RISK MINIMIZATION INVENTORY MODEL WITH A PROFIT TARGET AND OPTION CONTRACTS UNDER SPOT PRICE UNCERTAINTY

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ABSTRACT. This paper aims to analyze the inventory purchasing model for a manufacturer with an objective of minimizing risk and a constraint on profit target, where the manufacturer buys the components from the supplier or in the spot market and tailors them into the final products to meet a deterministic demand. This paper develops the mean-variance optimization models without and with option contracts, and conducts numerical examples to explore how the target profit level, the spot price uncertainty and option contracts affect the manufacturer’s optimal solutions and the level of risk. It is shown that without and with option contracts the manufacturer’s level of risk is non-decreasing in the target profit level. With (without) option contracts, the manufacturer suffers a zero risk from a higher spot price uncertainty if the profit target is low, whereas suffers a lower (higher) risk from a higher spot price uncertainty if the profit target is high. Finally, the level of risk faced by the manufacturer is not higher with option contracts than without them. This paper facilitates the application of option contracts in inventory purchasing management with a spot market for the risk minimization manufacturer with a profit target consideration. New insights are also provided for the manufacturer to set an appropriate profit target for an affordable level of risk, and establish the risk observation mechanism for hedging against the spot price volatility effectively.

1. Introduction. In today’s complex business environment, the daily operations of the firms are often affected by various uncertainties. Risk management plays a critical role in the success of firms. A great deal of efforts should be made by the firms to deal with the risks. For instance, Benetton, a fashion brand, dyes the garments after receiving the orders for the specific colors (Choi, 2016). This measure

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named risk pooling can help reduce high risk derived from demand volatility. In addition, risk management is restrained by many factors in business practice. The profit target is one of the most important considerations. Inappropriate profit target might result in high risk, while inappropriate risk management might lead to serious profit losses (Zhuo et al., 2018). For example, Li-Ning, a well-known sports brand in China, was over-optimistic about the future sales and had his inventory overhang after the 2008 Olympics. However, the effect of brand repositioning was swiftly evident later on. Between 2011 and 2012, more than 1800 stores were shuttered and the revenue fell extremely. Obviously, it is a significant challenge for the firms to attain a suitable tradeoff between the risk and the profit.

The expected measure is the classic approach within the realm of operational research for quantifying the level of risk. For example, the most basic and intuitive method to explore the level of risk in the newsvendor problem is to evaluate the shortage risk based on the expected under-stocking costs and assess the inventory risk based on the expected over-stocking costs. The optimal inventory decision is generated by balancing these two kinds of risks. As stated in Chiu and Choi (2016), the expected measure approach exhibits the magnitude of adverse outcomes, but not the level of risk. As a result, a great number of measures are proposed to derive an effective optimal control under a risk consideration. Among all such measures, the commonly used method is the mean-variance approach. Under the mean-variance framework, the payoff is measured by the expected profit (the mean of profit) and the risk is captured by the variance of profit. Obviously, the mean-variance method can reveal the level of risk. Thus, we apply the mean-variance model to explore the risk minimization inventory model with a profit target consideration.

Inventory purchasing problem is one of the most attractive research topics in operational management. Over the past few decades, the emergence and development of the e-commerce platforms has promoted the spot purchasing enormously. The contract market is no longer the sole purchasing source and the spot market becomes an alternative. A variety of commodities ranging from metals to electronics become available in the spot market (Inderfurth and Kelle, 2011; Wu et al., 2014). The spot purchasing provides a high flexibility so that the firms can obtain their needs at a negligible lead time to avoid the shortage risk. However, the prices for commodities purchased in the spot market have a high volatility. For example, the spot prices for the memory chips always fluctuate in a roller-coaster fashion. The high price might have more than doubled or tripled the low price within a year (Fu et al., 2010). In this context, the contract market is always combined with the spot market based procurement (Nagali et al., 2008; Fu et al., 2012). In practice, portfolio purchasing has gained popularity in more and more industries such as fresh food, automotive and high-tech (Wan and Chen, 2018).

Option contracts can postpone the purchasing until the uncertainties have been resolved. The option mechanism is often applied as a risk hedging for the capricious spot market, and is being explored in many procurement practices. For example, the ratio of the spot purchasing costs has increased up to over 15% of the total purchasing costs in Hewlett-Packard (Ma et al., 2013). As a result, a purchasing risk management (PRM) program containing option contracts has been initiated to avoid over reliance on the spot market (Nagali et al., 2008). Often, option contracts have two parameters, viz., the option price and the exercise price. The option price is an upfront allowance paid by the manufacturer to reserve the supplier’s component capacity. Since the options are the right but not the obligation, the manufacturer
can choose to exercise the options or not based on the specific market condition later on. If the spot price exceeds the strike price, the options are exercised first at a pre-negotiated strike price up to the reservation quantity. If the spot price falls below the strike price, the options are elapsed directly and the spot market turns into the alternative purchasing source. Obviously, option contracts can lock in a fixed quantity of future supply and protect against the spot price spikes effectively.

This research explores the risk minimization inventory decision with a target profit level in the presence of option contracts and a spot market. As presented in Section 2, the value of option contracts is well understood for the profit maximization supply chain agents in the presence of a spot market. However, very few studies explore the application effect of option contracts on the risk minimization supply chain actors in the presence of a spot market. As a result, the question that arises is to what extent option contracts affect the risk minimization firm in a supply chain under the spot price uncertainty. In this paper, we limit ourselves to a problem setting of deterministic demand. This is to focus on the analysis of contracting on the aspect of random spot price. As stated in Sobel and Zhang (2001), this setting is of practical relevance for the industries with make-to-order manufacturing systems where demand is most appropriately modeled as deterministic. By considering an inventory purchasing problem for a manufacturer with a risk minimization objective and a profit target constraint under random spot price and deterministic demand, we address the following questions:

1. What is the optimal purchasing policy for the manufacturer with a spot market, either without or with option contracts?
2. How does the target profit level affect the manufacturer’s optimal purchasing policy and the level of risk?
3. What effect does the spot price uncertainty have on the manufacturer’s optimal purchasing policy and the level of risk?
4. How the manufacturer’s optimal purchasing policy and the level of risk are affected by the introduction of option contracts?

The rest of this research is arranged as follows. Section 2 reviews the related literature. Section 3 presents the model formulation and assumptions. Sections 4 and 5 build the models without and with option contracts. Section 6 conducts numerical study to discuss the impacts of the target profit level, the spot price uncertainty and option contracts. Section 7 summarizes the results and provides the suggestions for future research.

2. Literature review. One stream of research focuses on the mean-variance (MV) analysis in operational research. Related studies can be classified into two categories. The first category is conducted from the perspective of a single firm. Choi et al. (2008a) applied the MV approach to study the optimal ordering policies and the corresponding mean and variance of profits for both risk-averse and risk-seeking newsvendors. Wu et al. (2009) investigated the optimal purchasing decision for a risk-averse newsvendor with the MV objective under consideration of stockout costs. Choi et al. (2011) derived the optimal inventory threshold policy for the multiperiod inventory control system under the MV framework. Liu and Nagurney (2011) applied the MV model to discuss the impacts of competition intensity and foreign exchange risk on risk-neutral and risk-averse supply chain firms involved in offshore-outsourcing activities. Choi and Chiu (2012) studied the inventory decision problem for a fashion retailer with the mean-downside-risk and MV objectives when the retail price is exogenous or endogenous. Chiu and Choi (2016) adopted
the MV method to analyze the multiperiod risk minimization inventory problem for a fashion retailer with considerations of budget, interest rate and profit target.

The second category is based on the perspective of a supply chain. Choi et al. (2008b) proposed the MV formulation for a two-stage supply chain to discuss the impact of a returns policy on channel coordination and risk control. Wei and Choi (2010) analyzed the impact of the wholesale pricing and profit sharing scheme on the coordination of a supply chain with two risk-averse agents under the MV framework. Shen et al. (2013) applied the MV model to explore the impact of the markdown money policy on a fashion supply chain consisted of a risk-averse manufacturer and a risk-neutral retailer. Chiu et al. (2015) developed two menus of contracts, viz., the menu of the target sales rebate with fixed order quantity contract and the menu of the target sales rebate with minimum order quantity and quantity discount contract, to coordinate a supply chain with a risk-neutral manufacturer and multiple heterogeneously MV retailers. Liu et al. (2016) adopted the MV objective to analyze the impact of the degree of risk aversion on the pricing decisions and the expected profits of a dual-channel supply chain with risk-averse members under symmetric and asymmetric information situations. Zhao et al. (2017) conducted the MV analysis to evaluate the performance of the wholesale price contract that incorporates the value risk of contract and the degree of the retailer’s risk-aversion on a two-stage supply chain when the demand is price dependent and downward sloping. Li et al. (2017) formulated the MV model to study the impacts of the retailer’s risk aversion and the manufacturer’s encroachment on the optimal solutions for a dual-channel supply chain under the information asymmetry situation. Zhao and Zhu (2018) applied the MV as a risk measure to investigate the impact of the risk-averse marketing strategy on the coordination of a remanufacturing supply chain under the market fluctuation situation. All these above papers never involve option contracts and the spot market.

Another stream of research focuses on the inventory purchasing problem with option contracts and a spot market. Wu et al. (2002) investigated the optimal bidding and contracting strategies between one seller and one or more buyers in the presence of option contracts and a spot market. Spinler et al. (2003) discussed the value of option contracts for physical delivery when the spot market is available. Wu and Kleindorfer (2005) analyzed the optimal portfolio usage of forwards, options and spot purchasing in a multiple-sellers and one-buyer system, in which the competition among multiple sellers with heterogeneous technologies is considered. Martínez-de-Albéniz and Simchi-Levi (2009) explored the purchasing strategy for one buyer and the pricing strategy for multiple suppliers in the presence of option contracts and a spot market, and then explore the effect of suppliers’ competition on the equilibrium outcomes. Fu et al. (2010) considered the single-period and two-period inventory purchasing problems with option contracts and a spot market, where the demand and the spot price are either correlated or independent. Arnold and Minner (2011) explored the optimal portfolio ordering strategy for one single firm with advance contracts, option contracts and a spot market in the asymmetric and duopolistic sales market. Fu et al. (2012) analyzed the multiperiod combined pricing and purchasing problem with option contracts and a spot market, where the demand is correlated with the current selling price and the spot price is dependent on the subsequent option price. Lee et al. (2013) studied the portfolio purchasing problem for a buyer who can purchase from multiple suppliers by signing option contracts or in a spot market at an uncertain spot price, where the capacity constraints
and the fixed ordering costs are taken into account. Xu et al. (2015) derived the optimal purchasing strategy for a risk-neutral buyer with option contracts in the single-period and multiperiod cases, where the spot selling and buying are subject to market liquidity. Merzhifonluoglu (2017) provided the novel optimization models to explore the sourcing and demand selection decisions for a buyer with option contracts and a spot market. Zhao et al. (2018) characterized the optimal policies for the portfolio procurement between option contract and spot markets, and design the option mechanism for supply chain coordination under demand information updating. Wan and Chen (2018) applied the dynamic programming approach to explore the multiperiod portfolio purchasing problems with a spot market in the presence of various option contracts. All these above papers never incorporate the risk minimization consideration into the analysis.

To the best of our knowledge, studies on the MV model with option contracts are very limited. Buzacott et al. (2011) conducted the MV analysis for commitment-option contracts with information updating to explore the optimal reservation and commitment decisions and illustrate the effect of forecast accuracy on the profit under supply and demand uncertainties. Zhuo et al. (2018) investigated the condition for coordinating a supply chain through option contracts under the MV framework, when the information on the risk aversion threshold of the retailer is symmetric or asymmetric to the supplier. Feng and Wu (2018) applied the MV approach to investigate the supplier’s risk and design the option contract from the supplier’s perspective. Their studies are analogous to ours, but there are obvious distinctions. First, they did not involve the spot market. However, we take the spot market as an emergency source. Moreover, they modeled the demand as stochastic. However, we consider the deterministic demand. Finally, they aimed to maximize the expected profit subjected to a constraint on the variance of profit. However, our objective is to minimize the variance of profit subjected to a constraint on the profit target.

3. **Model assumptions and formulation.** This paper analyzes the inventory purchasing problem for a manufacturer with an objective of minimizing risk and a constraint on profit target. The manufacturer purchases the components from the supplier or in the spot market and then tailors them into the final products to satisfy a deterministic demand. Here, the spot market acts as an emergency source of the components. That is to say, the manufacturer can make emergency replenishment by buying the components from the spot market or make speculative trade by selling the components on the spot market (Day et al., 2003; Wu and Kleindorfer, 2005; Luo and Chen, 2017). Without loss of generality, we assume that the spot market is open and the capacity of the spot market is unlimited. Thus, the manufacturer can go to the spot market for the component procurement at the last minute. However, since the spot price fluctuates randomly over time, the usage of flexible contracts is favorable for the manufacturer to hedge against the spot price uncertainty. Among all such contracts, option contracts are attractive as the manufacturer can lock the component supply by reserving the capacity in advance and obtain the flexibility by executing the options up to the reservation quantity later on. Thus, we discuss the risk minimization inventory purchasing problem for a manufacturer with a profit target in the presence of option contracts and a spot market.

The timeline of the event is described in Fig. 1. At the time point $t_0$, the manufacturer decides the order quantities of two types, including the firm order quantity (the order quantity of the components) and the options order quantity (the order quantity of the options), from the supplier. Each option gives the manufacturer
the flexibility to obtain an additional component on or before a specified time. At the time point $t_1$, the firm order arrives at the manufacturer’s site immediately. Between the time point $t_1$ and the time point $t_2$, the manufacturer could choose to execute the options or purchase in the spot market based on the realized spot price. Note that the options exercised quantity cannot exceed the options order quantity reserved at the time point $t_0$.

![Figure 1. The timeline of the event](image)

The manufacturer has an objective of minimizing risk and a constraint on profit target. Incorporating the risk and the payoff, the mean-variance model is the most commonly used approach. Often, the risk is measured by the variance of profit and the payoff is captured by the expected profit (the mean of profit). For clear interpretation, the parameters, variables and symbols used in this paper are listed in Tab. 1.

| Notations | Descriptions |
|-----------|--------------|
| $p_s$     | Random spot price. |
| $f(p_s), F(p_s)$ | PDF and CDF function of $p_s$. |
| $\mu_s, \sigma_s$ | Mean and standard deviation of $p_s$. |
| $D$       | Deterministic demand. |
| $r$       | Unit retail price of the final product. |
| $\omega$  | Unit wholesale price of the component. |
| $o$       | Unit option price. |
| $e$       | Unit exercise price. |
| $K$       | The target profit level. |
| $q_0$     | The firm order quantity without option contracts. |
| $q_1$     | The firm order quantity with option contracts. |
| $q_2$     | The options order quantity |
| $H$       | $\int_{e}^{+\infty} (p_s - e) f (p_s) \, dp_s$ |
| $J$       | $\int_{e}^{+\infty} (p_s - \mu_s) (p_s - e) f (p_s) \, dp_s$ |
| $L$       | $\int_{e}^{+\infty} (p_s - e)^2 f (p_s) \, dp_s$ |
| $E(\cdot)$ | Expected value. |
| $V(\cdot)$ | Variance value. |

Other notations are defined when they are needed. In addition, we view the manufacturer as a “female”.
To avoid unreasonable cases, series of assumptions need to be satisfied throughout this paper. (1) The manufacturer’s assembly cost is zero. (2) \( r > \mu_s \). This condition ensures the manufacturer’s profit for the spot purchasing. (3) \( o + e > \omega > o \). This condition ensures that the manufacturer would like to place the firm order and purchases the options simultaneously. (4) \( \sigma_s^2(L - H^2) > J^2 \). This condition ensures that there exists a unique optimal purchasing policy for the manufacturer to minimize risk in the presence of option contracts and a spot market. Otherwise, there is no motivation for the risk minimization manufacturer to apply option contracts to obtain the goods from the spot market.

4. **Model without option contracts.** To begin, we formulate the model without option contracts as a basis, where the manufacturer only orders from a firm. Then, the manufacturer’s profit function, denoted \( \Pi(q_0) \), is

\[
\Pi(q_0) = rD - \omega q_0 - p_s(D - q_0)
\]

Taking the expectation and variance of Eq. (1), we have

\[
E[\Pi(q_0)] = (r - \mu_s)D + (\mu_s - \omega)q_0
\]

\[
V[\Pi(q_0)] = \sigma_s^2(D - q_0)^2
\]

Without option contracts, the mean-variance optimization problem of the manufacturer is

\[
\min_{q_0 \geq 0} V[\Pi(q_0)] \\
\text{s.t. } E[\Pi(q_0)] \geq K
\] (P1)

As to the optimal purchasing policy without option contracts, the following proposition is obtained.

**Proposition 1.** Without option contracts, the manufacturer’s optimal firm order quantity is

\[
q_*^0 = \begin{cases} 
q_0^\alpha & \text{if } K > (r - \omega)D \\
D & \text{if } K \leq (r - \omega)D
\end{cases}
\]

where \( q_0^\alpha = \frac{K - (r - \omega)D}{\mu_s - \omega} \).

Proposition 1 shows that there is an obvious distinction between the optimal purchasing policies for the risk minimization manufacturer without and with a profit target. If \( K \leq (r - \omega)D \), then \( q_*^0 = D \). This indicates that the optimal firm order quantity equals to the demand quantity. In other words, when the target profit level is relatively low, the components bought from the supplier are only tailored by the manufacturer into the final products to satisfy the market demand. If \( K > (r - \omega)D \), then \( q_*^0 > D \). This indicates that the optimal firm order quantity exceeds the demand quantity. In other words, when the target profit level is relatively high, one part of the components bought from the supplier are processed by the manufacturer into the final products to meet the market demand and the other part of the components bought from the supplier are resold by the manufacturer on the spot market for speculation. The results are consistent with traditional and common understandings.

Based on the above analysis, it is easy to find that there also exists an obvious difference between the levels of risk faced by the manufacturer without and with a profit target. When \( K \leq (r - \omega)D \), then \( V[\Pi(q_0^\alpha)] = 0 \). This means that the
manufacturer will suffer a zero risk. When $K > (r - \omega)D$, then $V[\Pi(q_0^*)] > 0$. This means that the manufacturer will suffer a nonzero risk.

From Proposition 1, the following corollary is obtained.

**Corollary 1.** Without option contracts, the manufacturer’s optimal firm order quantity is non-decreasing in $K$.

Corollary 1 indicates that the target profit level exerts a sustainable impact on the optimal purchasing policy for the risk minimization manufacturer without option contracts. If a high profit target is set, the manufacturer will place a large firm order. Conversely, if a small firm order is placed, the manufacturer will set a low profit target.

5. Model with option contracts. In this section, we consider the model with option contracts, in which the manufacturer orders from a firm and purchases the option contracts. If a high profit target is set, the manufacturer will place a large firm order. Conversely, if a small firm order is placed, the manufacturer will set a low profit target.

\[ \text{Corollary 1. Without option contracts, the manufacturer's optimal firm order quantity is non-decreasing in } K. \]

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**5. Model with option contracts.** In this section, we consider the model with option contracts, in which the manufacturer orders from a firm and purchases the options simultaneously. If $p_s > e$, the manufacturer will obtain the components via the firm order at first, then he will execute the options up to the reserved quantity, and finally he will buy the inadequate components in the spot market. If $p_s < e$, the manufacturer will obtain the components via the firm order at first, and then he will buy the insufficient components in the spot market. Then, the manufacturer’s profit function, denoted $\Pi(q_1, q_2)$, is

\[ \Pi(q_1, q_2) = \begin{cases} rD - wq_1 - oq_2 - eq_2 - p_s(D - q_1 - q_2) & \text{if } p_s > e \\ rD - wq_1 - oq_2 - p_s(D - q_1) & \text{if } p_s < e \end{cases} \quad (4) \]

Taking the expectation and variance of Eq. (4), we have

\[ E[\Pi(q_1, q_2)] = (r - \mu_s)D + (\mu_s - w)q_1 + (H - o)q_2 \quad (5) \]

\[ V[\Pi(q_1, q_2)] = (L - H^2)q_2^2 - 2J(D - q_1)q_2 + \sigma^2_s(D - q_1)^2 \quad (6) \]

With option contracts, the mean-variance optimization problem of the manufacturer is

\[
\min_{q_1 \geq 0, q_2 \geq 0} V[\Pi(q_1, q_2)] \\
s.t. \ E[\Pi(q_1, q_2)] \geq K 
\]

(P2)

Regarding the optimal purchasing policy with option contracts, the following proposition is obtained.

**Proposition 2.** With option contracts, the manufacturer’s optimal firm order quantity is

\[ q_1^* = \begin{cases} q_1^0 & \text{if } K > (r - w)D \\ D & \text{if } K \leq (r - w)D \end{cases} \]

and the optimal options order quantity is

\[ q_2^* = \begin{cases} q_2^0 & \text{if } K > (r - w)D \\ 0 & \text{if } K \leq (r - w)D \end{cases} \]

where

\[ q_1^0 = D - \frac{[K - (r - w)D][J(H - o) - (\mu_s - w)(L - H^2)]}{(H - o)(\sigma^2_s(H - o) - J(\mu_s - w) - (\mu_s - w)[J(H - o) - (\mu_s - w)(L - H^2)]} \]

and

\[ q_2^0 = \frac{[K - (r - w)D][\sigma^2_s(H - o) - J(\mu_s - w)]}{(H - o)[\sigma^2_s(H - o) - J(\mu_s - w)] - (\mu_s - w)J(H - o) - (\mu_s - w)(L - H^2)}. \]
Proposition 2 suggests that with option contracts the manufacturer’s optimal purchasing policy is expressed by an interval. If $K \leq (r - w)D$, only the firm order will be placed, and the optimal firm order quantity equals to the demand quantity. If $K > (r - w)D$, the firm order and the options order will be placed simultaneously, and the optimal firm order quantity might fall behind, equal to, or exceed the optimal options order quantity. From Proposition 2, we also find that the optimal total order quantity (the sum of the optimal firm order quantity and the optimal options order quantity) might equal to or exceed the demand quantity. This result is accordance with proposition 1. In other words, if necessary, the manufacturer can go to the spot market to purchase insufficient components for satisfying the market demand or to resell excessive components for conducting speculative transaction. The results are consistent with traditional and common understandings.

Based on the above result, it is easy to see that with option contracts the level of risk faced by the manufacturer is an interval. When $K \leq (r - w)D$, then $V[\Pi(q_1^*, q_2^*)] = 0$. This means that the manufacturer will suffer a zero risk. When $K > (r - w)D$, then $V[\Pi(q_1^*, q_2^*)] > 0$. This means that the manufacturer will suffer a nonzero risk.

From Proposition 2, the following corollary is obtained.

**Corollary 2.** With option contracts, the manufacturer’s optimal firm order quantity is non-increasing in $K$, while the optimal options order quantity is non-decreasing in $K$.

Corollary 2 indicates that the target profit level exerts an important effect on the optimal purchasing policy for the risk minimization manufacturer with option contracts. An increased profit target might prompt the manufacturer to purchase fewer components and more options. This finding, combined with Corollary 1, reveals the relationship between the manufacturer’s purchasing decision and the target profit level.

6. **Discussion.** In this section, we conduct numerical study to explore the impacts of the target profit level and the spot price uncertainty on the manufacturer’s purchasing decisions and the level of risk (valued by the variance of profit). We also present parameter analysis to provide more insights with respective to the impact of option contracts.

Throughout this section, the spot price is assumed to be uniformly distributed. Partial parameters are kept constant as follows: $r = 20$, $D = 100$ and $\mu_s = 16$. The target profit level ($K$), the standard deviation of the spot price ($\sigma_s$), the wholesale price ($w$), the option price ($o$) and the exercise price ($e$) are changed to describe different cases.

**1. The impact of the target profit level**

We now examine the effect of the target profit level. For this, we set $w = 10$, $o = 3$, $e = 8$ and $p_s \sim (2, 30)$. By changing the value of $K$ from 950 to 1200, the related results are shown in Fig. 2.

Figure 2(a) suggests that when the profit target constraint is not binding, the target profit level has nothing to do with the manufacturer’s optimal solutions in two cases. Without and with option contracts, as the target profit level increases, the manufacturer will place a fixed firm order for which the optimal quantity equals to the demand quantity in the presence of a low target profit level. Moreover, when the profit target constraint is binding, the target profit level has a different impact on the manufacturer’s optimal solutions in two cases. Without option contracts, as
the target profit level increases, the manufacturer will place a larger firm order in the presence of a high target profit level. With option contracts, as the target profit level increases, the manufacturer will place a smaller firm order and a larger options order in the presence of a high target profit level. Especially, when the profit target constraint is binding, the manufacturer’s optimal firm order quantity with option contracts might be higher than, equal to, or lower than the optimal options order quantity. These numerical results are accordance with Corollary 1 and Corollary 2.

Figure 2. The impact of the target profit level

Figure 2(b) indicates that when the profit target constraint is not binding, the target profit level has nothing to do with the manufacturer’s level of risk in two cases. Without and with option contracts, as the target profit level increases, the manufacturer will suffer a zero risk in the presence of a low target profit level. Moreover, when the profit target constraint is binding, the target profit level exerts a positive impact on the manufacturer’s level of risk the in two cases. Without and with option contracts, as the target profit level increases, the manufacturer will suffer a higher risk in presence of a high target profit level. Especially, when the profit target constraint is binding, as the target profit level increases, the manufacturer’s level of risk has a smaller magnitude of change with option contracts than without them.

Based on the above analysis, the following remark can be obtained.

**Remark 1.** Without and with option contracts, the level of risk faced by the manufacturer is non-decreasing in $K$.

This remark shows that the target profit level has an important effect on the level of risk faced by the manufacturer, either without or with option contracts. When a high profit target is set, the manufacturer will suffer from a high risk. However, when a low risk is required, the manufacturer will set a low profit target. Obviously, it is important for the manufacturer to set an appropriate profit target for an affordable level of risk. The manufacturer should try the best to balance the risk and the profit.

**(2) The impact of the spot price uncertainty**

We now explore the effect of the spot price uncertainty (valued by $\sigma_s$). As illustrated in Fig. 2, without and with option contracts, when the profit target is
set at a low level, the manufacturer only orders from the firm to suffer a zero risk. In the following, we focus on the case that the profit target is set at a high level. For this, we set $K = 1100$, $w = 10$, $o = 3$ and $e = 8$. We let the range of the spot price be $(3,29)$, $(2.5,29.5)$, $(2,30)$, $(1.5,30.5)$, $(1,31)$ and $(0.5,31.5)$. Thus, the standard deviation of the spot price is the values of $7.51$, $7.79$, $8.08$, $8.37$, $8.66$ and $8.95$. By changing the value of $\sigma_s$ from 7.51 to 8.95, the related results are shown in Fig. 3.

Figure 3(a) indicates that when the profit target constraint is binding, the spot price uncertainty exerts a different effect on the manufacturer’s optimal solutions in two cases. Without option contracts, the spot price uncertainty does not influence the manufacturer’s optimal firm order quantity under a high target profit level. With option contracts, the spot price uncertainty negatively affects the manufacturer’s optimal firm order quantity, while positively affects his optimal options order quantity under a high target profit level.

Figure 3(b) suggests that when the profit target constraint is binding, the spot price uncertainty exerts a different impact on the manufacturer’s level of risk in two cases. Without option contracts, the spot price uncertainty positively affects the manufacturer’s level of risk under a high target profit level. With option contracts, the spot price uncertainty negatively affects the manufacturer’s level of risk under a high target profit level. Especially, when the profit target constraint is binding, as the spot price uncertainty increases, the manufacturer’s level of risk has a greater magnitude of change with option contracts than without them.

Based on the above analysis, the following remark can be obtained.

**Remark 2.** Without option contracts, the manufacturer suffers a zero risk from a higher spot price uncertainty when $K \leq (r - w)D$, while suffers a higher risk from a higher spot price uncertainty when $K > (r - w)D$. With option contracts, the manufacturer suffers a zero risk from a higher spot price uncertainty when $K \leq (r - w)D$, while suffers a lower risk from a higher spot price uncertainty when $K > (r - w)D$.

This remark shows that the application effect of option contracts is dependent on the spot price uncertainty in the presence of a high profit target. That is,
when the profit target is set at a high level, the higher the spot price uncertainty, the more obvious the application effect of option contract will be. Obviously, it is important for the risk minimization manufacturer to observe whether the spot price uncertainty is high or low in practice. Thus, the establishment of risk observation mechanism seems rather urgent and necessary.

(3) The impact of option contracts

Here, we mainly discuss the effect of option contracts by analyzing how the wholesale price, the option price and the exercise price influence the manufacturer’s optimal decisions and the level of risk. Similarly, due to the same reason stated above, we consider the cases with a high profit target in the following numerical examples. Here, “N.A.” is used as inapplicable, for the derived results are unreasonable.

First, we investigate the effect of the wholesale price. For this, we set \( K = 1100, \ o = 3, \ e = 8 \) and \( p_s \sim (2, 30) \). By changing the value of \( w \) from 9.9 to 10.4, the related results are shown in Tab. 2.

| \( w \) | Wholesale price contracts | Option contracts |
|-------|---------------------------|-----------------|
|       | \( q_0^* \) | \( V[\Pi(q_0^*)] \) | \( q_1^* \) | \( q_2^* \) | \( V[\Pi(q_1^*, q_2^*)] \) |
| 9.9   | 114.75 | 14222.00 | 86.66 | 30.37 | 12959.00 |
| 10.0  | 116.67 | 18148.10 | 75.91 | 43.33 | 15385.30 |
| 10.1  | 118.64 | 22709.90 | 64.74 | 56.36 | 17595.60 |
| 10.2  | 120.69 | 27966.70 | 53.77 | 68.78 | 19508.20 |
| 10.3  | 122.81 | 33983.80 | 43.51 | 80.10 | 21087.80 |
| 10.4  | 125.00 | 40833.30 | 34.24 | 96.07 | 22337.60 |

Table 2 indicates that when the profit target constraint is binding, the wholesale price exerts a different impact on the manufacturer’s optimal solutions in two cases. If the profit target is high, as the wholesale price increases, the manufacturer’s optimal firm order quantity without option contracts will increase. If the profit target is high, as the wholesale price increases, the manufacturer’s optimal firm order quantity with option contracts will decrease whereas the optimal options order quantity will increase. Moreover, when the profit target constraint is binding, the manufacturer’s optimal firm order quantity is lower with option contracts than without them. Notably, if the profit target is high, as the wholesale price increases, the manufacturer’s optimal firm order quantity has a smaller magnitude of change without option contracts than with them. Furthermore, when the profit target constraint is binding, the wholesale price has an identical impact on the manufacturer’s level of risk in two cases. If the profit target is high, the manufacturer will suffer a higher risk from a higher wholesale price, either without or with option contracts. Finally, when the profit target constraint is binding, the manufacturer’s level of risk is lower with option contracts than without them. Especially, if the profit target is high, as the wholesale price increases, the manufacturer’s level of risk has a smaller magnitude of change with option contracts than without them.

Next, we examine the effect of the option price. For this, we set \( K = 1100, \ w = 10, \ e = 8 \) and \( p_s \sim (2, 30) \). By changing the value of \( o \) from 2.9 to 3.4, the related results are shown in Tab. 3.
Table 3. The impact of the option price when $K > (r - w) D$

| $o$ | Wholesale price contracts | Option contracts |
|-----|---------------------------|------------------|
|     | $q^*_0$ | $V \{ \Pi (q^*_0) \}$ | $q^*_1$ | $q^*_2$ | $V \{ \Pi (q^*_1, q^*_2) \}$ |
| 2.9 | 116.67 | 18148.10 | 68.18 | 50.65 | 13999.33 |
| 3.0 | 116.67 | 18148.10 | 75.91 | 43.33 | 15385.30 |
| 3.1 | 116.67 | 18148.10 | 85.73 | 33.49 | 16620.79 |
| 3.2 | 116.67 | 18148.10 | 97.34 | 21.31 | 17563.07 |
| 3.3 | 116.67 | 18148.10 | 110.04 | 7.44 | 18078.89 |
| 3.4 | 116.67 | 18148.10 | N.A. | N.A. | N.A. |

Table 3 indicates that when the profit target constraint is binding, as the option price increases, the manufacturer’s optimal firm order quantity with option contracts will increase while the optimal options order quantity will decrease. Moreover, when the profit target constraint is binding, the manufacturer’s optimal firm order quantity is lower with option contracts than without them. Furthermore, when the profit target constraint is binding, the manufacturer will suffer a higher risk from a higher option price in the presence of option contracts. Finally, when the profit target constraint is binding, the manufacturer’s level of risk is lower with option contracts than without them.

Finally, we explore the effect of the exercise price. For this, we set $K = 1100$, $w = 10$, $o = 3$ and $p_s \sim (2, 30)$. By changing the value of $e$ from 7.8 to 8.8, the related results are shown in Tab. 4.

Table 4. The impact of the exercise price when $K > (r - w) D$

| $e$ | Wholesale price contracts | Option contracts |
|-----|---------------------------|------------------|
|     | $q^*_0$ | $V \{ \Pi (q^*_0) \}$ | $q^*_1$ | $q^*_2$ | $V \{ \Pi (q^*_1, q^*_2) \}$ |
| 7.8 | 116.67 | 18148.10 | 63.96 | 54.52 | 13533.20 |
| 8.0 | 116.67 | 18148.10 | 75.91 | 43.33 | 15385.30 |
| 8.2 | 116.67 | 18148.10 | 89.21 | 30.03 | 16847.18 |
| 8.4 | 116.67 | 18148.10 | 102.50 | 15.95 | 17776.12 |
| 8.6 | 116.67 | 18148.10 | 114.54 | 2.47 | 18138.83 |
| 8.8 | 116.67 | 18148.10 | N.A. | N.A. | N.A. |

Table 4 shows that when the profit target constraint is binding, as the exercise price increases, the manufacturer’s optimal firm order quantity with option contracts will increase while the optimal options order quantity will decrease. Moreover, when the profit target constraint is binding, the manufacturer’s optimal firm order quantity is lower with option contracts than without them. Furthermore, when the profit target constraint is binding, the manufacturer will suffer a higher risk from a higher exercise price in the presence of option contracts. Finally, when the profit target constraint is binding, the manufacturer’s level of risk is lower with option contracts than without them.

Based on the above analysis, the following remark can be obtained.
Remark 3. With option contracts, the manufacturer’s level of risk is constant in \((w, o, e)\) when \(K \leq (r - w)D\); while is increasing in \((w, o, e)\) when \(K > (r - w)D\).

Remark 4. The level of risk faced by the manufacturer is not higher with option contracts than without them.

Remark 3 illustrates the impacts of the contract parameters on the level of risk faced by the manufacturer with option contracts. When the profit target is set at a low level, no matter how the contract parameters change, the manufacturer’s level of risk is always zero. When the profit target is set at a high level, the manufacturer’s level of risk will increase as the contract parameters increase. Therefore, it is advised that such contract mechanism should be designed rationally so that the manufacturer can bear an affordable level of risk. Remark 4 suggests that the introduction of option contracts is helpful for the manufacturer to undertake a low level of risk when the profit target is set at a high level. Therefore, it is advised that the application of option contracts should be promoted actively so that the manufacturer can hedge against high spot price volatility.

7. Conclusions and suggestions for further research. This paper considers the inventory purchasing problem for one manufacturer who can either reserve the components from the supplier through option contracts or trap into the spot market for the prompt component procurement to satisfy a deterministic demand. The objective of the manufacturer is to minimize risk and achieve the profit target. We adopt the mean-variance approach to formulate the risk minimization inventory models for the manufacturer with the consideration of a profit target, either without or with option contracts. For these two cases, we identify the analytical expressions for the manufacturer’s optimal purchasing policies. We further conduct numerical examples to explore the impacts of the target profit level, the spot price uncertainty and option contracts on the manufacturer’s optimal solutions and the level of risk, respectively. Several important observations are presented as follows.

Observation 1. Without option contracts, the manufacturer’s optimal firm order quantity is non-decreasing in the target profit level. With option contracts, the manufacturer’s optimal firm order quantity is non-increasing in the target profit level, while his optimal options order quantity is non-decreasing in the target profit level. Moreover, the manufacturer’s level of risk is non-decreasing in the target profit level, either without or with option contracts.

Observation 2. Under a high target profit level, the manufacturer’s optimal firm order quantity without option contracts is constant in the spot price uncertainty. Under a high target profit level, the manufacturer’s optimal firm order quantity with option contracts is decreasing in the spot price uncertainty, while the optimal options order quantity is increasing in the spot price uncertainty. Moreover, under a high target profit level, the manufacturer’s level of risk without option contracts is increasing in the spot price uncertainty. Under a high target profit level, the manufacturer’s level of risk with option contracts is decreasing in the spot price uncertainty.

Observation 3. Under a high target profit level, the manufacturer’s optimal firm order quantity without option contracts is increasing in the wholesale price. Under a high target profit level, the manufacturer’s optimal firm order quantity with option contracts is decreasing in the wholesale price, while the optimal options order quantity is increasing in the wholesale price. Moreover, under a high target profit level,
the manufacturer’s level of risk is increasing in the wholesale price, either without or with option contracts.

Observation 4. Under a high target profit level, the manufacturer’s optimal firm order quantity with option contracts is increasing in the option price, while the optimal options order quantity is decreasing in the option price. Moreover, under a high target profit level, the manufacturer’s level of risk with option contracts is increasing in the option price.

Observation 5. Under a high target profit level, the manufacturer’s optimal firm order quantity with option contracts is increasing in the exercise price, while the optimal options order quantity is decreasing in the exercise price. Moreover, under a high target profit level, the manufacturer’s level of risk with option contracts is increasing in the exercise price.

Observation 6. Under a low target profit level, the manufacturer’s optimal firm order quantity equals to the demand quantity so that the manufacturer’s level of risk is zero, either without or with option contracts. Under a high target profit level, the manufacturer’s optimal firm order quantity is lower with option contracts than without them, and the manufacturer’s level of risk is lower with option contracts than without them.

The contribution of our research is twofold. First, most existing studies demonstrate the value of option contracts for the profit maximization supply chain agents in the presence of a spot market. However, the role of option contracts is little known for the risk minimization supply chain actors in the presence of a spot market. This paper contributes to the relevant literature by investigating the implication of the risk minimization consideration for option contracts in the presence of a spot market. Moreover, most existing studies exhibit the value of option contracts for the supply chain under stochastic demand and random spot price. However, the role of option contracts is little known for the supply chain under deterministic demand and random spot price. In real world business, the setting of deterministic demand is of practical relevance for the industries with make-to-order manufacturing system. In this paper, we limit ourselves to a setting of deterministic demand so as to focus on the analysis of contracting on the aspect of random spot price. To the best of our knowledge, this paper is the first to explore the risk minimization inventory decision for the manufacturer with a profit target and option contracts under the spot price uncertainty.

From this paper, we can obtain several important managerial insights as follows. First, when facing random spot price, the firms who set a high profit target would suffer from a high level of risk, in contrast, the firms who face a low level of risk would set a low profit target. Hence, it is important for the firms to set an appropriate profit target for an affordable level of risk. Second, if the profit target is set at a high level, the higher the spot price uncertainty, the better the application effect of option contracts will be. Hence, it is important for the firms to build the risk observation mechanism. Third, if the profit target is set at a high level, the level of risk faced by the manufacturer is increasing in the wholesale price, the option price and the exercise price. Hence, it is important for the firms to rationally design the contract mechanism to bear an affordable level of risk. Finally, the introduction of option contracts would help the firms reduce the risk derived from spot price volatility. Hence, it is important for the firms to apply option contracts reasonably to achieve the risk minimization goal.
Several potential extensions are worth being explored in the future research. First, this current paper considers the deterministic demand. It is a potential research direction to take demand uncertainty into account. Moreover, this current paper explores the risk minimization inventory purchasing problem from the perspective of a single firm. A possible extension is to analyze the supply chain coordination problem with risk minimization agents. Furthermore, this current paper only considers only a type of option contracts. It is a challenge to explore the impact of different option contracts on the risk minimization manufacturer. Finally, this current paper only analyzes the optimal purchasing policy for the manufacturer. It would be interesting to take the option and executive prices as the decision variables to investigate the ordering and pricing decisions for the manufacturer.

Appendix

Proof of Proposition 1.

Proof. From Eq. (3), \( \frac{dV[\Pi(q_0)]}{dq_0} = -2\sigma_s^2(D - q_0) \) and \( \frac{d^2V[\Pi(q_0)]}{dq_0^2} = 2\sigma_s^2 > 0 \). Hence, \( V[\Pi(q_0)] \) is convex in \( q_0 \). Let \( \frac{dV[\Pi(q_0)]}{dq_0} = 0 \), we obtain \( q_0^* = D \).

Define \( K = (r - w)D \).

(1) If \( K \leq \bar{K} \), the profit target constraint is not binding. In this case, the manufacturer’s optimal purchasing policy is \( q_0^* = q_0 \).

(2) If \( K > \bar{K} \), the profit target constraint is binding. In this case, the Kuhn-Tucker conditions are given as follows:

1) \( \lambda_1 [K - (r - \mu_s) D - (\mu_s - w)q_0] = 0; \)
2) \( \lambda_2 q_0 = 0; \)
3) \(-2\sigma_s^2 (D - q_0) = \lambda_1 (\mu_s - w) - \lambda_2; \)
4) \( \lambda_1 \geq 0, \lambda_2 \geq 0, q_0 \geq 0; \)

where \( \lambda_1 \) and \( \lambda_2 \) are the generalized Lagrange multipliers.

Given \( q_0 > 0 \), we get \( \lambda_2 = 0 \). From the Kuhn-Tucker conditions 4) and the profit target constraint, we have \( \lambda_1 = \frac{2\sigma_s^2[K - (r - w)D]}{(\mu_s - w)^2} \) and \( q_0^* = \frac{K - (r - \mu_s)D}{\mu_s - w} \). Hence, \( q_0 > 0 \) is satisfied.

Proof of Corollary 1.

Proof. If \( K \leq (r - w)D \), we have \( \frac{dq_0^*}{dK} = 0 \), which indicates that \( q_0^* \) is constant in \( K \). If \( K > (r - w)D \), we have \( \frac{dq_0^*}{dK} > 0 \), which indicates that \( q_0^* \) is increasing in \( K \).

Proof of Proposition 2.

Proof. From Eq. (6),

\[
\frac{\partial V[\Pi(q_1, q_2)]}{\partial q_1} = 2J q_2 - 2\sigma_s^2 (D - q_1),
\]

\[
\frac{\partial V[\Pi(q_1, q_2)]}{\partial q_2} = 2(L - H^2) q_2 - 2J (D - q_1),
\]

\[
\frac{\partial^2 V[\Pi(q_1, q_2)]}{\partial q_1^2} = 2\sigma_s^2,
\]

\[
\frac{\partial^2 V[\Pi(q_1, q_2)]}{\partial q_2^2} = 2(L - H^2)
\]
and 
\[
\frac{\partial^2 V}{\partial q_1 \partial q_2} = \frac{\partial^2 V}{\partial q_2 \partial q_1} = 2J.
\]
then
\[
\begin{vmatrix}
\frac{\partial^2 V}{\partial q_1^2} & \frac{\partial^2 V}{\partial q_1 \partial q_2}
\end{vmatrix}
\begin{vmatrix}
\frac{\partial^2 V}{\partial q_2^2}
\end{vmatrix}
= 4 \left[ \sigma_s^2 (L - H^2) - J^2 \right] > 0.
\]

Hence, \( V[\Pi(q_1,q_2)] \) is joint convex in \( q_1 \) and \( q_2 \). Let \( \frac{\partial V}{\partial q_1} = 0 \) and \( \frac{\partial V}{\partial q_2} = 0 \), we obtain \( \bar{q}_1 = D \) and \( \bar{q}_2 = 0 \).

Define \( K = (r - w) D \).

(1) If \( K \leq \bar{K} \), the profit target constraint is not binding. In this case, the manufacturer’s optimal purchasing policies are \( q_1^* = \bar{q}_1 = D \) and \( q_2^* = \bar{q}_2 = 0 \).

(2) If \( K > \bar{K} \), the profit target constraint is binding. In this case, the Kuhn-Tucker conditions are given as follows:

1) \( \theta_1 [K - (r - \mu_s) D - (\mu_s - w) q_1 - (H - o) q_2] = 0 \);
2) \( \theta_2 q_1 = 0 \);
3) \( \theta_3 q_2 = 0 \);
4) \( 2J q_2 - 2\sigma_s^2 (D - q_1) = \theta_1 (\mu_s - w) - \theta_2 \);
5) \( 2 (L - H^2) q_2 - 2J (D - q_1) = \theta_1 (H - o) - \theta_3 \);
6) \( \theta_1 > 0, \theta_2 > 0, \theta_3 \geq 0, q_1 \geq 0, q_2 \geq 0 \).

where \( \theta_1, \theta_2 \) and \( \theta_3 \) are the generalized Lagrange multipliers.

**Case 1:** Given \( q_1 = 0 \) and \( q_2 > 0 \), we get \( \theta_3 = 0 \). From the Kuhn-Tucker conditions 4), we have
\[
q_2 = \frac{2\sigma_s^2 D + \theta_1 (\mu_s - w) - \theta_2}{2J}.
\]

From the Kuhn-Tucker conditions 5), we have
\[
q_2 = \frac{2JD + \theta_1 (H - o)}{2(L - H^2)},
\]
that is,
\[
\theta_1 = \frac{2D \left[ \sigma_s^2 (L - H^2) - J^2 \right] - \theta_2 (L - H^2)}{J (H - o) - (\mu_s - w) (L - H^2)}.
\]

Then, it follows that
\[
q_2 = \frac{2D [\sigma_s^2 (H - o) - J (\mu_s - w)] - \theta_2 (H - o)}{2 [J (H - o) - (\mu_s - w) (L - H^2)]}.
\]

By considering \( q_2 > 0 \), we obtain
\[
\theta_2 < \frac{2D [\sigma_s^2 (H - o) - J (\mu_s - w)]}{H - o},
\]
which contradicts the Kuhn-Tucker condition 6). Hence, \( q_2 > 0 \) does not hold, and \( q_1 = 0 \) is satisfied.

**Case 2:** Given \( q_1 > 0 \) and \( q_2 > 0 \), we get \( \theta_2 = 0 \) and \( \theta_3 = 0 \). From the Kuhn-Tucker conditions 4), 5) and the profit target constraint, we have
\[
\theta_1 = \frac{2[K - (r - w) D] \left[ \sigma_s^2 (L - H^2) - J^2 \right]}{(H - o) \left[ \sigma_s^2 (H - o) - J (\mu_s - w) \right] - (\mu_s - w) (J (H - o) - (\mu_s - w) (L - H^2))^2}.
\]
\[ q_1^* = D - \frac{[K-(r-w)D][J(H-o)-(\mu_s-w)(L-H^2)]}{(H-o)[\sigma^2_s(H-o)-J(\mu_s-w)-(\mu_s-w)]J(H-o)-(\mu_s-w)(L-H^2)]} \]

and

\[ q_2^* = \frac{[K-(r-w)D][\sigma^2_s(H-o)-J(\mu_s-w)]}{(H-o)[\sigma^2_s(H-o)-J(\mu_s-w)]J(H-o)-(\mu_s-w)(L-H^2)]} \]

Hence, \( q_1 > 0 \) and \( q_2 > 0 \) are constant in \( K \).

**Proof of Corollary 2.**

Proof. If \( K \leq (r-w)D \), we have \( \frac{d q_1^*}{d K} = 0 \) and \( \frac{d q_2^*}{d K} = 0 \), which indicates that \( q_1^* \) and \( q_2^* \) are constant in \( K \). If \( K > (r-w)D \), we have \( \frac{d q_1^*}{d K} < 0 \) and \( \frac{d q_2^*}{d K} > 0 \), which indicates that \( q_1^* \) is decreasing in \( K \), while \( q_2^* \) is increasing in \( K \). \( \square \)

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