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Risk averse supply portfolio selection with supply, demand and spot market volatility ☆

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ABSTRACT

Enterprise Risk Management (ERM) has become one of the most essential subjects in business management. This paper establishes how risk modeling can be applied to supply chain management, specifically to supply portfolio procurement decisions of a firm. In a single period setting, parts can be procured via traditional forward contracts, option contracts or spot purchases. Customer demand and spot prices are random and possibly correlated and firm's primary suppliers are subject to complete disruptions and yield uncertainties. This paper analyzes several scenarios where the spot market is not available, available for buying only, and available for both buying and selling. This article develops and solves mathematical models considering the risk neutral and risk averse (CVaR) objectives independently or simultaneously. For the special case of normally distributed random variables and a risk neutral objective, optimality properties were developed. A broad numerical study examines the sensitivity of procurement strategies to key problem parameters such as, risk attitude, demand and spot price volatilities, correlation between demand and spot prices and terms of option contracts.

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1. Introduction

Supply chains are now operating in volatile and competitive business environment more than ever. Despite the recent progress in forecasting techniques, estimating customer demand accurately is generally challenging due to ever-shrinking product lifecycles and changing customer preferences. In addition to unpredictability of customer demand, there also exist volume and price uncertainties at the supply end. Effective management of demand and supply uncertainty and associated risks using the state of art techniques is critical for firms to keep customers satisfied and costs low.

Enterprise Risk Management (ERM) is a systematic approach to managing all risks that organizations face [11]. ERM is defined by Wu et al. [45] as “the integrated process of identification, analysis and either acceptance or mitigation of uncertainty in investment decision making”. Traditionally, ERM techniques were used by financial services firms such as banks, insurance companies, etc., who have needed to “match” their liabilities with their underlying assets. ERM has further developed to include managing all areas of risk and is now used by firms in all industries [6]. According to Olson and Wu [30], the scope of ERM can be categorized under five perspectives of risk content: financial risk management, accounting, supply chain management, information systems, and disaster management. Choi et al. [8] provided an extensive literature review on ERM where the primary ERM methodologies are categorized as statistical methods, data envelopment analysis (DEA), the analytic hierarchy process (AHP), fuzzy set theory, grey relationship analysis, balanced scorecards, and financial risk measures [8].

Supply chain risk management is interested in coordination and collaboration of processes and activities across functions within a network of organizations [46]. A customized ERM model depends on risk elements as well as the adopted ERM methodologies. For example, defining procurement strategy of a firm is a major managerial issue within supply chain risk management. Wu and Olson [43] compared three types of supplier selection methodologies in supply chains with risks: chance constrained programming, DEA, and multi-objective programming. Wu and Olson [44] developed a new approach called “DEA Value at Risk (VaR)” for selection of suppliers. Olson and Wu [31] also demonstrated two tools (DEA and simulation) that can aid firms in measuring, evaluating, and assessing risk involved in supply chain sourcing decisions. This paper presents how an advanced ERM approach, i.e. Conditional Value-at-Risk (CVaR), can be applied to define sourcing strategies of firms.

Procurement is one of the fundamental drivers of a firm to survive and compete in the global marketplace. On the other hand, firms are now part of complex supply chains working with many suppliers over longer distances, and this increases the risk. This risk can be a

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systematic one affecting a group of suppliers, such as natural disasters, terrorism, exchange rate volatility, or port congestion. There can also be supplier specific risks such as supply shortages/disruptions due to machine breakdowns, labor strikes, and quality problems [24]. Supply shortages or complete disruptions can have devastating outcomes on companies. For example, in September 2000, Sony announced its inability to meet initial demand for the new PlayStation console, due to shortages in capacitors, LCDs, and flash memory chips. Sony's stock price had dropped by about 9% after this announcement [4]. In another example, a fire due to lightning on March 17, 2000 caused the Philip's semiconductor fabrication plant (Albuquerque, New Mexico) shut down for months. Nokia were able to obtain chips from alternate suppliers while Ericsson had no alternate suppliers. As a result, Ericsson reported long-term losses of $2.34 billion and ultimately withdrew from the cell phone market [7]. In a similar case, Toyota's assembly plants were forced to shut down after a fire at Aisin (prime supplier for *P*-valves) on February 1, 1997 [28]. Toyota officials called different suppliers to obtain *P*-valves, and Somic had the flexibility to shift its production line and delivered its first *P*-valves to Toyota on February 6 [33]. These examples prove that it may be worthwhile for many firms to develop effective sourcing strategies to mitigate the risk of shortages in primary suppliers. Having a backup supplier may prepare companies for unpredicted primary supply disruptions. A backup supplier is also crucial for firms to meet changing market demand in the complex global environment [49]. Firms may reserve some capacity in advance from backup (secondary/reliable) suppliers through option contracts. This approach is being exploited by firms in different industries such as semiconductors, consumer electronics, telecommunications, and pharmaceuticals [17,34].

In many cases, the spot market can be another powerful tool for hedging risk due to unpredicted changes in supply and demand in the supply chain. Spot markets have been used for grains, livestock, and oil [39] but recently they have been formed for other industries such as memory chips, chemicals, energy, telecommunication bandwidth, etc. Many firms have already started to use them in addition to their traditional procurement contracts [38]. For instance, spot market procurement is estimated to be 30% of total memory chip sales [9,16]. On the other hand, many companies are still hesitant to enter spot markets and still utilize them in an ad hoc manner. McKinsey and Company and CAPS Research carried a survey on the impact of B2B e_marketplaces and recognized the need “to determine the appropriate contract-to-spot ratio for commodity purchases” [23]. It is crucial to produce effective quantitative tools to help firms to decide the role of spot markets in their procurement strategies.

Hewlett Packard (HP) is one of the pioneer firms utilizing a portfolio approach where they maximize expected profits while managing risks. In 2000, HP was unable to procure sufficient supply of the flash memory to meet its demand of profitable printers. This experience forced HP to develop a new framework to manage supply chain risk, known as Procurement Risk Management (PRM). The ultimate profit contribution of PRM approach is estimated to amount to $1 billion [27]. It has been reported that HP invests in 50% forward (long) contracts, 35% option contracts, and leaves 15% of its commodities purchasing needs open to the spot market [4].

This paper examines optimal procurement strategies of firms where supplies can be purchased via forward (long/fixed price) contracts, option contracts or spot markets. The firm can sign traditional *forward contracts* with its *primary suppliers* to buy components at a certain future time for a certain price. To reflect the supply side risks in contemporary supply chains, we assume that primary suppliers are subject to supply uncertainties (disruptions and/or random yields). The firm can also sign *option contracts* with its *secondary (backup) suppliers*; in this case a fee is paid up front to reserve certain capacity at a certain price. This option may be exercised when there are shortages due to uncertainties of primary suppliers and customer demand. The third procurement option of the firm is to make *spot purchases* which involve paying market price on the day when the component is needed. Spot market requires no commitment on the firm however prices can be quite unstable.

This study considers decision models where the firm satisfies uncertain demand and has only one selling season as in the newsvendor problem. A two-stage setting is considered; in the first stage the model determines size of forward and option contracts. After monitoring the risk of primary suppliers, customer demand and the spot price, the firm makes second stage decisions. In this stage, the firm has a recourse option to selectively utilize the capacity reserved at the secondary (backup) suppliers via option contracts and to make purchases from the spot market (or sell leftovers at the spot market). The models provided by this paper can be used to quantify the benefits that can be achieved by utilization of spot markets, and option contracts in hedging risks of supply shortages and demand volatility. Our optimization models can also be used to assess the effect of risk-averse decision making on the optimal supply portfolio selection of a firm. The CVaR measure is utilized to integrate risk in our problem.

The remainder of this paper is organized as follows. In Section 2, we provide the literature review. In Section 3, we formulate the problem with both risk neutral and risk averse objective functions independently and simultaneously. In Section 4, we present the solution methodologies. In Section 5, we summarize our observations based on the numerical study, and recommend managerial insights through a sensitivity analysis of the key problem parameters. Finally, in Section 6, we deliver concluding remarks.

2. Literature review

There is a rich body of supply chain literature that addresses various aspects of the procurement problem. Two major lines of this literature are relevant to our research: the literature on spot market procurement and the literature considering procurement decisions in a multiple (unreliable) supplier setting. Haksoz and Seshadri [18] survey the recent literature on the use of spot market operations to manage procurement in supply chains. Elmaghraby [14] and Minner [26] provide literature surveys in sourcing strategies and the optimal number of suppliers.

We first reviewed the literature on the single period procurement problem when spot market option is available. Akella et al. [2] considered a single period model, and focused on reserving an appropriate capacity level to meet demand via option contracts. They showed that a mixed procurement strategy consisting of both an option contract and spot market procurement is optimal. Seifert et al. [38] also considered a single period setting to determine the optimal order quantity to purchase via forward contracts and the optimal quantity to purchase via spot markets. They compared the results for situations where spot markets are not available and spot markets are restricted to either buying or selling only. They showed that companies who use spot markets can offer a higher expected service level, but that they might experience a higher variability in profits than companies who do not use spot markets. Wu and Kleindorfer [42] considered multiple suppliers offering option contracts as well as a spot market with random price. However, their model assume a price (and quantity)-dependent demand function, which is not randomly or exogenously generated. That is, once its determinants are set, demand is fully determined. Martínez-de-Albéniz and Simchi-Levi [22] studied a single period portfolio procurement problem to understand the competitive behavior among the suppliers. However, they assumed a constant spot price, where the spot market acts essentially as a supplier with a zero

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