



# Optimal procurement of long-term contracts in the presence of imperfect spot market<sup>☆</sup>



Jinpeng Xu<sup>a</sup>, Gengzhong Feng<sup>a</sup>, Wei Jiang<sup>b,\*</sup>, Shouyang Wang<sup>c</sup>

<sup>a</sup> The School of Management, Xi'an Jiaotong University, Xi'an, PR China

<sup>b</sup> Antai College of Economics and Management, Shanghai Jiao Tong University, Shanghai, PR China

<sup>c</sup> Academy of Mathematics and Systems Science, Chinese Academy of Sciences, Beijing, PR China

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## ABSTRACT

B2B spot market has grown rapidly and become an effective trading channel for commodity products. Besides long-term contract procurement from conventional suppliers (forward and option), a buyer can procure or sell commodities at any time in B2B spot market to adjust her inventory level. However, spot prices are generally volatile and the market is imperfect in the sense that spot trading may be realized with uncertainty in a given period of time and often comes with extra transaction cost. This paper considers a commodity buyer who can order forward and option contracts in advance and trade in a B2B spot market when spot price and demand are observed stochastically. Based on a single-period newsvendor model, we discuss three optimal order strategies and derive respective expected profits when the buyer is risk-neutral. The sensitivity of purchase costs, market liquidity and transaction cost is investigated. We also compare the optimal expected profits for different strategies to illustrate the effects of the two long-term contracts in the presence of the B2B spot market. We then extend our model to a multi-period setting and derive the optimal strategy. Finally, we numerically compute the optimal order strategy for a risk-averse buyer and analyze the impact of spot market, risk aversion, as well as the correlation between customer demand and spot price.

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## 1. Introduction

With the development of e-commerce, B2B spot market has grown rapidly and become an effective trading channel for commodity products (e.g., [26,22,7]). For instance, until the end of 2011 in China, there are more than 200 B2B e-markets providing spot or/and option trading of bulk commodities such as raw materials, energy, and agricultural products. Among them, some B2B e-markets have been developed quite maturely with a large number of players and huge trading volumes. For example, Shanghai Steel Exchange Center hosted a trading volume of 110 million tons in 2010. Guangxi Sugar Market Net represented about 30% of China's total sugar production in 2011. B2B e-markets especially for spot trading (B2B spot market) have become one of the important transaction channels in certain industries and changed the corresponding operations of their supply chains.

In traditional supply chains, buyers procure commodity mainly through offline long-term contracts that are ordered in advance. Forward contract with a wholesale price is common for a

conventional supplier to keep a long-term relationship with buyers, but the quantity cannot be changed after contract signed. Option contract with a reservation price and an execution price is another long-term contract [14] widely used to cope with demand uncertainty. Buyers order an option contract in advance, and decide at the end of a specified period on the execution quantity, which cannot be more than the ordered quantity. With the emergence of B2B spot markets, firms can now trade commodity at any quantity in a short term. As discussed in Fu et al. [5], forward contract has no volume flexibility and option contract has medium flexibility, compared with short-term spot trading with the highest flexibility.

Although B2B spot market provides a very flexible channel for supply chain procurement, spot prices are often volatile and the risk is rather high due to arbitrage. For example, in 2009, the price of cold rolled steel in China almost doubled from March to August and then suddenly dropped by 20% in September. Moreover, B2B spot market is imperfect in the sense that spot trading is not completely reliable due to market liquidity, and often comes with extra transaction cost which traders should pay additionally when they trade at spot price. In financial literature, market liquidity is an asset's ability to be converted into cash and generally includes several dimensions such as tightness, depth, resiliency, and immediacy (e.g., [17,12]). Factors such as economic policy, industry cycle, and different expectations between sellers and buyers, etc. usually drive B2B spot markets illiquid. For

<sup>☆</sup>This manuscript was processed by Associate Editor Gel.

\* Corresponding author.

E-mail address: [jiangwei@sjtu.edu.cn](mailto:jiangwei@sjtu.edu.cn) (W. Jiang).

instance, it was found that no transaction had been realized for four successive weeks during November 2012 in China Iron Ore Spot Trading Platform. In addition, extra transaction costs such as transaction fee and cost due to product differences [28,20] also affect the benefit of spot trading and cannot be ignored.

Therefore, long-term contracts and short-term spot trading in B2B spot markets are complementary and should be combined to improve profitability. Jörnsten et al. [13] studied a mixed forward and option contract and demonstrated the mixed contract is superior to option contract under variance constraints. However, they only considered the mix of two long-term contracts. Actually, buyers can procure commodities through traditional channels in advance and adjust their inventory levels by spot trading when demand is observed. In particular, buyers can timely purchase or sell commodities in B2B spot markets if their inventory is less or more than actual demand. For example, Hewlett-Packard (HP) engaged forward, option and spot market to meet demands with low, medium and high risk accordingly, and its portfolio procurement had saved HP over US\$425 million since 2000 [23]. The integration of long-term contracts and spot trading has been proved cost effective and commonly used in industry. However, at the same time, coordination between offline long-term procurement and online spot trading has become a challenge in practice [15]. This paper aims at optimal procurement of long-term contracts to maximize the buyer's profit in presence of an imperfect spot market. Besides the B2B spot market, we assume that two long-term procurement channels can be ordered in advance: a forward contract and an option contract. After the forward contract delivery and demand realization, the buyer can further purchase commodities or sell inventory (including leftover options if effective) in the B2B spot market. Finally, the buyer produces end products to meet customer demand.

Based on a single-period newsvendor model, this paper derives the optimal forward and option order quantities for a risk-neutral buyer, and analyzes the effects of the two long-term contracts in the presence of the imperfect spot market. As discussed in the next section, although portfolio procurement has been widely studied, the effect of one long-term contract in the presence of the other has not been examined when the buyer has the choice to order between the two long-term contracts. We contribute to the literature mainly by deriving the analytical solution and providing a full sensitivity analysis for optimal strategy of long-term contracts in the presence of an imperfect spot market. We then extend our model to an infinite horizon framework and explore the optimal strategy. We also numerically derive the optimal strategy for a risk-averse buyer and analyze the impact of spot market, risk aversion, as well as correlation between customer demand and spot price.

The rest of this paper is organized as follows. Section 2 discusses literature related to forward and option contracts as well as spot trading to identify research gaps for this paper. Section 3 solves a single-period problem for a risk-neutral buyer by deriving the analytical solution for optimal strategy of long-term contracts, provides some sensitivity analyses for optimal strategy, and analyzes the effects of the two long-term channels in terms of the improvement of optimal expected profit when the buyer orders both long-term contracts rather than only one of them. Section 4 extends the model to a multi-period setting and derives the respective optimal strategy. Section 5 provides numerical analysis for optimal strategy for a risk-averse buyer. We finally conclude in Section 6 with directions for future research.

## 2. Literature review

The procurement problem has long been discussed based on the tradeoff between the flexibility offered by short-term spot

trading and price certainty associated with the long-term contracts. For example, Cohen and Agrawal [3] studied a contract selection problem between a long-term contract and a short-term contract with random market price, and showed long-term contract may not be always optimal. Considering a spot market as purchasing source besides long-term contracts, Peleg and Lee [25] compared three procurement strategies: a long-term strategy with a single supplier that keeps strategic partnership; a short-term strategy based online search; and a combination strategy of the both. Chen and Liu [2] developed an analytical model to compare two distinctive procurement strategies: the pure procurement system and the mixed procurement system of regular supplier with a supplier in spot markets. Li et al. [18] compared two pure strategies: purchasing from spot market and signing a long-term contract with a single supplier, and developed a stochastic dynamic programming model to incorporate mixed strategies. Goel and Gutierrez [8] studied procurement and distribution policies for a firm that procures and distributes a commodity from spot and forward markets. Besides forward contract, the optimal procurement strategy of option contract and spot buying has also been investigated in literature. Woo et al. [29] derived the efficient frontiers for electricity procurement with forward contract, option contract and spot market by solving a mathematical programming model. Aggarwal and Ganeshan [1] modeled a scenario where a manager can purchase from the preferred supplier with an exogenously determined contract price and B2B e-market which provides option and spot trading. Ganeshan et al. [7] computed the optimal quantities of option contract and physical product purchased from spot market to minimize relevant procurement and inventory costs. Fu et al. [5] examined a single-period portfolio procurement problem of forward contract, option contracts and spot market, and obtained the optimal solution for general problem with a shortest-monotone path algorithm. Following this framework, Fu et al. [6] further investigated the optimal decisions for portfolio option procurement and retail price in a single-product periodic-review inventory system.

The above research assumes that the spot market is only used as a one-way transaction channel for buying commodities. In practice, spot market can be both a buying channel for shortages and a selling channel for excess inventory to the buyer. Seifert et al. [26] assumed that commodities can be both bought and sold via a spot market and derived closed-form results for the optimal order quantity of forward contract for risk-averse buyers. Haksöz and Seshadri [10] did an excellent review on supply chain operations in the presence of a spot market, and developed a model to value a supply contract with abandonment option. Milner and Kouvelis [22] studied the impact of B2B online exchanges on the use of long-term contracts where an exchange takes the role of a secondary market in which buyers can trade excess inventory to address supply and demand imbalances. Mendelson and Tunca [21] analyzed the equilibrium of a dynamic game between a single supplier and multiple manufacturers who first contract with the supplier at a fixed price and then trade in a spot market. Dong and Liu [4] studied the determination of an equilibrium forward contract on a non-storable commodity between two risk-averse firms that negotiate the forward contract through a Nash bargaining process in the presence of a liquid spot market. Haksöz and Seshadri [11] addressed a multi-period procurement problem for a risk-neutral commodity producer who sells to its buyer via forward contract and trades in a spot market for the commodity. Kouvelis et al. [16] integrated sourcing decisions with financial hedging decisions to manage price risk and consumption risk of storable commodity for a risk-averse buyer, and derived optimal hedging policies for multiple period problems. Ma et al. [19] investigated the optimal ordering and production decisions in a decentralized supply chain under random yield. Unfortunately,

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