European Journal of Operational Research 227 (2013) 423–433

Contents lists available at SciVerse ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Production, Manufacturing and Logistics

The effect of supply uncertainty in price-setting newsvendor models

Minghui Xu [a], Ye Lu [b,*]

[a] School of Economics and Management, Wuhan University, Wuhan 430072, PR China
[b] Department of Management Sciences, City University of Hong Kong, Kowloon, Hong Kong

ARTICLE INFO

Article history:
Received 1 March 2012
Accepted 7 December 2012
Available online 5 January 2013

Keywords:
Supply uncertainty
Price-dependent newsvendor model
Stochastic comparisons
Emergency supply option

ABSTRACT

We consider a price-setting newsvendor model in which a firm needs to make joint inventory and pricing decisions before the selling season. The supply process is uncertain such that the received quantity is the product of the order quantity and a random yield rate. Two cost structures are investigated, the in-house production case in which the firm pays for the input quantity and the procurement case in which the firm pays for the quantity received only. Our objective is to investigate the effect of yield randomness on optimal decisions and expected profit. By using the theory of stochastic comparisons, we find that under both cost structures, a less variable yield rate leads to a lower optimal price and a higher expected profit. Moreover, we show that in the in-house production case, a stochastically larger yield rate also results in a lower optimal price and a higher profit, but this is not true in the procurement case. Examples show that the effect of supply uncertainty on optimal order quantity is not universal.

1. Introduction

A fundamental problem in supply chain management is how to match supply and demand so that the system operates effectively. However, manufacturers and retailers often suffer supply process uncertainty in addition to demand uncertainty. When the supply process is random, the quantity received may be different from the quantity ordered. Random yield is one common manifestation of supply uncertainty, whereby the firm receives a random portion of an order placed with a supplier. Yield uncertainty exists in many industries, including semiconductors, electronic fabrication and assembly, food processing, bio-pharmaceuticals, and resource-based industries such as mining and agriculture.

The existence of supply process uncertainty often results in lower supply chain performance. Firms may engage in various yield improvement activities and efforts such as new production technology, total quality control, RFID (radio frequency identification), and process-improvement to alter yield rates or increase the accuracy of yield rate information. In other words, these efforts make the yield rate stochastically larger or less variable. Hence, many interesting questions arise. Will these efforts increase the firm's profit? Under a stochastically larger or less variable yield rate, will the firm decrease order quantities? If the firm is a price setter, will a larger or less variable yield rate decrease the optimal price? The need to answer these questions is the motivation of this paper. Besides supply uncertainty, we assume that the firm faces a price-dependent and stochastic demand. Before the selling season, the firm makes joint pricing and inventory decisions. If the realized demand is less than the inventory, leftover inventory is salvaged. If demand exceeds inventory, unmet demand is satisfied by an emergency order/production option at a higher unit cost.

In practice, there are two costing schemes: the in-house production case (manufacturing setting), where the cost depends on the production input quantity, and the procurement case (retailing setting), where the firm only pays for the quantity received. In the in-house production case, yield uncertainty is usually caused by defective units during the production process but the manufacturer needs to pay for all of the input quantity. This is an especially common phenomenon when remanufacturing returned products. In the procurement case, the firm usually pays for the quantity received. We assume in both cases that the received quantity ("good" products) is the product of the production/order quantity and a random yield rate.

By using the method of stochastic comparisons, we can show the effects of yield randomness on the optimal decisions and the expected profits for both the in-house production case and the procurement case. When the yield rate becomes less variable, its effects in these two cases are similar. A less variable yield rate (please refer to Definition 2) will lead to a lower optimal price and higher expected profit, whereas the order quantity may be higher or lower. However, when the yield rate becomes stochastically larger (please refer to Definition 1), its effects on the two cases are quite different. For the in-house production case, a stochastically larger yield rate leads to a lower selling price and higher expected profit. For the pure procurement case, a stochastically larger yield rate may result in a lower or higher selling price, and

* Corresponding author. Tel.: +852 3442 8656.
E-mail addresses: mhxu@whu.edu.cn (M. Xu), yelu22@cityu.edu.hk (Y. Lu).

0377-2217/$ - see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ejor.2012.12.008

a lower or higher expected profit. In both cases, a larger yield rate may lead to a lower or higher order quantity.

The rest of the paper is organized as follows. The relevant literature is reviewed in Section 2. We present the model and give some definitions and preliminaries in Section 3. Then, we investigative the effects of supply uncertainty on optimal decisions and expected profits for the in-house production case and the pure procurement case in Sections 4 and 5, respectively. Finally, we conclude the paper in Section 6. All proofs are put in Appendix A. The analysis on the additive form of yield error structure can be found in Appendix B.

2. Literature review

This paper is related to several streams of literature. The first stream is on the price-setting newsvendor problem. For a comprehensive review, see the work of Petruzzi and Dada (1999), Yano and Gilbert (2003), Yao et al. (2006), Qin et al. (2011) and the references therein. Additive and multiplicative forms are two commonly used demand models in the newsvendor pricing literature (see, e.g., Petruzzi and Dada, 1999; Agrawal and Seshadri, 2000; Chen et al., 2009). We assume that the demand model is multiplicative, which can be represented as the product of a deterministic, price-dependent demand function and a random noise term (see, e.g., Monahan et al., 2004; Granot and Yin, 2005, 2008; Song et al., 2009; Chen and Bell, 2009). Studies in this stream do not usually consider supply uncertainty.

The second stream cares optimal inventory decisions under supply uncertainty due to random yield. Yano and Lee (1995) provide an excellent review of this literature. Recent works include those of Bollapragada and Morton (1999), Khouja (1999), Gupta and Cooper (2005), Keren (2009), Guler and Bilgic (2009), and Li et al. (2012). The stochastically proportional yield model is the most widely studied (see, e.g., Shih, 1980; Henig and Gerchak, 1990; Li and Zheng, 2006; and Liu et al., 2010), and is also used in this paper. Burke et al. (2009) investigate a model with multiple unreliable suppliers. They derive some structural results including the total order quantity, the number of suppliers selected for order placement, and the exact quantity of units ordered from each of these suppliers. Rekik et al. (2007) consider both the stochastically proportional yield and additive yield error models and characterize the structure of optimal order quantity based on different system parameters when both demand and yield error follow some commonly-used distributions. They also study the benefit of making supplier 100% reliable. The additive yield error model was also exploited in Keren (2009) and Li et al. (2012). For other classes of yield models, please refer to Dada et al. (2007). Most papers in this line of research focus on determining optimal lot size or characterizing the structure of the optimal inventory policy.

Several papers have studied the effect of supply uncertainty on optimal expected profit (Gerchak and Henig, 1994; Gupta and Cooper, 2005; Liu et al., 2010). Gerchak and Henig (1994) show that when yield is binomial, a stochastically larger yield results in a greater expected profit. Gupta and Cooper (2005) present an example to show that a stochastically larger yield rate may not be beneficial to the firm (due to existence of holding cost), i.e., a better yield rate distribution may give lower optimal expected profit. The single period model that Gupta and Cooper (2005) consider can be handled by the current model when the price is given. However, we assume that the leftover inventory is salvaged. Liu et al. (2010) study the impact of supply reliability on a retail firm's performance under joint marketing and inventory decisions and show that a stochastically larger yield rate always leads to a higher expected profit. However, all of these papers assume an exogenous price and only consider the cost structure of the in-house production case.

In the literature on production planning under supply uncertainty, selling price is commonly assumed to be exogenously given. However, there are a few exceptions. Tang and Yin (2007) study the pricing policy under supply uncertainty and examine the impact of that uncertainty on optimal decisions with a known, price-dependent demand. Kazaz (2004) studies production planning for olive oil with random yield and stochastic demand where both the selling price and purchasing cost of fruit are yield-dependent. Recently, Kazaz and Webster (2011) consider an agricultural firm that operates under supply uncertainty and yield-dependent trading costs. They extend Kazaz (2004) by considering deterministic, price-dependent demand and offering a risk-averse analysis, and considering the influence of fruit futures. Kazaz and Webster (2011) focus on the impact of the yield-dependent trading cost on the optimal selling price and production quantity. Kazaz (2008) studies a similar model with two model settings: an early pricing model and a postponed pricing model. Kazaz (2008) focuses on identifying the optimal selling price and production decisions for the two models. Our paper is close to those of Kazaz and Webster (2011) and Kazaz (2008) because we also model the problem by using an emergent purchasing option and price-dependent stochastic demand. However, our focus is on the impact of supply uncertainty on both optimal decisions and expected profits, and analyzing the differences between the in-house production and pure procurement cases. To the best of our knowledge, this is the first paper to study the effect of supply uncertainty on optimal decisions and expected profit with a price-dependent stochastic demand under the cost structures of both the in-house production case and the procurement case.

In this paper, we assume that the firm has an emergency order/production option for excessive demand. Hence, papers that adopt an emergency supply option in newsvendor models constitute the third stream of related literature. The emergency supply option can be traced back to Barankin (1961) in the newsvendor setting. With the emergency supply option, in additional to a "normal order" before the start of the selling season, the inventory manager may use an "emergency order" to fulfil shortages after demand realization, usually at a higher production/purchase cost. The emergency supply option in the newsvendor setting has been further considered by Gallego and Moon (1993), Eeckhoudt et al. (1995), Khouja (1996), Agrawal and Seshadri (2000), Lodree et al. (2008), and Lee and Lodree (2010). Lee and Lodree (2010) provide a practical example of textbook ordering in a bookstore wherein an emergency order may be used after demand realization. Xu (2010) studies the order and production problems in a decentralized supply chain with random yield and random demand. In his model, the manufacturer places an option order to the supplier before the selling season and the supplier may carry out an emergency production if the realized yield is low or the realized demand is high. The existence of an emergency supply option may have more advantages in enhancing supply chain performance, especially in random yield settings, see the examples offered by He and Zhang (2008, 2010), and He and Zhao (2012).

Finally, we adopt stochastic comparison techniques to study the effect of supply uncertainty. In the field of operations management, a number of papers study the effect of demand uncertainty using stochastic orders. Gerchak and Mossman (1992) show that less variable demand through risk pooling (when several independent random demands are aggregated into one) does not necessarily lead to a lower order quantity in a newsvendor setting. Ridder et al. (1998) show that demand distributions with higher variability may lead to a lower cost in a newsvendor problem. Song (1994) indicates that more variable leadtime demand will always lead to a higher long-run average cost, but a stochastically larger leadtime