Computers & Industrial Engineering 84 (2015) 113–121

Contents lists available at ScienceDirect

Computers & Industrial Engineering

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

On the risk-averse procurement strategy under unreliable supply

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ARTICLE INFO

Article history:
Available online 7 January 2015

Keywords:
Supply risk
Inventory strategy
Expected utility
Stochastic demand

ABSTRACT

This study investigates an effective procurement/inventory strategy for a risk-averse retailer facing unreliable supply and stochastic demand. By using an increasing and concave utility function to describe risk aversion, we construct a basic newsvendor (single-period) model and its multi-period extension. Both models are found to have unique solutions, as the optimized expected utility is strictly concave in initial inventory level. As a result, there is a unique optimal order quantity for the effective control of supply risk. For the single-period model, the optimal order quantity is derived in its analytical form. We then show by numerical analysis that the value of the optimized expected utility is a function of the initial inventory level when the retailer is risk-averse, becomes less sensitive to initial inventory level when the degree of risk aversion decreases, and is insensitive for the risk-neutral case. This finding suggests that in our setting the inventory holding matters only when the retailer is risk-averse. For the multi-period model, we propose a solution procedure using backward induction since a direct extension of the single-period solution is impossible. We also conduct a sensitivity analysis of demand and supply with the aim of giving some managerial suggestions for demand risk control and supplier selection.

1. Introduction

Procurement is an essential function as it is capital intensive. According to De Boer, Labro, and Morlacchi (2001), the procurement expenses account for over 50% of the total cost for industrial firms. Apparently, firms will benefit from a more competitive procurement or sourcing environment. Therefore, sourcing on an international scale allows firms to choose from various suppliers who could deliver, and importantly, at the right cost. For over two decades, the tremendous development in global logistics and other enabling technologies have made the global supply network a critical support for most advanced industrial firms' operations. For instance, the suppliers of Boeing are distributed in more than 50 countries all over the world; and the examples are legion. Unfortunately, such a powerful supply network is also susceptible to both the internal problems of suppliers and extraneous events. The latter is due to unexpected developments in the environment, economy and politics, and are hence uncontrollable. For example, the serious flooding in Thailand in October 2011 caused extensive and disruptive production problems for the Southeast Asian, Japanese and other international manufacturers. Toyota's production was simply throttled due to a shortage of more than 100 types of manufacturing components; Honda had to shut down its factories in Thailand, cutting down its output by 100,000 vehicles. Moreover, the production of major hard-disk manufactures including Western Digital, Seagate, Hitachi and Toshiba was hard hit due to supply shortage. Therefore, this study will address the issue of unreliable supply that causes procurement risk, other than stochastic demand and volatile supply price.

Inventory is commonly used as the means to buffer the variation between supply and demand; and a buyer could invest on (more inventory) to guard against such supply shortage. In this discussion, the shortage is due to unreliable supply. For example, when Hurricane Katrina took place in Gulf coast in 2005, many local supply chains were paralyzed. Wal-Mart successfully avoided a big loss by overstocking some items that would be needed (Schmitt & Snyder, 2012). However, most existing work on inventory models have assumed that the firm is risk neutral, and hence are incapable of addressing the risks involved. In this complex and uncertain environments, most firms would rather choose to become cautious and risk-averse in making procurement and inventory decisions. Therefore, instead of aiming at optimizing the expected profit or cost, as is in the case of a risk-neutral decision maker, such procurement and inventory models should consider the risk implications in making realistic suggestions to management. To address these shortcomings, therefore, it is

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http://dx.doi.org/10.1016/j.cie.2014.12.034
0360-8352/

necessary to study supply risk control from the perspective of a risk-averse buyer. This study considers both unreliable supply and stochastic demand in developing a procurement/inventory model/strategy to optimize the expected return and the associate risk. We employ an exponential utility function, which is both increasing and concave, to represent the buyer's risk-averse attitude towards its risky operating profit. We introduce a single-period procurement risk control model and also its possible extension to the multi-period case. In each model, it is proved that there is a unique optimal inventory strategy for the buyer to control supply risk. For the single-period model, an analytical solution is obtained and based on that, we perform a sensitivity analysis on the proposed inventory strategy in response to changes of various parameters. For the multi-period model, a solution procedure is developed based on backward induction. Therefore, this study extends the basic newsvendor model by considering the risk due to unreliable supply and, by doing so, further investigating the influence of the buyer's attitude on its optimal inventory decisions.

The remainder of this paper is organized as follows. Section 2 gives a brief literature review of extant work on procurement risk, especially supply risk. In Section 3, a description of risk-averse procurement problem under unreliable supply is presented. Sections 4 and 5 develop and analyze the single-period model and multi-period model, respectively. Finally, the conclusion is given in Section 6.

2. Literature review

We define procurement risk as the variation of profit or cost incurred in a procurement activity under uncertain environment such as stochastic demand, volatile price and unreliable supply. Such a risk can therefore manifest itself as demand risk, price risk, supply risk or any combination of these three types of risk. In the literature, the first two types of risk (i.e. demand risk and price risk) arising from procurement have been extensively studied. For example, some forms of portfolio approach have been proposed to explore the synergy that could be derived from a combined use of various supply channels that offer different trade-offs (e.g. cost/quality) or supply flexibilities (e.g. a variable supply quantity agreed by the supplier and buyer). Such procurement portfolio approaches have been shown effective to control both demand risk and price risk (Chen & Wu, 2011; Martínez-de-Albéniz & Simchi-Levi, 2005; Shi, Wu, Chu, Sculli, & Xu, 2011; Wu, Shu, & Chen, 2014). For effective control of demand risk, Buzacott, Yan, and Zhang (2011) incorporated demand information updating into a portfolio strategy for demand risk management. With more information, buyers can forecast demand more precisely, and thus endure less demand risk. Moreover, Ni, Chu, Wu, Sculli, and Shi (2012) combined information updating with financial hedging to mitigate demand risk and price risk simultaneously. Other strategies include emergent purchase (Ma, Zhao, Xue, Cheng, & Yan, 2012; Sun, Liu, & Lan, 2010), dynamic pricing (Araman & Caldentey, 2009; Gong, Chao, & Zheng, 2014), etc. However, all these strategies cannot be directly utilized to control supply risk.

As for the procurement problem under unreliable supply, inventory investment is probably the most basic and commonly known approach to safeguard possible shortage (Burke, Carrillo, & Vakharia, 2009; Rekik, Sahin, & Dallery, 2007). Also, inventory could be suitably incorporated in various supplier diversification strategies for managing supply and demand (Dada, Petruzzi, & Schwarz, 2007; Federgruen & Yang, 2011; Feng & Shi, 2012; Yan, Ji, & Wang, 2012). For example, multiple suppliers with different structures of supply cost and reliability could be deployed in a portfolio to control procurement risk. However, inventory investment and diversification strategy in existing studies have mainly adopted a risk-neutral assumption that aims only at maximizing the expected profit. Likewise, studies in other supplier strategies including supply learning (Tomlin, 2009) and process improvement (Wang, Gilland, & Tomlin, 2010), have also taken the view of a risk-neutral decision maker. Apparently, this risk-neutrality assumption is inappropriate in view of today's complex and uncertain operating environment, especially for supplies that are susceptible to various forms of disruptions. Even a supplier can be risk-averse (Xu, Lu, Huang, & Zhang, 2013), not to mention a cautious buyer facing both stochastic demand and unreliable supply. Therefore, this study addresses the problem of unreliable supply and considers the possible risks or losses incurred due to a specific procurement decision by a risk-averse decision maker. It extends the existing risk-averse inventory management approaches (Chahar & Taaffe, 2009; Chen, Sim, Simchi-Levi, & Sun, 2007; Wu, Wang, Chao, Ng, & Cheng, 2010) by considering the problem of unreliable supply.

Previously, Giri (2011) studied a single-period problem in which the retailer can source multiple products from two suppliers – one unreliable and the other totally reliable. Compared with Giri's work, this study considers only one product. However, our single-period model is similar to Giri's in that the initial inventory is taken as adjustable – the initial inventory is regarded in our model as a reliable supply source while those to be ordered as unreliable. In addition, Giri's model has employed a mean–variance framework to address downside risks. Such a framework is based on a transformation of an exponential utility function and the framework is more suitable for buyers who tend to be less risk-averse; and it may not be suitable for the more cautious buyers. For the effective control of the downside risks, the risks associated with specific procurement strategies or decisions have to be effectively modelled and measured. In this paper, an exponential utility (Chen et al., 2007) is used for this purpose. This utility function is found to have the desirable properties of both increasing and concave, and thus can address buyers with any degree of risk aversion.

3. Problem and preliminaries

We consider a retailer who procures products from an unreliable supplier and sells them to the market in which demand is stochastic. The supplier is said to be unreliable when he fails to deliver the retailer's order in the right quantity. In other words, the retailer may only receive part of the ordered products after ordering, making him exposed to an unnecessary shortage when the realized demand is high. One possible solution to such shortage is to build up some inventory as the buffer, but such inventory built-up practice may incur a significant inventory holding cost. As a result, the retailer must seek for a balance between the cost of carrying the excessive inventory and the cost of failure to satisfy the customer demands. For an appropriate description of this problem, the traditional newsvendor model is first applied.

The key symbols and variables used in this paper are summarized as follow.

r	unit selling price of the end product
p	unit wholesale price set by the supplier
b	unit shortage cost
h	unit inventory holding cost
d	uncertain customer demand, with a cumulative distribution function (CDF) $G(d)$
x	initial inventory level
λ	discount factor
π	operating profit of the newsvendor
$u(\cdot)$	the (exponential) utility function of the newsvendor
α	an utility parameter $(\alpha < 0)$ that captures newsvendor's degree of risk aversion
Q	order quantity
θ	supply ratio

In the multi-period model, these symbols defined here are extended with subscript t to denote each period in the decision