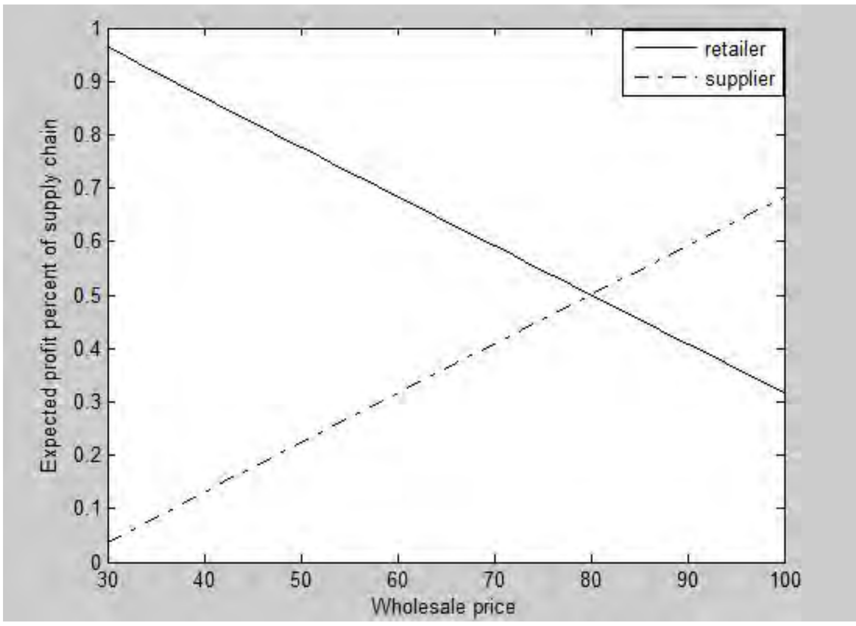

Figure 6: The impact of changing w on the members' expected profits with selective buyback contracts.

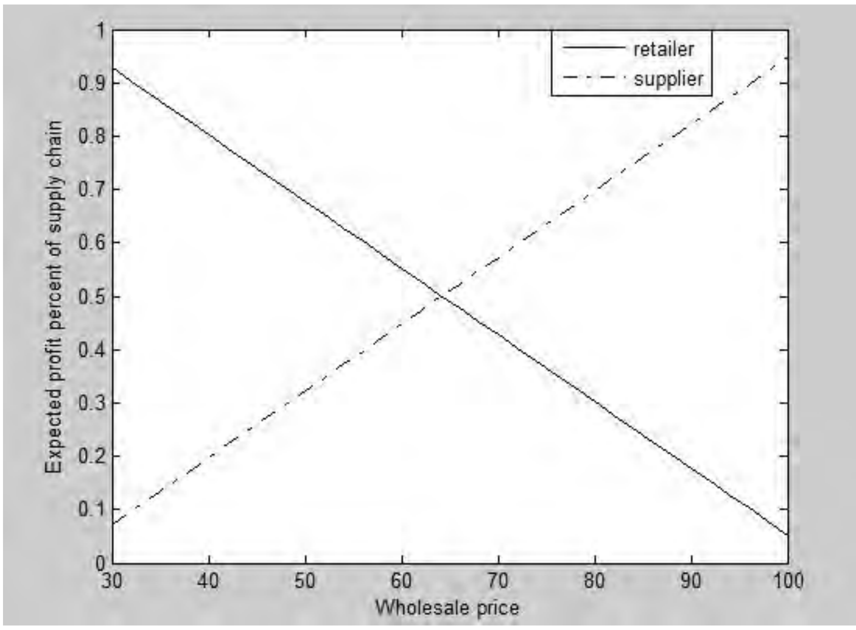

Figure 7: The impact of changing w on the members' expected profits with classical buyback contracts.

The contrast of supplier's and retailer's expected profits is studied in Figs. 6 and 7 by increasing w from 30 to 100. The waste aversion coefficient λ is set to be 10.

According to Figs. 6 and 7, under the selective buyback contracts, the supplier's expected profit increases gradually but the retailer's expected profit decreases gradually with the increase of wholesale price. It demonstrates that the profit can be transferred between supply chain members through adjusting the wholesale price w.

Comparing Fig. 6 with Fig. 7, it can be seen that with the change of wholesale price w, the expected profit changes at a greater rate under classical buyback contracts than under selective buyback contracts. Therefore, the members with classical buyback contracts are more sensitive to the change of wholesale price w.

6. CONCLUSION

The selective buyback contracts studied in this paper can coordinate supply chains with risk-averse retailers. The retailer can transfer part of his overstock risk to the supplier through purchasing put option contracts at the time of ordering and at the same time, the supplier can get risk compensation. The contract can work even if the retailer's degree of risk aversion is undisclosed because the supplier's decision is not affected by the retailer's risk aversion under this contract. The coordination effect of the selective buyback contract was compared with that of the classical buyback contract and base model in the numerical studies. The comparative analysis showed that the retailer prefers to accept the selective buyback contract when demand follows a uniform distribution.

This study demonstrates that the retailer's optimal purchase quantity of option contracts increases with his waste aversion coefficient, but the changes reduce with the increase of waste aversion coefficient. In effect, it is significant for a retailer to buy more option contracts when his waste aversion coefficient is small while it is almost counterintuitive for a retailer to buy more option contracts if his waste aversion coefficient is big.

The study also finds that when the supplier's profit is the same as the retailer's profit, the wholesale price under the selective buyback contracts is higher than that under the classical buyback contract if all the other conditions are same between the two kinds of contract. Therefore in reality, it is better to employ selective buyback contracts with a low price if the supplier is stronger than the retailer.

In reality, besides the overstock risk aversion of retailers, sometimes the supplier in the supply chain also exhibits risk preference, such as overstock risk aversion or stockout risk aversion. The risk preference of the supplier is not considered in our current research but its impact on supply chain coordination will be studied in the future. On the other hand, with the rise of e-commerce, most products are sold through multi-sales channels. The retailers have different risk preferences because of the distinct marketing costs in different sales channels and another valuable future study could concern the supplier's ability to coordinate the contradictions between the retailers in different sales channels.

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