



Stochastics and Statistics

Dual sourcing using capacity reservation and spot market: Optimal procurement policy and heuristic parameter determination

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ARTICLE INFO

Article history:

Received 5 July 2011

Accepted 30 August 2012

Available online 12 September 2012

Keywords:

Dual sourcing

Capacity reservation

Spot market

Procurement policy

Stochastic dynamic programming

Heuristics

ABSTRACT

This contribution focuses on the cost-effective management of the combined use of two procurement options: the short-term option is given by a spot market with random price, whereas the long-term alternative is characterized by a multi period capacity reservation contract with fixed purchase price and reservation level. A reservation cost, proportional with the reservation level, has to be paid for the option of receiving any amount per period up to the reservation level. A long-term decision has to be made regarding the reserved capacity level, and then it has to be decided – period by period – which quantities to procure from the two sources. Considering the multi-period problem with stochastic demand and spot price, the structure of the optimal combined purchasing policy is derived using stochastic dynamic programming. Exploiting these structural properties, an advanced heuristic is developed to determine the respective policy parameters. This heuristic is compared with two rolling-horizon approaches which use the one-period and two-period optimal solution. A comprehensive numerical study reveals that the approaches based on one-period and two-period solutions have considerable drawbacks, while the advanced heuristic performs very well compared to the optimal solution. Finally, by exploiting our numerical results we give some insights into the system's behavior under problem parameter variations.

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1. Introduction and literature review

Supply strategy is getting more important with the tendency of increased outsourcing and higher value of purchased materials and parts. With the increase of component production outsourcing, the share of purchasing cost increased up to 50–90% of the total revenue of manufacturing companies (de Boer et al., 2001), becoming a critical element of competitiveness. The number of available procurement alternatives also increased with a wide range of spot purchase opportunities and different contract based supply options. With this increased importance and complexity, the strategic sourcing attracted substantial managerial and quantitative research recently.

Spot market purchasing provides flexibility and a benefit in case of a low spot market price or insufficient reserved capacity. Around 30% of the memory chips are bought on spot markets according to the Gartner Group estimates (see Andren, 2000; Seifert et al., 2004). With the growing importance of electronic commerce and global sourcing, the spot market is competing with contract based procurement. A 2002 survey shows that 57% of industrial buyers

ranging from automotive to electronics increased spot purchases and reduced buying based on long term contracts (Ansberry, 2002).

Capacity reservation contract is used as an operational risk hedging for high spot market price incidents. The simple price contract has been extended to several contract forms including the *capacity reservation contract* extensively used for purchasing chemicals, commodity metals, semiconductors, and electric power (Kleindorfer and Wu, 2003). In electric power generation the so-called “tolling agreement” (see Woo et al., 2006) gives the local electricity distribution companies the right, but not the obligation, to dispatch a generation unit specified by the agreement. Typically, the capacity option contract needs to be fixed for a longer time horizon specifying the price and quantity and pay the reservation price up front. Short-term decisions are required in each period how much to order from the reserved capacity source up to the available capacity or purchase completely on spot market or use both sources.

Leading companies are combining different purchasing options strategically to reap the benefits of the alternative sources. Applications include chemicals, commodity metals, raw materials, oil, liquefied gas, and semiconductors. Reiner and Jammernegg (2010) examined the practice of a chemical company buying raw materials using contracts and spot market. With simulation they showed the advantages of multiple sourcing including the benefit

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of speculative inventory purchased from spot market. A multiple sourcing strategy is also used in Liquefied Natural Gas (LNG) purchasing as it is reported in Yacef (2010). The combined forward contract and spot purchase strategy is applied in electricity market to combine the risk hedging and price benefits as it is discussed in Giacometti et al. (2010). Food packaging industry also uses the forward buying combined with spot purchase as it is reported in Vukina et al. (2009). Recent publications in electricity trading practices applying combining contracts and spot market include Benth et al. (2012), Gülpınar and Oliveira (2012), and Ruiz et al. (2012).

In our research we address a procurement problem of a component/material that is used for producing finished goods in a make-to-stock environment under stochastic demand. For the component we consider two sourcing options: the spot market and a capacity reservation contract. The capacity reservation contract is a real option contract where a reservation price, proportional with the reserved quantity, has to be paid for the option of receiving any amount per period for the contract price up to the reservation quantity. The combined strategic sourcing decision is quite challenging because it requires looking ahead for several periods that have stochastic demand and random spot market price fluctuations. A long-term decision has to be made regarding the reserved capacity level fixed with the long-term supplier. It should create sufficient protection for high spot market price incidents. Then it has to be decided – period by period – which quantities to procure from the different sources. Due to a non-negligible production lead time both procurement decisions, i.e. exercising the long-term option and buying at the spot market, have to be made before the demand for the finished product has been realized. Thus, the combined procurement strategy has to protect against risks of insufficient demand fulfillment and exploit the benefits of forward buying in periods with low spot price levels. The decision on capacity reservation has to take into account the short-term capacity utilization of each source which itself depends on the available long-term capacity. Thus, there is a highly complex interdependence of long-term and short-term decisions under uncertainties in demand and spot market price. In this context, the multi-period approach allows for integrating capacity reservation, forward buying and safety stock holding aspects in a single model.

We formulate a stochastic dynamic optimization model for the above problem and prove that, for random stationary demand and spot market price, the optimal procurement decisions can be made based upon a three-parameter policy. Two parameters are fixed numbers, the order-up-to level for ordering from the long-term supplier and the long-term capacity reservation level. The third policy parameter, the order-up-to level for short-term spot market procurement, is a function of the spot price. It is very cumbersome to numerically calculate the optimal values of all policy parameters; therefore, we develop a fairly simple heuristic approach for determining all parameters including the parameter function.

Several papers consider capacity contracts or spot purchase as the only sourcing option. We refer to the capacity contracts papers of Kamrad and Siddique (2004), Burnetas and Ritchken (2005), Erkok and Wu (2005), Hazra and Mahadevan (2009), and Kirche and Srivastava (2010) that have the closest connection to our research. The spot purchase related papers by Geman (2005), Tapiero (2008), Arnold et al. (2009), and Guo et al. (2011) do not examine the trade-offs between the spot market and long-term contracts.

Dual sourcing and order splitting are also major research streams related to our problem. We refer to the papers of Minner (2003) and Thomas and Tyworth (2006) for a comprehensive review of this research area. Despite the considerable number of researches extending different dimensions of dual- or multiple-sourcing problems, only a few of them is dealing with combining

spot market purchases with purchases made in advance from a specific long-term supplier. Henig et al. (1997) derived a three-parameter optimal policy without the consideration of uncertainty on the procurement side, which is a critical factor in practice. Bonser and Wu (2001) study the fuel procurement problem for electric utilities in which the buyer can use a mix of long-term and spot purchases.

Our problem was first defined and studied in the inventory literature in Serel et al. (2001). They considered the simple (R, S) capacity reservation – order up policy, but they disregarded the spot market price uncertainty. Wu et al. (2002) consider uncertainty in spot market prices and analyze the contracts for non-storable goods involving options executable at a predetermined price. Kleindorfer and Wu (2003) linked this literature to evolving B2B exchanges on the Internet. In Sethi et al. (2004) a situation with both demand and price uncertainty is taken into consideration, and a quantity flexibility contract is employed; however, no capacity reservation takes place. Seifert et al. (2004) also analyzed a single-period dual sourcing problem from the buyer's standpoint with changing levels of buyer's risk preferences. Using a similar single-period model, Spinler and Huchzermeier (2006) show that the combination of an options contract and a spot market is Pareto improving with respect to the other alternative market structures. Martínez-De-Albéniz and Simchi-Levi (2005) address the dynamic supply contract selection problem using long-term and options contracts as well as the spot market. They assume that the demand is known before stock is replenished in contrast to our model which considers the uncertainty of demand at the time of ordering. Haksöz and Seshadri (2007) published a review paper in this topic. Talluri and Lee (2010) propose a methodology for optimal contract selection based on a mixed-integer programming approach. Arnold and Minner (2011) deal with a two-period problem with dual sourcing. Gallego et al. (2011) analyzed the dual sourcing using spot market and real option market from the point of revenue management.

The analysis in Serel (2007) is the closest to ours. The main difference is that they consider a spot market with random capacity at a given price instead of a random price without capacity restriction. Furthermore, they assume that the spot capacity is not known when the ordering decision is made so that procurement decisions will not depend on the respective capacity level at the spot market. Under these circumstances, the optimal policy in Serel (2007) has a simple three-parameter structure, but is not capacity-contingent. Li et al. (2009) develop a stochastic dynamic programming model, as we do in our paper. They incorporate mixed strategies that include purchasing commitments and contract cancellations but they left out the inventory policy and replenishment decisions within each contract review period. In the paper of Fu et al. (2010) the buyer has three choices, either procure using fixed price contracts or option contracts or use spot purchases. However, they consider a single-period problem unlike our multi-period decision making framework. Zhang et al. (2011) consider two supply sources: one is the contract supplier from which the buyer orders over a specific contract period at a pre-agreed price, and the other is the spot market. However, when ordering from the contract supplier, the buyer must fulfill a pre-determined total order quantity, unlike in our problem where a downward flexibility is allowed but a reservation price must be paid ahead that is proportional with the reservation quantity. Xu (2011) considers the effect of minimum order quantity on the capacity contract. Adilov (2012) deals with the interaction of forward contract and spot market from the point of view of the supplier.

The recent publication of Fu et al. (2012) addresses a procurement problem where reservation decisions under the option contracts are made in a short-term setting period-by-period. Our paper, in contrast, studies a situation in which a long-term

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