



A single-period stocking and pricing problem involving stochastic emergency supply



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ABSTRACT

We develop a model for determining jointly optimal price and production policy of products with short life cycles subject to partially uncertain supply capacity. Within the price-setting newsvendor framework, we consider that demand in excess of the stocking quantity can be met by an emergency order. Due to the randomness of emergency supply capacity, it may not always be possible to satisfy the demand completely. Assuming that all customers are charged the same price, we explore the optimal sourcing and pricing decisions in the commonly used additive and multiplicative demand scenarios. The first-order conditions imply that the optimal price in the problem with random emergency supply is less than the optimal price associated with the deterministic demand problem when demand uncertainty is additive, and it is greater than the optimal price associated with the deterministic demand problem when demand uncertainty is multiplicative. We also find that the same type of comparative static applies in the multiplicative uncertainty case when there exists a dual source emergency system consisting of a perfectly reliable supplier and a second supplier with a stochastic capacity.

1. Introduction

The growing competition among firms in the global economy has created an environment in which disruptions in the supply of raw materials or finished goods may lead to significant costs for the manufacturers and retailers. As a result of this development, a recently popular research topic in operations management is how to respond to the adverse impact of supply disruptions on a firm's operational performance. In that direction many traditional inventory models have been reformulated to explicitly account for uncertainty in supply of raw materials or traded goods.

The single period (newsvendor) inventory problem with price-sensitive customer demand has attracted an increasing attention from researchers in recent years. In this problem a retailer (newsvendor) needs to determine the stocking quantity and selling price of a product such that the expected profit in a single selling season is maximized. Because the demand for the product is uncertain and the product must be produced/ordered before the sale of the product begins, there exist risks of overstocking and understocking the product relative to the realized demand level. In this paper we explore an extension of the classic price-setting newsvendor problem in which the supply process is unreliable to a certain extent.

Fashion clothing, toys, and gardening items are the examples of products to which the newsvendor model is relevant in practice. Market demand for fashion products may be influenced by unpredictable

events. As an example of uncertain seasonal demand, consider the demand for U.S. soccer apparel stocked by retailers. In the first five days of the 2014 World Cup, the sales of Team USA shirts carrying the names of U.S. national soccer team players was boosted due to the successful performances of team players in the tournament (Nella, 2014). Although it has generally been assumed that a single production batch is completed before the selling season in the newsvendor setting, sometimes it may be possible to initiate an additional production run after demand uncertainty is resolved. If demand for the product exceeds expectations, this second production opportunity helps prevent the profit loss resulting from unsatisfied demand. In the literature, the production phase prior to the selling season has been referred to as *speculative* production whereas the second production run made after observing demand has been called *reactive* production. The speculative production has to be completed without the knowledge of the realized market demand; hence it involves the risk of overproducing which is not an issue in the reactive production. However, speculative production is usually more cost-efficient than reactive production. The unit production cost associated with reactive production is likely to be higher than that associated with speculative production as the need for rapid order delivery may call for engaging in more costly production and transportation activities. Thus the optimal production strategy strives for achieving a balance between the speculative and reactive production alternatives. Considering the overall expected profit, a mixed production strategy containing both speculative and reactive

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elements may be suited to the firms that manufacture high tech consumer electronics products with short product life cycles (Cattani et al., 2008).

The uncertainty in supply of raw materials and finished goods occasionally influence the producers and retailers. In early 2012, the extreme heat experienced over the past summer combined with a significant increase in the price of organic feed for dairy cows caused a decrease in organic milk production, which resulted in an organic milk supply shortage in the supermarkets in the U.S.A. (DeFeo, 2012). Some manufacturers resort to emergency supply sources such as subcontractors or spot market when their own production capacity falls short of customer demand. According to market traders, in 2013, the Korean zinc smelter firm Korea Zinc purchased metal from London Metal Exchange stocks in Malaysia in order to cover its contractual sales (Burton, 2013).

Our primary objective is to study optimal pricing and production/stocking policies for a firm when a particular type of supply uncertainty exists in a short term planning horizon. More specifically, we consider a single period production/procurement problem in which demand in excess of the seasonal stocking level may be satisfied through an emergency supplier, which is not perfectly reliable. Hence, the risk of not meeting all demand is not fully eliminated. Given that supply capacity of the emergency supplier is a random variable, we address the problem of setting the selling price and the pre-season order quantity to maximize the expected profit. The drug retail business is a practical example for the problem we consider. Shortages of certain medicines in the pharmaceutical market is not an uncommon event. In case of shortages, distributors may ration the supplies to the retailers. In late 2009, due to a change in the source of supply for a drug used in the treatment of Parkinson's disease, the manufacturer of the drug, Merck, announced that supply of the drug would be limited for a certain period (Epda, 2009). Thus, supply of a medicine may be limited as a consequence of reduced production rate of the manufacturer. Supply constraints may also arise from import problems, manufacturing quality problems, or transportation delays in the supply network. In general, this kind of supply disruptions may limit the availability of drugs to the retailers when they need urgent deliveries. Because of concerns about manufacturing quality, Food and Drug Administration (FDA) in the U.S. ordered to shut down the Genzyme plant producing Cerezyme, which is a drug used in the treatment of Gaucher's disease. To counteract the resulting supply shortages in the market, FDA issued fast-track approval to an alternative drug marketed jointly by Pfizer and Protalix Biotherapeutics (Ebel et al., 2014).

The randomness in the quantity of supply available via emergency delivery also may be observed when the product is sourced via transshipment from another branch of the parent company. The quantity that the other retail branch can transship is uncertain due to the fact that its own stock available on-hand depends on the random demand it faces for the product from its retail customers.

Our research provides answers to questions such as: How should the pricing and stocking decisions be adjusted in the newsvendor setting when there exists a randomly available emergency supply? What is the effect on selling price when we move from an unlimited emergency supply availability to the uncertain emergency supply scenario? Should the newsvendor increase or decrease its selling price when the expected available emergency supply quantity increases? How different is the optimal policy when the type of demand uncertainty is additive versus multiplicative? How does the optimal value of one decision variable change when the value of the other decision variable is decided and manipulated in a customary manner?

Our analytical results can be collected in two groups, each of which corresponds to a specific procurement setting. We consider a different emergency supply structure in each setting. The results in the first group describe the optimal pricing and stocking policy in the problem with a random emergency supply. Based on the assumption of sufficiency of the first order conditions, we show that the optimal price

in the problem with random emergency supply and additive demand is lower than that in the problem with deterministic demand. This result is not consistent with the effect of supply uncertainty observed in the periodic review problem with backlogged demand which was studied in the previous literature. The differences in the modeling of supply uncertainty and particular assumptions such as the timing of orders and demand backordering appear to drive this difference between our result and the earlier findings. On the other hand, subject to certain conditions on the cost parameters, the optimal price in the problem with random emergency supply and multiplicative demand is higher than that in the problem with deterministic demand. These results regarding the effect of the type of demand uncertainty on the optimal price parallel the results for the traditional newsvendor problem with lost sales. We also find in the additive demand model that optimal selling price decreases when supply uncertainty is introduced into the environment of unlimited emergency supply.

We analyze a special case of the problem with an additive error term and random emergency supply. Using a linear demand function, and uniformly distributed demand error and emergency supply, we show that solving the first order optimality condition is equivalent to finding the roots of a third-order or a fifth-order polynomial in a single variable.

Our results in the second group concern the optimal policy when there exist two emergency sources, one of which has a random capacity, and the second emergency source has unlimited capacity. When the demand uncertainty is additive, the optimal price in this problem is the same as the optimal price in the deterministic demand problem. However, if the demand uncertainty is multiplicative, the optimal price is higher than that in the problem with deterministic demand. Provided the supply price of the second emergency source does not exceed a threshold level, the optimal regular order quantity in the two-emergency-source case is lower than that in the case with a single, random emergency source and additive demand.

The remainder of the paper is organized as follows. Following the literature review in Section 2, we describe the basic model features in Section 3. In Section 4 we analyze the problem involving an emergency supplier with random supply capacity. In Section 5 we characterize the optimal ordering and pricing policy in the problem with two emergency sources; one of the sources has a random supply capacity whereas the second source can deliver any amount required albeit at a higher supply price. Numerical examples are presented in Section 6 and concluding remarks can be found in Section 7.

2. Literature review

Although there are several recent papers studying combined inventory and pricing policies when both demand and supply are stochastic (Li and Zheng, 2006; Feng, 2010), the current level of knowledge on this interface of supply chain management is limited, and to our knowledge, there is no earlier work that investigates the effect of an unreliable emergency supply source in the price-dependent newsvendor setting. Previous inventory research taking into account emergency delivery has typically considered no randomness in emergency supply (e.g., Agrawal and Seshadri, 2000) so that regardless of how many units are stocked prior to the selling season, all demand can be satisfied. It can be thought that uncertainty in emergency supply stems from the requirement that the order placed with the supplier needs to be fulfilled within a short time frame. Even if there might be a long lead time associated with the pre-season order, the newsvendor (buyer) can take into account this lead time information and can determine an appropriate time for the pre-season order accordingly. Hence the supplier for the pre-season order is given sufficient time to schedule its production and plan the allocation of its production capacity to the orders received from different customers. Thus normally the buyer's pre-season order is expected to be satisfied in a reliable manner. On the other hand, when the buyer requires delivery

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