COORDINATION OF VMI SUPPLY CHAIN WITH A LOSS-averse MANUFACTURER UNDER QUALITY-DEPENDENCY AND MARKETING-DEPENDENCY

FUYOU HUANG
Institute of Transportation Development Strategy & Planning of Sichuan Province
School of Transportation and Logistics, Southwest Jiaotong University
Chengdu 610036, China

JUAN HE*
School of Transportation and Logistics, Southwest Jiaotong University
Chengdu 610036, China

JIAN WANG
School of Economics and Management, Jiang Su University of Science and Technology
Zhenjiang 212003, China

(Communicated by Stefan Wolfgang Pickl)

Abstract. This paper addresses a vendor-managed inventory (VMI) supply chain with a loss-averse manufacturer and a risk-neutral retailer. Market demand faced by the retailer is stochastic and dependent on product quality level and marketing effort level. We propose a combined contract composed of option and cost-sharing to investigate coordination and profit allocation issues of the supply chain. To model loss aversion of the manufacturer, we employ multiple mental accounts and apply the utility function to upside and downside potentials of manufacturer’s production decision separately. We derive the optimal strategy for each member with a Stackelberg game in which the retailer acts as the leader. It is proved that both coordination of the supply chain and Pareto-improvement can be achieved synchronously by the combined contract. In the premise of coordination, the system-wide profit can be allocated arbitrarily only by option price. Through negotiation, the retailer and the manufacturer just need to confirm an appropriate option price to obtain that neither of them becomes worse off. We also find that the manufacturer’s loss aversion is a significant element for contract design and profit allocation, and the manufacturer could benefit from its own loss aversion behavior under certain condition.

2010 Mathematics Subject Classification. Primary: 90B50; Secondary: 91A35.

Key words and phrases. Supply chain coordination, VMI, loss aversion, option contract, product quality, marketing effort.

The paper is supported by the National Natural Science Foundation of China (Grant No.71273214) and the Philosophy and Social Science Research Grand of Sichuan Province (Grant No.SKA13-01).

* Corresponding author: Juan He.
1. Introduction. Nowadays, more and more enterprises have realized that external collaboration and coordination across the supply chain can bring an efficient supply chain and greater benefit for each supply chain member. As a new inventory management mode, vendor-managed inventory (VMI) is a well-known and widely used supply chain practice between a supplier/manufacturer and a retailer for reducing the overall inventory cost and improving performance of supply chain \[14, 17, 36\]. In a VMI system, the retailer is no longer responsible for managing inventory, but transfers this burden to the supplier who then becomes responsible for ensuring the availability of products at retailer’s location; and the supplier takes all inventory risk but has the opportunity to organize his production and distribution process for maximizing individual expected profit according to actual consumer demands without distortion. Indeed, since the VMI partnership is popularized by Wal-Mart and Procter & Gamble (P&G) in 1985, which is increasingly being adopted by many companies (such as K-mart, Home Depot, and JC Penny) in retailing industry \[5, 22\] because VMI helps retailers transfer inventory risk and gain competitive advantage and greater benefit \[37\].

Motivated by the VMI system in retailing industry, in this paper, we address a VMI supply chain in which the retailer acts as the leader. It is well documented in supply chain literature that VMI can reduce inventory cost and improve supply chain performance, but VMI cannot be efficient without the support of a coordinated contract \[5, 19, 25, 29\]. It is crucial to introduce an effective cooperative mechanism to strengthen the collaborative relationship between supply chain members. Supply chain contracts are generally considered as a useful tool to bring supply chain actors in a decentralized setting to operate in coordination \[3\]. Option contract is a viable alternative and increasingly prevalent to obtain an efficient supply chain, which has attracted substantial attention in the area of supply chain management \[10, 42, 46\]. In practice, option contracts have been extensively adopted by many companies across various industries such as retailing \[40\], communications \[11\], toys \[1\] and food processing industry \[10\]. For instance, as a famous electric appliance retailer in China, Suning adopts option contract to coordinate its suppliers’ production quantities so as to improve supply chain performance \[40\].

The literature on supply chain coordination with option contracts is also abundant. Using a two-period model, Barnes-Schuster et al. \[1\] analysed how options provide flexibility to a buyer to respond to market changes in the second period, and studied the implications of such arrangements between a buyer and a supplier for coordination of the channel. Wang and Liu \[40\] explored channel coordination and risk sharing in a retailer-led supply chain where the retailer designed option contract and the manufacturer decided the production quantity for maximizing individual expected profit, they proved that a successful coordination was reachable. Sarmah et al. \[33\] investigated a coordination problem in a single-manufacturer and multiple heterogeneous buyers situation by option contract. Zhao et al. \[46\] considered the coordination issue with a cooperative game approach by option contract, and demonstrated that option contract can coordinate the supply chain and bring about Pareto-improvement compared to the wholesale price contract. Wang et al. \[41\] investigated that pre-purchasing relief supplies from a supplier with an option contract was superior to both pre-purchasing with a buyback contract and instant-purchasing with a return policy. Liu et al. \[31\] found that option contract was also effective in coordinating an express delivery service supply chain wherein the selling season included both regular periods and online sales periods. Cai et al.
[4] verified that option contract was especially suitable for a supply chain operating under VMI, in which the retailer acted as a leader role in supply chain. Further, Cai et al. [6] introduced an option contract to improve the performance of a VMI supply chain under yield uncertainty. However, most of them engaged in coordination problems with option contracts based on the assumption of risk neutrality.

Indeed, supply chains become more vulnerable to uncertainty, decision makers focus more on potential loss than on expected profit. Thus the assumption of risk neutrality is inadequate for contemporary supply chain management [10, 23]. A series of experimental studies and observations of managerial decision-making under uncertainty showed that decision-making behaviors of managers deviate from maximizing expected profit and are consistent with loss aversion [18, 26, 34]. Loss aversion is introduced by Kahneman and Tversky [27] in the framework of prospect theory, which means that the decision-makers have different perceived values and are more sensitive to losses than to same-sized gains. In a VMI supply chain in retailing industry, from the behavioral theory’s viewpoint, the giant retailer can always diversify its assets across multiple enterprises and is risk-neutral, while the follower, such as small manufacturer, whose security of its business and income is related to the principal, is loss-averse. As a result, the loss-averse behavior of manufacturer affects its production decision even supply chain’s performance. Therefore, it is significant to examine the effect of the manufacturer’s loss aversion on supply chain decision-making. In the last decades, the problem with loss-averse firms has received more and more attention in operations and supply chain management [2, 9, 10, 15, 16, 30, 38, 39]. Different from most studies where a simple piecewise-linear value function is used to model the loss-averse behavior, we will employ multiple mental accounts and apply the utility function to upside and downside potentials of manufacturer's production decision separately [2, 15], thus we can obtain analytical solutions easily. Moreover, taking the loss-averse behavior of enterprise into consideration, although the existing studies have made great contributions to the operations management problem, the study on the coordination and profit allocation issues of VMI supply chain under quality-dependency and marketing-dependency is still lacking.

Quality is an important dimension of a product, and product quality has been regarded as the second most important factor affecting consumers’ purchasing decisions after product price [7]. In order to increase customer demand and market share, manufacturers invest in the technology and management used to make the product in practice, a larger investment in technology and management improves the quality of the product which results later in an increased demand potential for the product [21]. For instance, in the fast food retail industry, the final market demand is not only affected by the retail price and the value added by the buyer, it also depends on the investments made by the franchisor in its brand name [28]. Similarly, retailers in supply chains have the opportunity to enhance the final market demand by choosing the appropriate marketing activities such as sales promotion, advertisement and aftersales service support [12]. That is, marketing effort is also a crucial decision variable in supply chain management, and has sufficient impact on performance of supply chain. So far, there are many studies that concentrate on product quality [7, 8, 13, 43] and marketing effort [24, 35, 44, 45] separately, and a few researches have been done to focus simultaneously on product quality and marketing effort [20, 21, 32]. To the best of our knowledge, however, under
quality-dependency and marketing-dependency, there are no studies that address coordination issue of VMI supply chain with a loss-averse firm.

Differing from the aforementioned papers, our work focuses mainly on investigating coordination problem in a VMI supply chain with a loss-averse manufacturer under quality-dependency and marketing-dependency. Most related works are found in Cai et al.\[4\] and Chen et al.\[10\]. Cai et al.\[4\] investigated channel coordination problem in a VMI supply chain consisting of a risk-neutral supplier and a risk-neutral retailer by option contract. In this paper, we consider the effect of the loss-averse behavior of the upstream firm on supply chain decisions further. Chen et al.\[10\] explored channel coordination issue in a supply chain with a loss-averse retailer via option contract, and modeled the loss aversion of the retailer by a simple piecewise-linear value function. Compared with Chen et al.\[10\], we discuss channel coordination issue in a VMI supply chain with a loss-averse manufacturer, and we employ multiple mental accounts and apply the utility function to upside and downside potentials of manufacturer’s production decision separately. Also, we assume that the final market demand can be enhanced by investment of product quality and marketing effort.

The contribution of our work is threefold. First, we develop basic models based on the wholesale price contract and derive the optimal strategy for each member with a Stackelberg game in which the retailer acts as the leader. Meanwhile, we employ multiple mental accounts and apply the utility function to upside and downside potentials of manufacturer’s production decision separately, and we analyze the impact of loss aversion degree on the optimal decisions. Second, we propose a combined contract composed of option and cost-sharing to investigate supply chain coordination. Our results identify the combined contract can coordinate the supply chain, and the manufacturer’s loss aversion is a significant element for contract design and profit allocation. Last, we discuss how to flexibly allocate the system-wide profit between the supply chain members to achieve a Pareto-improvement.

The remainder of this paper is organized as follows. Section 2 presents the model setting, notations and assumptions. In Section 3, we develop a basic model in the decentralized system, and derive the equilibrium decisions with a Stackelberg game. We consider a centralized system in Section 4. Section 5 investigates coordination and profit allocation issues of the supply chain by a combined contract composed of option and cost-sharing. A series of numerical experiments are given in Section 6. We conclude our findings and highlight possible future work in Section 7.

2. Model description. Consider a VMI supply chain consisting of a risk-neutral retailer and a loss-averse manufacturer in a single period with information symmetry, a short life-cycle product of the manufacturer is only sold via the dominant retailer to end consumers with stochastic demand in the selling season. The final market demand can be enhanced by investment of product quality and marketing effort.

Notations used in this paper are listed as follows.
\[D\]: market demand faced by the retailer.
\[c\]: production cost per unit of product.
\[w\]: wholesale price per unit of product.
\[p\]: retail price per unit of product.
\[v\]: salvage value per unit of product.
\[g_m\]: manufacturer’s unit shortage cost for any unmet demand.
In this study, $q$, $s$ and $Q$ are decision variables. Following [20, 21, 32], the final market demand faced by the retailer is given by

$$D = a + \alpha q + \beta s + x,$$

where $a$ is the primary intrinsic demand of product, which is irrespective of product quality-improvement level and marketing effort level. $\alpha$ measures the influence of product quality-improvement on demand and $\beta$ measures the impact of marketing effort on demand. These parameters are required to satisfy $\alpha, \beta > 0$. $x$, called demand risk, is a random variable with probability density function $f(x)$ and cumulative distribution function $F(x)$. $F(x) = 1 - F(x)$ denotes the tail distribution. For notational convenience, we let $d(q, s) = a + \alpha q + \beta s$, thus the final market demand is rewritten as $D = d(q, s) + x$.

In addition, we assume that the cost of investment in product quality at level $q$ is $mq^2$, which aligns with [20, 32]. It implies that the cost of quality improvement have a decreasing-return property, that is, the next dollar invested would produce less unit of quality level than the last dollar, i.e., it becomes more expensive to provide the next unit of quality level. Also, similar to the case of investment in product quality, the retailer’s cost of marketing effort has diminishing impact on demand and is assumed to be $ns^2$ [21, 24].

Due to the stochastic nature of market demand, as we mentioned previously, the manufacturer is usually loss-averse since it takes inventory risk under VMI. We adopt multiple mental accounts and apply the utility function to upside and downside potentials of manufacturer’s production decision separately [2, 15]. For any given market demand, the upside potential is the income associated with selling products, and the downside potential is the loss associated with surplus products and goods out of stock. The objective of the manufacturer is to maximize its expected utility. The utility function is given by

$$U(A) = -\lambda [A]^- + [A]^+,$$

where $A$ is the upside/downside potential of manufacturer’s production decision, $[A]^- = \text{max}(0, -A)$ is equal to the absolute value of $A$ if $A$ is negative and 0 otherwise, and $[A]^+ = \text{max}(0, A)$ is equal to $A$ if $A$ is positive and 0 otherwise. $\lambda$ is the manufacturer’s loss aversion coefficient.
coefficient. In this paper, we assume $\lambda > 1$, which means that the decision maker is more sensitive to losses than to same-sized gains. Higher value of $\lambda$ corresponds to a higher level of decision maker’s loss aversion. Especially, $\lambda = 1$ corresponds to the risk neutrality scenario.

Note that, the variables in this paper may have the superscripts (such as $I$, $wp$ and $cc$) to denote the corresponding value under each scenario, where $I$, $wp$ and $cc$ represent the centralized system, the decentralized system with wholesale price contract and combined contract, respectively.

3. Basic model with wholesale price contract. Since the wholesale price contract is commonly used in practice, we employ the wholesale price contract as the benchmark against which we will compare the combined contract developed in this paper. The sequence of events is described as follows. Before the start of the selling season, the retailer sets a marketing effort level $s_{wp}$ independently. Then, for a given marketing effort level, the manufacturer decides the product quality-improvement level $q_{wp}$ and the production quantity $Q_{wp}$. After the products are produced, the inventory is always placed at the retailer’s warehouse. The manufacturer manages the inventory and bears unit cost of holding inventory $h$. At the beginning of the selling season, according to the actual demand information and the manufacturer’s inventory level, the retailer may purchase a quantity of product up to $Q_{wp}$ units from the manufacturer at the wholesale price $w$, and resell to the end consumer at retail price $p$. After the selling season, any unsold product owned by the manufacturer can be salvaged. And any shortage will impose unit penalty costs $g_m$ and $g_r$ on the manufacturer and the retailer, respectively. In order to avoid the unreasonable cases, we assume $p > w > c + h > v$.

Obviously, the game between the manufacturer and the retailer here is a Stackelberg game in which the retailer acts as the leader. We will derive the optimal strategy for each member via backwards induction to find the equilibrium of the Stackelberg game. First, we explore the manufacturer’s product quality and production decisions, then we investigate the retailer’s strategy on the marketing effort level.

Under the wholesale price contract, for any given marketing effort level $s_{wp}$, the utility of the manufacturer, denoted as $U_{wp}^m$, is given by

$$U_{wp}^m = \begin{cases} (w - c - h)Q_{wp} - \lambda g_m (D_{wp} - Q_{wp}) - m(q_{wp})^2 & D_{wp} > Q_{wp} \\ (w - c - h)D_{wp} - \lambda(c + h - v)(Q_{wp} - D_{wp}) - m(q_{wp})^2 & D_{wp} \leq Q_{wp} \end{cases}$$

Then, the expected utility of the manufacturer can be given as

$$EU_{wp}^m = (w - c - h + \lambda g_m)Q_{wp} - \lambda g_m (\mu + d(q_{wp}, s_{wp})) - m(q_{wp})^2$$

$$- (w - c - h + \lambda(c + h - v + g_m)) \int_{0}^{Q_{wp} - d(q_{wp}, s_{wp})} F(x)dx.$$ (4)

We can show that $EU_{wp}^m$ is a jointly concave function of $Q_{wp}$ and $q_{wp}$, hence there exist optimal solutions that will maximize the expected utility of the manufacturer, then we have the following theorem.
Theorem 3.1. Under the wholesale price contract, for any given \( s^{wp} \), there exist unique optimal decisions \( (Q^{wp*}, q^{wp*}) \) which satisfy

\[
Q^{wp*} = F^{-1} \left( \frac{w - c - h + \lambda g_m}{w - c - h + \lambda (c + h - v + g_m)} \right) + d(q^{wp*}, s^{wp}) \tag{5}
\]

and

\[
q^{wp*} = \frac{\alpha(w - c - h)}{2m}. \tag{6}
\]

Proof. From (4), for any given \( s^{wp} \), we have

\[
\frac{\partial^2 EU^{wp}_m}{\partial Q^{wp2}} = -(w - c - h + \lambda(c + h - v + g_m)) f(Q^{wp} - d(q^{wp}, s^{wp})) < 0. \tag{7}
\]

and

\[
\left| \frac{\partial^2 EU^{wp}_m}{\partial Q^{wp2} \partial q^{wp}} \right| = 2m(w - c - h + \lambda(c + h - v + g_m)) f(Q^{wp} - d(q^{wp}, s^{wp})) > 0. \tag{8}
\]

That is, the Hessian matrix of \( EU^{wp}_m \) is negative definite for all values of \( Q^{wp} \) and \( q^{wp} \), it implies that \( EU^{wp}_m \) is jointly concave in \( Q^{wp} \) and \( q^{wp} \). Taking the first-order derivative of \( EU^{wp}_m \) with respect to \( Q^{wp} \) and \( q^{wp} \), it follows that

\[
\frac{\partial EU^{wp}_m}{\partial Q^{wp}} = w - c - h + \lambda g_m - (w - c - h + \lambda(c + h - v + g_m)) F(Q^{wp} - d(q^{wp}, s^{wp})) \tag{9}
\]

and

\[
\frac{\partial EU^{wp}_m}{\partial q^{wp}} = \alpha (w - c - h + \lambda(c + h - v + g_m)) F(Q^{wp} - d(q^{wp}, s^{wp})) - \lambda g_m \alpha - 2mq^{wp}. \tag{10}
\]

Thus, by the first-order condition, we can obtain the optimal production quantity \( Q^{wp*} = F^{-1} ((w - c - h + \lambda g_m)/(w - c - h + \lambda (c + h - v + g_m)) + d(q^{wp*}, s^{wp}) \) and the optimal product quality-improvement level \( q^{wp*} = \alpha(w - c - h)/(2m) \).

Theorem 3.1 characterizes the manufacturer’s best response to the retailer’s marketing effort level. Although the optimal production quantity relies on the loss aversion coefficient of the manufacturer, as we can see from Theorem 3.1, the optimal product quality-improvement level is independent on the loss aversion coefficient. That is, the loss-averse behavior of the manufacturer affects only on the production decision.

Corollary 1. If \( g_m \leq \frac{(c + h - v) F(Q^{wp} - d(q^{wp}, s^{wp}))}{F(Q^{wp} - d(q^{wp}, s^{wp}))} \), then \( \frac{\partial Q^{wp*}}{\partial \lambda} \leq 0 \), otherwise, \( \frac{\partial Q^{wp*}}{\partial \lambda} > 0 \).

Proof. Using implicit function theorem, we have

\[
\frac{\partial Q^{wp*}}{\partial \lambda} = - \frac{\partial^2 EU^{wp}_m / \partial Q^{wp} \partial \lambda}{\partial^2 EU^{wp}_m / \partial Q^{wp2}} = \frac{g_m - (c + h - v + g_m) F(Q^{wp} - d(q^{wp}, s^{wp}))}{(w - c - h + \lambda(c + h - v + g_m)) f(Q^{wp} - d(q^{wp}, s^{wp}))}. \tag{11}
\]

So if \( g_m - (c + h - v + g_m) F(Q^{wp} - d(q^{wp}, s^{wp})) \leq 0 \), then we have \( \frac{\partial Q^{wp*}}{\partial \lambda} \leq 0 \), otherwise, \( \frac{\partial Q^{wp*}}{\partial \lambda} > 0 \).
Corollary 1 reveals the effect of changes in loss aversion coefficient on the manufacturer’s optimal production quantity. When the manufacturer’s penalty of stockout is not more than a threshold value ($g_m < \frac{(c + h - w)F(Q^{wp} - d(q^{wp}, s^{wp}))}{F(Q^{wp} - d(q^{wp}, s^{wp}))}$), the optimal production quantity is decreasing in the loss aversion coefficient. That is rational because the loss-averse manufacturer would like to avoid the risk of overstock by decreasing its production. The more loss-averse the manufacturer is, the smaller the optimal production quantity is. Conversely, the loss-averse manufacturer prefers to built up more inventory in order to avert shortage risk.

In what follows, we discuss the retailer’s optimal strategy on the marketing effort level. The retailer’s problem is to seek an optimal marketing effort level to maximize its own expected profit by taking the manufacturer’s best response into consideration. Let $E\pi_{r}^{wp}$ denote the expected profit of the retailer, we have

$$E\pi_{r}^{wp} = E[(p - w) \min\{Q^{wp}, D^{wp}\} - g_r \max\{D^{wp} - Q^{wp*}, 0\} - n(s^{wp})^2]$$

$$= (p - w + g_r)(Q^{wp*} - \int_0^{Q^{wp*} - d(q^{wp*}, s^{wp})} F(x)dx - g_r(\mu + d(q^{wp*}, s^{wp})) - n(s^{wp})^2. 

The first term is the retailer’s sale profit, the second term is the retailer’s penalty of stockout, and the last term is the cost of implementing marketing effort at level $s^{wp}$. Then, we can obtain the optimal marketing effort for the retailer.

**Theorem 3.2.** Under the wholesale price contract, there exists a unique optimal marketing effort level $s^{wp*}$ which satisfies

$$s^{wp*} = \frac{\beta(p - w)}{2n}. \tag{13}$$

**Proof.** Taking the first-order and second-order derivative of $E\pi_{r}^{wp}$ with respect to $s^{wp}$, we have $\frac{\partial E\pi_{r}^{wp}}{\partial s^{wp}} = (p - w + g_r)\beta - g_r\beta - 2ns^{wp}$ and $\frac{\partial^2 E\pi_{r}^{wp}}{\partial s^{wp2}} = -2n < 0$. This implies that $E\pi_{r}^{wp}$ is concave in $s^{wp}$, thus there exists a unique optimal marketing effort level $s^{wp*}$ by solving $\frac{\partial E\pi_{r}^{wp}}{\partial s^{wp}} = 0$. \[\square\]

Let $E\pi_{m}^{wp*}$ denote the optimal expected profit of the manufacturer under the wholesale price contract, we have

$$E\pi_{m}^{wp*} = E[w \min\{Q^{wp*}, D^{wp}\} + v \max\{Q^{wp*} - D^{wp}, 0\} - g_m \max\{D^{wp} - Q^{wp*}, 0\} - (c + h)Q^{wp*} - m(q^{wp})^2]$$

$$= (w - c - h + g_m)Q^{wp*} - g_m(\mu + d(q^{wp*}, s^{wp})) - m(q^{wp})^2 - (w - v + g_m)\int_0^{Q^{wp*} - d(q^{wp*}, s^{wp})} F(x)dx. \tag{14}$$

Therefore, under the wholesale price contract, the joint optimal expected profit of the supply chain, denoted as $E\pi_{sc}^{wp*}$, can be given by

$$E\pi_{sc}^{wp*} = E\pi_{r}^{wp*} + E\pi_{m}^{wp*}$$

$$= (p - c - h + g_m + g_r)Q^{wp*} - (p - v + g_m + g_r)\int_0^{Q^{wp*} - d(q^{wp*}, s^{wp})} F(x)dx - (g_m + g_r)(\mu + d(q^{wp*}, s^{wp})) - m(q^{wp})^2 - n(s^{wp})^2. \tag{15}$$
4. Centralized supply chain. In the centralized system, there is only one large and risk-neutral decision-maker who controls the channel and decides the marketing effort $s^I$, the quality-improvement level $q^I$ and the production quantity $Q^I$ to maximize the system-wide expected profit. Let $E\pi^{I}_{sc}$ denote the expected profit of the centralized entity, we have

$$E\pi^{I}_{sc} = E[p \min \{Q^I, D^I\} + v \max \{Q^I - D^I, 0\} - (g_m + g_r) \max \{D^I - Q^I, 0\} - cQ^I - hQ^I - m(q^I)^2 - n(s^I)^2].$$

(16)

The first term is the sales revenue, the second term is the salvage value, the third term is the system’s shortage cost, the fourth term is the manufacturing cost, the fifth term is the cost of holding inventory, the sixth term is the cost for investment in product quality, and the last term is the cost for exerting marketing effort. With some algebra, the expected profit function of the centralized entity can be rewritten as

$$E\pi^{I}_{sc} = (p - c - h + g_m + g_r)Q^I - (p - v + g_m + g_r) \int_0^{Q^I-d(q^I, s^I)} F(x)dx - ((g_m + g_r)(\mu + d(q^I, s^I)) - m(q^I)^2 - n(s^I)^2).$$

(17)

Then, we derive the optimal decisions of the centralized system as follows.

**Theorem 4.1.** In the centralized system, there exist unique optimal solutions $(Q^{I*}, q^{I*}, s^{I*})$ which are jointly determined by

$$Q^{I*} = F^{-1} \left( \frac{p - c - h + g_m + g_r}{p - v + g_m + g_r} \right) + d(q^{I*}, s^{I*}),$$

(18)

$$q^{I*} = \frac{\alpha(p - c - h)}{2m},$$

(19)

and

$$s^{I*} = \frac{\beta(p - c - h)}{2n}.$$  

(20)

**Proof.** From Equation (17), for any given $q^I$ and $s^I$, taking the first-order and second-order derivative of $E\pi^{I}_{sc}$ with respect to $Q^I$, it follows that $\partial E\pi^{I}_{sc}/\partial Q^I = p - c - h + g_m + g_r - (p - v + g_m + g_r)F(Q^I - d(q^I, s^I))$ and $\partial^2 E\pi^{I}_{sc}/\partial Q^I^2 = -(p - v + g_m + g_r)f(Q^I - d(q^I, s^I)) < 0$. This implies that $E\pi^{I}_{sc}$ is concave in $Q^I$ for any given $q^I$ and $s^I$, then we get $Q^{I*} = F^{-1}((p - c - h + g_m + g_r)/(p - v + g_m + g_r)) + d(q^I, s^I)$ by setting $\partial E\pi^{I}_{sc}/\partial Q^I = 0$. Substituting $Q^{I*}$ into Equation (17), we have

$$\begin{vmatrix}
\frac{\partial^2 E\pi^{I}_{sc}}{\partial q^I^2} & \frac{\partial^2 E\pi^{I}_{sc}}{\partial q^I \partial s^I} \\
\frac{\partial^2 E\pi^{I}_{sc}}{\partial s^I \partial q^I} & \frac{\partial^2 E\pi^{I}_{sc}}{\partial s^I^2}
\end{vmatrix} = 4mn > 0.$$

(21)

The Hessian matrix of $E\pi^{I}_{sc}$ is negative definite for all values of $q^I$ and $s^I$, it implies that $E\pi^{I}_{sc}$ is jointly concave in $q^I$ and $s^I$. Thus, by the first-order condition, we can obtain $q^{I*} = \alpha(p - c - h)/(2m)$ and $s^{I*} = \beta(p - c - h)/(2n)$.

Note that, Equation (15) is identical to Equation (17) except for the decision variables $(Q^{wp}, q^{wp}, s^{wp})$ which should be replaced by $(Q^I, q^I, s^I)$. It is obvious that $Q^{I*} > Q^{wp*}$, $q^{I*} > q^{wp*}$ and $s^{I*} > s^{wp*}$, as a result, we have $E\pi^{I*}_{sc} > E\pi^{wp*}_{sc}$. It implies that the wholesale price contract is not efficient in coordinating the supply.
chain, and greater supply chain performance can be achieved by a coordinated contract.

5. Supply chain coordination with combined contract. To obtain supply chain coordination, we introduce a combined contract composed of option and cost-sharing in this section. The combined contract is characterized by three parameters, namely option price $o$, exercise price $e$ and cost-sharing coefficient $\gamma$. The option price is essentially an allowance paid by the retailer to the manufacturer for reserving one unit of all the production capacity, the exercise price is to be paid by the retailer to the manufacturer for one unit of the product purchased by exercising option after market demand is realized, and the cost-sharing coefficient is the fraction of the cost of investment in both product quality and marketing effort which the manufacturer just needs to bear. Under the combined contract, the retailer can not only collaborate closely with the manufacturer in investment of product quality and marketing effort to enhance the market demand, but also induce the manufacturer to produce more products before the selling season.

Under the combined contract, the sequence of events can be described as follows. Before the selling season, the retailer offers a combined contract $(o, e, \gamma)$ to the manufacturer through negotiation and decides the marketing effort level $s_{cc}$ independently. According to the combined contract, the retailer will pay the manufacturer unit option price for all products. Then, the manufacturer decides the product quality-improvement level $q_{cc}$ and the production quantity $Q_{cc}$ based on the retailer's marketing effort and the combined contract. After the products are produced, the inventory is always placed at the retailer's warehouse. The manufacturer takes charge of the inventory and bears the cost of holding inventory. At the beginning of the selling season, market demand is observed, the retailer may purchase a quantity of product up to $Q_{cc}$ units from the manufacturer at the exercise price $e$ to satisfy market demand during the selling season. After the selling season, any unsold product owned by the manufacturer can be salvaged. For any unmet demand, both the manufacturer and the retailer endure punishment cost.

To avoid trivialities, we focus on the reasonable and non-trivial case where $c - \nu > o \geq 0$, $e > \nu > 0$ and $p > o + e > c + h > \nu$. The first condition avoids the unreasonable case where the manufacturer is risk-free for production, if $c - \nu \leq o$, the manufacturer can always gain positive earnings by disposing of all unsold product, and has a positive incentive to produce infinite amounts of product. The second condition ensures that the retailer can exercise option for meeting the market demand, if $e < \nu$, the manufacturer would dispose of the product in the salvage market rather than sell them to the retailer. And the last condition ensures positive profit for each member.

Under the combined contract, there is still a Stackelberg game between the manufacturer and the retailer in which the retailer acts as the leader. Therefore, we examine the manufacturer’s optimal decisions firstly. For any given marketing effort level $s_{cc}$, the utility of the manufacturer, denoted as $U^c_{m}$, is given by

\[
U^c_{m} = \begin{cases} 
(o + e - c - h)Q_{cc} - \lambda g_m(D_{cc} - Q_{cc}) - \gamma(m(q_{cc})^2 + n(s_{cc})^2) & D_{cc} > Q_{cc} \\
(o + e - c - h)D_{cc} - \lambda(c + h - o - \nu)(Q_{cc} - D_{cc}) - \gamma(m(q_{cc})^2 + n(s_{cc})^2) & D_{cc} \leq Q_{cc}.
\end{cases}
\]

(22)
Then, the expected utility of the manufacturer is given as

\[ EU_m^{cc} = (o + e - c - h + \lambda g_m) Q^{cc} - \lambda g_m(\mu + d(q^{cc}, s^{cc})) - \gamma(m(q^{cc})^2 + n(s^{cc})^2) - (o + e - c - h + \lambda(c + h - o - v + g_m)) \int_{0}^{Q^{cc} - d(q^{cc}, s^{cc})} F(x)dx. \]

(23)

For any given \( s^{cc} \), the objective of the manufacturer is to seek a production quantity \( Q^{cc} \) and a product quality-improvement level \( q^{cc} \) to maximize the expected utility \( EU_m^{cc} \), then we have the following theorem.

**Theorem 5.1.** Under the combined contract, the manufacturer’s expected utility function \( EU_m^{cc} \) is jointly concave in \( Q^{cc} \) and \( q^{cc} \), there exists a unique optimal production quantity \( Q^{cc*} \) and a unique optimal quality-improvement level \( q^{cc*} \) which satisfy

\[
Q^{cc*} = F^{-1} \left( \frac{o + e - c - h + \lambda g_m}{o + e - c - h + \lambda(c + h - o - v + g_m)} \right) + d(q^{cc*}, s^{cc})
\]

(24)

and

\[
q^{cc*} = \frac{\alpha(o + e - c - h)}{2\gamma m}.
\]

(25)

**Proof.** From Equation (23), for any given \( s^{cc} \), we can obtain

\[
\frac{\partial^2 EU_m^{cc}}{\partial Q^{cc2}} = -(o + e - c - h + \lambda(c + h - o - v + g_m)) f(Q^{cc} - d(q^{cc}, s^{cc})) < 0.
\]

(26)

and

\[
\begin{vmatrix}
\frac{\partial^2 EU_m^{cc}}{\partial Q^{cc} \partial s^{cc}} & \frac{\partial^2 EU_m^{cc}}{\partial q^{cc} \partial s^{cc}} \\
\frac{\partial^2 EU_m^{cc}}{\partial q^{cc} \partial Q^{cc}} & \frac{\partial^2 EU_m^{cc}}{\partial q^{cc2}}
\end{vmatrix}
= 2m\gamma (o + e - c - h + \lambda(c + h - o - v + g_m)) f(Q^{cc} - d(q^{cc}, s^{cc})) > 0.
\]

(27)

That is, the Hessian matrix of \( EU_m^{cc} \) is negative definite for all values of \( Q^{cc} \) and \( q^{cc} \), it implies that \( EU_m^{cc} \) is jointly concave in \( Q^{cc} \) and \( q^{cc} \). Taking the first-order derivative of \( EU_m^{cc} \) with respect to \( Q^{cc} \) and \( q^{cc} \), it follows that

\[
\frac{\partial EU_m^{cc}}{\partial Q^{cc}} = (o + e - c - h + \lambda g_m)
- (o + e - c - h + \lambda(c + h - o - v + g_m)) F(Q^{cc} - d(q^{cc}, s^{cc}))
\]

(28)

and

\[
\frac{\partial EU_m^{cc}}{\partial q^{cc}} = -\lambda g_m \alpha - 2m\gamma q^{cc} + \lambda(c + h - o - v + g_m)) F(Q^{cc} - d(q^{cc}, s^{cc})).
\]

(29)

Thus, by the first-order optimality condition, we can obtain Equation (24) and Equation (25).

**Theorem 5.1** characterizes the manufacturer’s best response to the retailer’s marketing effort level. Now, consider the retailer’s decision on the marketing effort level. As the leader in supply chain, the problem of the retailer is to maximize individual
expected profit anticipating the manufacturer’s best-response, which is expressed as
\[
\max_{s^cc} E\pi_{s^cc}^m = E[(p - \epsilon) \min \{Q_{ccs}, D^{cc}\} - g_r \max \{D^{cc} - Q_{ccs}, 0\} - oQ_{ccs} - (1 - \gamma)(m(q^{ccs})^2 + n(s^{ccs})^2)].
\] (30)

The first term is the sales profit, the second term is the retailer’s punishment cost for any unmet demand, the third term is the allowance pay-out for the reserved capacity, and the last term is the cost share for product quality improvement and marketing effort. Using simply algebra, the expected profit function of the retailer is rewritten as
\[
E\pi_{s^cc}^r = (p - o - e + g_r)Q_{ccs} - (p - e + g_r)\int_0^{Q_{ccs} - d(q^{ccs}, s^{ccs})} F(x)dx
- g_r(\mu + d(q^{ccs}, s^{ccs})) - (1 - \gamma)(m(q^{ccs})^2 + n(s^{ccs})^2).
\] (31)

Then, we derive the optimal marketing effort level for the retailer.

**Theorem 5.2.** Under the combined contract, there exists a unique optimal marketing effort level \(s^{ccs}\) which satisfies
\[
s^{ccs} = \frac{\beta(p - o - e)}{2(1 - \gamma)n}.
\] (32)

**Proof.** From Equation (31), taking the first-order and second-order derivative of \(E\pi_{s^cc}^r\) with respect to \(s^{ccs}\), it follows that \(\partial E\pi_{s^cc}^r / \partial s^{ccs} = (p - o - e)\beta - 2(1 - \gamma)n s^{ccs}\)
and \(\partial^2 E\pi_{s^cc}^r / \partial s^{ccs} = -2(1 - \gamma)n < 0\), this implies that \(E\pi_{s^cc}^r\) is concave in \(s^{ccs}\). Thus we get the optimal marketing effort \(s^{ccs} = \beta(p - o - e)/(2(1 - \gamma)n)\) by the first-order condition.

Under the combined contract, let \(E\pi_{m}^{ccs}\) denote the optimal expected profit of the manufacturer, we have
\[
E\pi_{m}^{ccs} = E[oQ_{ccs} + e \min \{Q_{ccs}, D^{cc}\} + v \max \{Q_{ccs} - D^{cc}, 0\} - cQ_{ccs}]
- hQ_{ccs} - g_m \max \{D^{cc} - Q_{ccs}, 0\} - \gamma(m(q^{ccs})^2 + n(s^{ccs})^2)]
= (o + e - c - h + g_m)Q_{ccs} - (e - v + g_m)\int_0^{Q_{ccs} - d(q^{ccs}, s^{ccs})} F(x)dx
- g_m(\mu + d(q^{ccs}, s^{ccs})) - \gamma(m(q^{ccs})^2 + n(s^{ccs})^2).
\] (33)

Thus, the joint optimal expected profit of the supply chain under the combined contract, denoted as \(E\pi_{sc}^{ccs}\), is given by
\[
E\pi_{sc}^{ccs} = E\pi_{s^cc}^r + E\pi_{m}^{ccs}
= (p - c - h + g_m + g_r)Q_{ccs} - (p - v + g_m + g_r)\int_0^{Q_{ccs} - d(q^{ccs}, s^{ccs})} F(x)dx
- (g_m + g_r)(\mu + d(q^{ccs}, s^{ccs})) - m(q^{ccs})^2 - n(s^{ccs})^2.
\] (34)

Compared Equation (34) with Equation (17), to enable the supply chain coordination, the members of the supply chain just need to push \(Q_{ccs} = Q^*\), \(q^{ccs} = q^*\) and \(s^{ccs} = s^*\) by the combined contract. This perspective yields the following theorem.
Theorem 5.3. Under the combined contract \((o, e, \gamma)\), coordination of the supply chain can be achieved by setting:

\[
e = \frac{(c + h - o - v)(c + h - \lambda c - \lambda h + \lambda p + \lambda g_r) + o(v - \lambda g_m)}{c + h - v}
\]

and

\[
\gamma = \frac{\lambda((c + h)^2 + (p + g_r)(o + v) - (c + h)(p + o + v + g_r) + g_m o)}{(o + e + c - h + \lambda g_m)(c + h - p)(c + h - v)}.
\]

Proof. According to the above analysis, it is obvious that coordination of the supply chain is achievable only when \(Q_{ccs}^*=Q_1^*, Q_{ccs}^*=q_1^*\) and \(s_{ccs}^*=s_1^*\), which implies that

\[
\frac{o + e + c - h + \lambda g_m}{o + e + c - h + \lambda g_m + g_r} = \frac{p - c - h + g_m + g_r}{p - c - h + g_m + g_r}, \quad \frac{\alpha(o + e - c - h)}{2mn} = \frac{\alpha(p - c - h)}{2(1 - \gamma)n} \quad \text{and} \quad \frac{\beta(p - o - e)}{2n} = \frac{\beta(p - c - h)}{2n}.
\]

Rearranging, we obtain Equation (35) with Equation (36).

Theorem 5.3 characterizes the specific condition under which coordination of the supply chain is achievable. Compared with the wholesale price contract, the combined contract can increase the expected profit of the supply chain system by

\[
\Delta E\pi = (p - c - h + g_m + g_r)(Q_1^* - Q_{wp^*}) - \int_{Q_{wp^*} - d(q_{wp^*}, s_{wp^*})}^{Q_1^* - d(q_{wp^*}, s_{wp^*})} F(x)dx - (g_m + g_r)(d(q_1^*, s_1^*) - d(q_{wp^*}, s_{wp^*}))
\]

Further, under coordination with the combined contract \((o, e, \gamma)\), we have the following corollary.

Corollary 2. Under coordination with the combined contract \((o, e, \gamma)\), both \(e\) and \(\gamma\) are strictly decreasing in \(o\).

Proof. From Equation (35), taking the first-order derivative of \(e\) with respect to \(o\), it follows that \(\partial e/\partial o = -(c + h - v + \lambda(p - c - h + g_m + g_r))/(c + h - v) < 0\), this implies that \(e\) is strictly decreasing in \(o\). Similarly, we have \(\partial \gamma/\partial o = -\lambda(p - c - h + g_m + g_r)/((p - c - h)(c + h - v)) < 0\), that is, \(\gamma\) is also strictly decreasing in \(o\).

Under coordination with the combined contract, the exercise price negatively correlates with the option price, that is, the higher the option price is, the lower the exercise price is. It indicates that the manufacturer needs to seek an appropriate production quantity to maximize individual expected utility because that the option price bring fixed revenue while uncertain revenue is brought by the exercise price in the future. Furthermore, we can see easily from Theorem 5.3 that the loss aversion coefficient is also a significant factor for parameters design of the combined contract. Recall that, under coordination with the combined contract, both the exercise price and the cost-sharing coefficient are functions of the option price, thus both the expected utility and the expected profit of the manufacturer are dependent only on the option price when other exogenous parameters are given, which yields the following corollary.

Corollary 3. Under coordination with the combined contract, both the expected utility and the expected profit of the manufacturer are decreasing in the option price.
Proof. Substituting \( e = \frac{(c+h-o-v)(c+h-\lambda c-\lambda h+\lambda p+\lambda g_r)+o(v-\lambda g_m)}{c+h-v} \) and \( \gamma = \frac{\lambda((c+h)^2+(p+g_r)(c+h)-(c+h)(p+v+g_r)+g_m(o))}{(c+h-p)(c+h-v)} \) into Equation (23), and taking the first-order derivative of \( EU_{m}^{cc*} \) with respect to \( o \), it follows that

\[
\frac{\partial EU_{m}^{cc*}}{\partial o} = -\frac{\lambda}{c+h-v}(p-c-h+g_m+g_r)Q^{I_s} + \frac{\lambda}{c+h-v}(p-v+g_m+g_r)\int_{0}^{F^{-1}(\frac{p-c-h+g_m+g_r}{p-v+g_m+g_r})} F(x)dx \tag{38}
\]

It is obvious that \( \frac{\partial EU_{m}^{cc*}}{\partial o} < 0 \). Namely, the expected utility of the manufacturer under coordination with the combined contract is decreasing in the option price.

Similarly, substituting \( e = \frac{(c+h-o-v)(c+h-\lambda c-\lambda h+\lambda p+\lambda g_r)+o(v-\lambda g_m)}{c+h-v} \) and \( \gamma = \frac{\lambda((c+h)^2+(p+g_r)(c+h)-(c+h)(p+v+g_r)+g_m(o))}{(c+h-p)(c+h-v)} \) into Equation (33), and differentiating \( E\pi_{m}^{cc*} \) with respect to \( o \) gives

\[
\frac{\partial E\pi_{m}^{cc*}}{\partial o} = -\frac{\lambda}{c+h-v}(p-c-h+g_m+g_r)Q^{I_s} + \frac{\lambda}{c+h-v}(p-v+g_m+g_r)\int_{0}^{F^{-1}(\frac{p-c-h+g_m+g_r}{p-v+g_m+g_r})} F(x)dx \tag{39}
\]

Since \( c+h-v+\lambda(p-c-h+g_m+g_r) < \lambda(p-v+g_m+g_r) \), we can get \( \frac{\partial E\pi_{m}^{cc*}}{\partial o} < 0 \) easily, that is, \( E\pi_{m}^{cc*} \) is decreasing in \( o \).

Corollary 3 shows the effects of the option price on the expected utility and the expected profit of the manufacturer under coordination with the combined contract. Since the sum of the retailer’s and the manufacturer’s expected profits under coordination is a constant, which is equal to the expected profit in the centralized system, it follows from Corollary 3 that the retailer’s expected profit is increasing in the option price under coordination. This indicates that the profit of the supply chain system can be allocated arbitrarily between the manufacturer and the retailer only by the option price when other exogenous parameters are given.

To ensure that the combined contract can be accepted willingly by each member in practice, the effective and reasonable contracts must be designed to obtain coordination of the supply chain and Pareto-improvement synchronously, i.e., the combined contract can bring additional profit to each party. As we have demonstrated previously, we know that the system-wide profit of the supply chain can be allocated arbitrarily between the manufacturer and the retailer under coordination with the combined contract. Therefore, it is obvious that there always exist some coordinating combined contracts that make each member better off than the wholesale price contract. Let \( E\pi_{m}^{cc}(o) \) and \( E\pi_{m}^{cc*}(o) \) denote the expected profits of the retailer and the manufacturer under coordination with the combined contract, respectively. Corollary 4 characterizes the specific condition under which neither of the retailer and the manufacturer is becoming worse off compared with the wholesale price contract.
Corollary 4. With the combined contract \((o, e, \gamma)\), both coordination of the supply chain and Pareto-improvement can be achieved synchronously by setting:

\[
e = \frac{(c + h - o - v)(c + h - \lambda c - \lambda h + \lambda p + \lambda g_r) + o(\nu - \lambda g_m)}{c + h - v},
\]

\[
\gamma = \frac{\lambda((c + h)^2 + (p + g_r)(\nu + o) - (c + h)(p + o + v + g_r) + g_m o)}{(c + h - p)(c + h - v)}
\]

and

\[o_{\text{min}} < o < o_{\text{max}},\]

where \(E_{\pi^{cc}}(o_{\text{min}}) = E_{\pi^{wp}}^*\) and \(E_{\pi^{cc}}(o_{\text{max}}) = E_{\pi^{wp}}^*\).

Corollary 4 reveals that the combined contract is incentive compatible for both the retailer and the manufacturer, that is, the specific combined contract is applicable in practice. Especially, by setting \(o = o_{\text{max}}\), the retailer can take all extra system profit from coordination, and the manufacturer’s earning is unchanged compared with the wholesale price contract.

6. Numerical analysis. In this section, using several numerical experiments, we mainly illustrate how the system-wide expected profit of the supply chain is allocated by the option price. Also, we examine the effects of the loss aversion factor on the optimal production quantity, the expected profits of both parties and parameters of the combined contract. In our study, the stochastic variable \(x\) is assumed to follow a normal distribution with \(F(x) \sim N(\mu, \sigma^2)\), and we let \(\mu = 100\) and \(\sigma = 400\). The other parametric values are set to \(a = 1000, \alpha = 2, \beta = 1, m = 0.05, n = 0.02, c = 9, h = 1, w = 18, p = 30, \nu = 5, g_m = 3, g_r = 2\).

In the decentralized system with wholesale price contract, Figure 1 and Figure 2 illustrate the effects of the manufacturer’s loss aversion coefficient on the optimal production quantity and the expected profits of both parties respectively. As the loss aversion degree increases, the optimal production quantity decreases, and the expected profits of both the manufacturer and the retailer decrease accordingly. These imply that it is more beneficial to coordinate the supply chain when the manufacturer becomes more loss-averse.

![Figure 1. Effect of the loss aversion coefficient on the optimal production quantity.](image-url)
Figure 2. Effects of the loss aversion coefficient on the expected profits of both parties.

Figure 3. Expected profits with respect to option price under coordination ($\lambda = 2$).

From Figure 3 and Figure 4, as we have proved previously, under coordination with the combined contract, the expected profit of the manufacturer is decreasing in the option price while the retailer’s expected profit is increasing in the option price. For Figure 3, when $o = 3.78$, the retailer takes all extra system profit from coordination while the manufacturer earns zero additional profit compared with the wholesale price contract, and the converse is applicable to the option price $o = 3.47$. Therefore, in comparison with the wholesale price contract, a feasible region for the option price under which both the retailer and the manufacturer become better off is $3.47 < o < 3.78$.

We can also see that from Figure 3 and Figure 4, in the presence of supply chain coordination, given profit allocation of the supply chain between the retailer and the manufacturer, the more loss-averse the manufacturer is, the higher the option
price is. Besides, with the increase of the loss aversion coefficient, both the upper bound value and lower bound value on the feasible region of the option price increase. Additionally, keep the option price constant, with the increase of the loss aversion coefficient, the expected profit of the manufacturer increases while the retailer’s expected profit decreases with the increase of the loss aversion coefficient. It implies that the manufacturer could benefit from its own loss aversion behavior under certain condition, and the loss aversion of the manufacturer is a very important factor for contract design and profit allocation between the retailer and the manufacturer.

7. Conclusions. In this paper, we propose and apply a combined contract composed of option and cost-sharing in a VMI supply chain with a loss-averse manufacturer under quality-dependency and marketing-dependency. Under the combined contract, the retailer can not only cooperate with the manufacturer in both product quality-improvement and marketing effort but also induce the manufacturer to produce more products before the selling season. To model loss aversion of the manufacturer, we employ multiple mental accounts and apply the utility function to upside and downside potentials of manufacturer’s production decision separately. We discuss how to coordinate the supply chain and allocate the system-wide profit by the combined contract, as well as the effects of the loss aversion factor on contract parameters and profit allocation.

We find that both the optimal product quality-improvement level and marketing effort level are independent on the loss aversion degree of the manufacturer, although the optimal production quantity relies on the loss aversion degree. And we have proved that both coordination of the supply chain and Pareto-improvement can be achieved synchronously by the combined contract. In the premise of coordination, with the increase of the option price, the retailer’s expected profit increases while the expected profit of the manufacturer decreases with the increase of the option price. Therefore, the system-wide profit of the supply chain can be allocated
arbitrarily only by the option price, and the combined contract is convenient for implementation in practice.

Under coordination with the combined contract, we also find that the expected profit of the manufacturer is increasing in the loss aversion coefficient while the retailer’s expected profit is decreasing in the loss aversion coefficient when the option price is given. Moreover, given the allocation of the system profit, the more loss-averse the manufacturer is, the higher the option price is. These indicate that the manufacturer’s loss aversion is a significant element for contract design and profit allocation.

There are several directions for the future. For example, we can further investigate coordination issue under competition, dual channel and multiple periods. Furthermore, both product supply and customer demand have become more and more uncertain in today’s ever changing business environment, thus a loss-averse supply chain with both supply and demand uncertainties is potentially meaningful research direction.

Acknowledgments. The authors sincerely thank the editor and the anonymous referees for their very valuable remarks and constructive suggestions.

REFERENCES

[1] D. Barnes-Schuster, Y. Bassok and R. Anupindi, Coordination and flexibility in supply contracts with options, Manufacturing & Service Operations Management, 4 (2002), 171–207.
[2] M. Becker-Peth, E. Katok and U. W. Thonemann, Designing buyback contracts for irrational but predictable newsvendors, Management Science, 59 (2013), 1800–1816.
[3] G. P. Cachon, Supply chain coordination with contracts, Handbooks in Operations Research and Management Science, 11 (2003), 227–339.
[4] J. Cai, X. Hu, Y. Han, H. Cheng and W. Huang, Supply chain coordination with an option contract under vendor-managed inventory, International Transactions in Operational Research, 23 (2016), 1163–1183.
[5] J. Cai, X. Hu, P. R. Tadikamalla and J. Shang, Flexible contract design for VMI supply chain with service-sensitive demand: Revenue-sharing and supplier subsidy, European Journal of Operational Research, 261 (2017), 143–153.
[6] J. Cai, M. Zhong, J. Shang and W. Huang, Coordinating VMI supply chain under yield uncertainty: Option contract, subsidy contract, and replenishment tactic, International Journal of Production Economics, 185 (2017), 196–210.
[7] G. H. Chao, S. M. R. Iravani and R. C. Savaskan, Quality improvement incentives and product recall cost sharing contracts, Management Science, 55 (2009), 1122–1138.
[8] J. Chen, L. Liang, D. Q. Yao and S. Sun, Price and quality decisions in dual-channel supply chains, European Journal of Operational Research, 259 (2017), 935–948.
[9] K. Chen and T. Xiao, Reordering policy and coordination of a supply chain with a loss-averse retailer, Journal of Industrial and Management Optimization, 9 (2013), 827–853.
[10] X. Chen, G. Hao and L. Li, Channel coordination with a loss-averse retailer and option contracts, International Journal of Production Economics, 150 (2014), 52–57.
[11] X. Chen and Z. Shen, An analysis on supply chain with options contracts and service requirement, IIE Transactions, 44 (2012), 805–819.
[12] J. Dai and W. Meng, A risk-averse newsvendor model under marketing-dependency and price-dependency, International Journal of Production Economics, 160 (2015), 220–229.
[13] Y. Dai, S. X. Zhou and Y. Xu, Competitive and collaborative quality and warranty management in supply chains, Production and Operations management, 21 (2012), 129–144.
[14] M. A. Darwish and O. M. Odah, Vendor managed inventory model for single-vendor multi-retailer supply chains, European Journal of Operational Research, 204 (2010), 473–484.
[15] A. M. Davis, E. Katok and N. Santamaría, Push, pull, or both? A behavioral study of how the allocation of inventory risk affects channel efficiency, Management Science, 60 (2014), 2666–2683.
[16] X. Deng, J. Xie and H. Xiong, Manufacturer-retailer contracting with asymmetric information on retailer’s degree of loss aversion, *International Journal of Production Economics*, 142 (2013), 372–380.

[17] Y. Dong, M. Dresner and Y. Yao, Beyond information sharing: An empirical analysis of vendor-managed inventory, *Production and Operations Management*, 23 (2014), 817–828.

[18] T. Feng, L. R. Keller and X. Zheng, Decision making in the newsvendor problem: A cross-national laboratory study, *Omega*, 39 (2011), 41–50.

[19] R. Guan and X. Zhao, On contracts for VMI program with continuous review (r, Q) policy, *European Journal of Operational Research*, 207 (2010), 656–667.

[20] H. Gurnani and M. Erkoc, Supply contracts in manufacturer-retailer interactions with manufacturer-quality and retailer effort-induced demand, *Naval Research Logistics*, 55 (2008), 200–217.

[21] H. Gurnani, M. Erkoc and Y. Luo, Impact of product pricing and timing of investment decisions on supply chain co-operation, *European Journal of Operational Research*, 180 (2007), 228–248.

[22] M. Hariga, M. Gumus and A. Daghfous, Storage constrained vendor managed inventory models with unequal shipment frequencies, *Omega*, 48 (2014), 94–106.

[23] J. He, C. Ma and K. Pan, Capacity investment in supply chain with risk averse supplier under risk diversification contract, *Transportation Research Part E: Logistics and Transportation Review*, 106 (2017), 255–275.

[24] X. He, A. Krishnamoorthy, A. Prasad and S. P. Sethi, Retail competition and cooperative advertising, *Operations Research Letters*, 39 (2011), 11–16.

[25] Y. He and X. Zhao, Contracts and coordination: Supply chains with uncertain demand and supply, *Naval Research Logistics*, 63 (2016), 305–319.

[26] T. H. Ho and J. Zhang, Designing pricing contracts for boundedly rational customers: does the framing of the fixed fee matter?, *Management Science*, 54 (2008), 686–700.

[27] D. Kahneman and A. Tversky, Prospect theory: An analysis of decision under risk, *Econometrica*, 47 (1979), 263–291.

[28] R. Lal, Improving channel coordination through franchising, *Marketing Science*, 9 (1990), 299–318.

[29] J. Y. Lee, R. K. Cho and S. K. Paik, Supply chain coordination in vendor-managed inventory systems with stockout-cost sharing under limited storage capacity, *European Journal of Operational Research*, 248 (2016), 95–106.

[30] W. Liu, S. Song, Y. Qiao and H. Zhao, The loss-averse newsvendor problem with random supply capacity, *Journal of Industrial and Management Optimization*, 13 (2017), 1417–1429.

[31] X. Liu, Q. Gou, L. Alwan and L. Liang, Option contracts: A solution for overloading problems in the delivery service supply chain, *Journal of the Operational Research Society*, 67 (2016), 187–197.

[32] P. Ma, H. Wang and J. Shang, Supply chain channel strategies with quality and marketing effort-dependent demand, *International Journal of Production Economics*, 144 (2013), 572–581.

[33] S. P. Sarmah, D. Acharya and S. K. Goyal, Coordination of a single-manufacturer/multi-buyer supply chain with credit option, *International Journal of Production Economics*, 111 (2008), 676–685.

[34] M. E. Schweitzer and G. P. Cachon, Decision bias in the newsvendor problem with a known demand distribution: experimental evidence, *Management Science*, 46 (2000), 404–420.

[35] Y. C. Tsao and G. J. Sheen, Effects of promotion cost sharing policy with the sales learning curve on supply chain coordination, *Computers & Operations Research*, 39 (2012), 1872–1878.

[36] N. K. Verma, A. Chakraborty and A. K. Chatterjee, Joint replenishment of multi retailer with variable replenishment cycle under VMI, *European Journal of Operational Research*, 233 (2014), 787–789.

[37] M. Waller, M. E. Johnson and T. Davis, Vendor-managed inventory in the retail supply chain, *Journal of Business Logistics*, 20 (1999), 183–204.

[38] C. X. Wang and S. Webster, Channel coordination for a supply chain with a risk-neutral manufacturer and a loss-averse retailer, *Decision Sciences*, 38 (2007), 361–389.

[39] C. X. Wang and S. Webster, The loss-averse newsvendor problem, *Omega*, 37 (2009), 93–105.

[40] X. Wang and L. Liu, Coordination in a retailer-led supply chain through option contract, *International Journal of Production Economics*, 110 (2007), 115–127.
[41] X. Wang, F. Li, L. Liang, Z. Huang and A. Ashley, Pre-purchasing with option contract and coordination in a relief supply chain, *International Journal of Production Economics*, 167 (2015), 170–176.

[42] D. J. Wu and P. R. Kleindorfer, Competitive options, supply contracting, and electronic markets, *Management Science*, 51 (2005), 452–466.

[43] T. Xiao, Y. Xia and G. P. Zhang, Strategic outsourcing decisions for manufacturers competing on product quality, *IIE Transactions*, 46 (2014), 313–329.

[44] Y. Yu and G. Q. Huang, Nash game model for optimizing market strategies, configuration of platform products in a vendor managed inventory (VMI) supply chain for a product family, *European Journal of Operational Research*, 206 (2010), 361–373.

[45] J. Zhang, Coordination of supply chain with buyer’s promotion, *Journal of Industrial and Management Optimization*, 3 (2007), 715–726.

[46] Y. Zhao, S. Wang, T. C. E. Cheng, X. Yang and Z. Huang, Coordination of supply chains by option contracts: A cooperative game theory approach, *European Journal of Operational Research*, 207 (2010), 668–675.

Received July 2017; 1st revision November 2017; final revision March 2018.

E-mail address: fuyou.huang@hotmail.com
E-mail address: hejunlin93@163.com
E-mail address: wangjsclf@just.edu.cn