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Integrated demand and procurement portfolio management with spot market volatility and option contracts

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ABSTRACT

The newsvendor problem aims to optimally choose a level of order quantity to respond to a known demand distribution with the objective of maximizing expected return. In practice, the decision maker is often challenged with more complex settings involving multiple decisions and uncertainties. For instance, firms may benefit from choosing the set of customer orders to satisfy. It may also be worthwhile for many firms to select a supply portfolio instead of relying on a single procurement mode. This paper provides novel optimization models and solution techniques that can help businesses to achieve the maximum performance from a given production system by optimally selecting customer demands, procurement quantity, spot market purchase and option contract usage. We specifically focus on the special case of normally distributed random variables, and provide an exact solution method. When the primary procurement quantity is not a decision variable, the problem becomes a version of a Stochastic Knapsack Problem. For this case, we present an efficient heuristic solution algorithm based on properties of an optimal solution and empirically show that it provides high-quality solutions. We also provide a broad numerical study to examine the sensitivity of integrated procurement and demand selection strategies to key problem parameters.

1. Introduction

The newsvendor problem aims to optimally choose a level of capacity (or order quantity) to respond to a known demand distribution with the objective of maximizing expected return. In this classical problem, the distribution of demand is given and the only decision variable is order quantity. In many practical situations, the decision maker is often challenged with more complex settings involving multiple decisions and multiple uncertainties. Especially for products with short life cycles, an integrated view of operations and marketing is essential to provide high degree of responsiveness to customers without substantial compromises in cost efficiency.

Supply and demand mismatches may result in loss of market shares and devastating financial outcomes for businesses. Firms, therefore, have to develop state of the art strategies to balance volatile customer demand and supply capacity to minimize this risk. A well-known strategy is process postponement where the manufacturing and distribution processes are designed in a way that product differentiation is delayed and the push-pull boundary is moved toward the final customer. For instance, in the semiconductor industry, semiconductor output is generally done according to certain specifications. On the other hand, programmable semiconductors allow postponement of the final design of the semiconductor until the market demand is known (Brown, Lee, & Petrakian, 2000). For such industries, the use of option contracts, integrated spot markets and innovative modeling techniques play increasingly important role in promoting efficient risk management (Kleindorfer & Wu, 2003). When the firm signs option contracts with its suppliers, a reservation fee is paid up front in return for a commitment to reserve a certain capacity. This capacity is used when there are shortages due to uncertainties in the system. In this study we consider a primary procurement mode (forward contract) that is less expensive but has a longer procurement lead time and a flexible procurement mode (option contract) that is more expensive but has a shorter procurement lead time. This is also similar to the Intel's practice described by Peng, Erhun, Hertzler, and Kempf (2012). Intel makes an up-front payment to reserve some capacity ahead of time. The flexible mode allows Intel to learn more about demand before committing to purchase capacity and in this way they share the demand risk with its suppliers.

Spot markets have also been utilized as a powerful mechanism to hedge supply-demand imbalance risks in the supply chain. In history, they have been developed for wide-ranging commodities such as grains, livestock, and oil but recently they have also been

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established for some other industries such as memory chips, chemicals, energy, telecommunication bandwidth, etc. Many firms in these industries have already started to use spot markets in addition to their primary procurement modes (Seifert, Thonemann, & Hausman, 2004). For instance, spot market procurement is estimated to be 30% of total memory chip sales (Crothers, 1999; Flannery, 1999). Spot markets offer products at essentially negligible lead time, but naturally results a higher and volatile price for this extra flexibility. Hewlett Packard (HP) is one of the leading firms exploiting the portfolio approach in sourcing decisions. It has been reported that HP invests in 50% traditional contracts, 35% option contracts, and leaves 15% of its purchasing needs open to the spot market (Billington, Johnson, & Triantis, 2002). On the other hand, many firms are still doubtful to enter spot markets. It is, therefore, essential to produce effective decision tools guiding managers on the spot market usage in their procurement strategies.

One important characteristic of most hi-tech industries is that product demands are highly uncertain due to ever-shrinking product lifecycles and changing customer preferences. When the production planning is done in advance of the selling season based on sales forecasts, firms may end up capacity shortages or unsold products. On the other hand, firms may benefit from the flexibility of choosing customers/orders it chooses to satisfy and shape their demand curve. Consider a firm who is subject to shared forecasted orders of customers which can be considered “soft orders” as customers generally revise them in terms of quantity or delivery dates due to changes in their business environments. Chahar and Taaffe (2009) provided an example of a large manufacturer whose marketing department attempts to secure orders for telecommunications infrastructure equipment. This firm plans their future production schedule based on the unconfirmed orders for which customization is postponed to a relatively late point in the production process. So the manufacturer can procure and assemble materials and then customize the product once the orders are finalized. Each customer is unique in terms of negotiated product price, order quantity and forecast accuracy.

Simultaneously selecting the most desired demand set and setting the appropriate procurement quantity has been referred to as the “selective newsvendor problem” (SNP). Current study is a version of the SNP where the firm may also reserve some capacity at a backup supplier. When the size of the selected customer orders exceeds the primary procurement quantity, the firm can execute this reserved capacity at some additional cost. Part of the customer demand that is not satisfied by the primary procurement quantity or the reserved quantity at the backup supplier is supplied via spot market purchases. Henceforth, this problem will be referred to as “selective newsvendor problem with recourse” (SNPR).

When the primary procurement quantity cannot be easily changed, the problem becomes a version of the “Stochastic Knapsack Problem” (SKP) where the decision maker allocates a finite capacity to demands with stochastic sizes which would be selected from a larger set. SKP has various practical applications in manufacturing or logistics. For example consider a single-machine scheduling problem: given a set of jobs with known profit values and uncertain durations, SKP determines the best set of jobs to assign to the machine with a fixed deadline (Dean, Goemans, & Vondrak,). In another example, consider a freight transportation company’s problem: given a set of customer orders with unknown freight quantities, SKP determines the best set of customers to be served by the fixed capacity (Claro & Sousa, 2010). Allowing capacity reservation flexibility at a backup resource and procurement option from spot markets widens the applicability of the SKP for these and many other business settings. This decision problem will be referred to as “Stochastic Knapsack Problem with Recourse” (SKPR) hereafter.

This paper provides modeling and solution techniques that can help businesses to achieve the maximum performance from a given production system by optimally selecting customer demands, procurement quantity, spot market purchase and option contract usage. Our models provide substantial value through its ability to determine the optimal fit between demand levels and supply capacities and to quantify the benefits of an integrated view. A two-stage setting is considered; in the first stage the decision maker determines the customer demands to be satisfied. In this stage, the firm also has the capacity reservation opportunity via an option contract with a backup supplier. If the primary procurement quantity is a decision variable, it is also determined at this stage, otherwise, the firm is subject to a constant supply capacity. In the second stage, the firm has a recourse possibility to use the reserved capacity at the backup and to make purchases from the spot market after monitoring the risk of selected customer demands. The primary contributions of this paper are threefold: (I) integration of demand and procurement planning decisions in a tractable model; (II) efficient and high performing solution methodologies; (III) sound managerial insights based on solution properties and a computational study.

The remainder of this paper is organized as follows. In Section 2, we provide the literature review. In Section 3, we provide a mathematical programming formulation for the SNPR and present an exact solution approach. In Section 4, we introduce a mathematical programming formulation for the SKPR and present a heuristic solution approach. In Section 5, we test the performance of the proposed solution procedures against a commercial solver and recommend managerial insights through a sensitivity analysis of the key problem parameters. Finally, in Section 6, we provide concluding remarks.

2. Literature review

We classify the related literature into three parts: the literature considering SNP, SKP, and procurement through option contracts and/or spot markets.

SNP is first introduced by Taaffe, Geunes, and Romeijn (2008), and analyzes a setting where the firm procures and delivers a good within a single selling season to a number of different markets. The price for the good is market dependent and each market has an independent demand distribution. The risk-neutral version of this problem has an optimal solution based on an intuitive ranking scheme. Bakal et al. (2008) has considered an extension of this problem where each market/customer observes price-sensitive demands. Strinka, Romeijn, and Wu (2013) studied a class of selective newsvendor problems in which a decision maker must choose the most profitable combination of customizations from a set of raw materials which can be customized shortly before satisfying demand. The aforementioned studies assumed that the demands of different markets are independent and normally distributed. Taaffe, Romeijn, and Tirumalasetty (2008) considered a different version of this problem in which demand for an individual market is defined by a Bernoulli distribution such that the amount ordered is “all or nothing.”

When the procurement quantity is constant, SNP transforms to a version of a SKP with random weights which aims to choose a subset of demands to be put into a knapsack with constant capacity. Each demand has a reward and a random weight and weight in excess is charged with a unit penalty. Goel and Indyk (1999) studied this problem to maximize the total expected value by selecting a set of demands whose probability of violating the knapsack’s capacity is at most some probability value. Barnhart and Cohn (1998) considered a very similar setting in which demand sizes are normally distributed. Kleywegt, Shapiro, and de Homem Mello (2001) suggested a Sample Average Approximation