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Optimal lead time policy for short life cycle products under Conditional Value-at-Risk criterion ☆

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ABSTRACT

The lead time reduction problem in a supply chain with a risk-averse retailer and a risk-neutral manufacturer for short life cycle products is studied in this paper. Lead time can be reduced by additional crashing cost to enhance forecast accuracy of uncertain demand. Under Conditional Value-at-Risk (CVaR) criterion, the effects of decision maker's risk aversion and additional crashing cost for lead time reduction on optimal decisions are analyzed. Moreover, a revenue sharing contract is proposed to achieve supply chain coordination. The results suggest that when the retailer is more risk-averse and when forecast error is larger, the retailer tends to select a shorter lead time despite the higher wholesale price charged by the manufacturer. However, if the retailer is mildly risk-averse and the forecast error is small, he might not select to shorten the lead time because of associated additional crashing cost. Thus, the retailer should carefully balance the benefit against the cost of lead time reduction. In addition, we find lead time reduction is conductive to improving supply chain efficiency compared to the case without lead time reduction. Revenue sharing contract can achieve supply chain coordination and Pareto improvement for both supply chain agents. The improved utilities increase as the decision maker is more risk-averse and the forecast error is higher.

1. Introduction

Products with short life cycles are becoming important sources of profits for organizations because their marginal profits are higher than "functional" products (Fisher, 1997; Milner & Kouvelis, 2005). These "innovative" products are characterized by high intrinsic uncertainty and unpredictable demand, long lead time coupled with a short life cycle, and a concentrated selling season (Fisher, 1997). For example, the reported lead time for Oxford shirts ordered by J.C. Penney is seven months and the lead time for Liz Claiborne apparel is five months (Iyer & Bergen, 1997). With a long lead time, retailers must place orders with manufacturers far in advance of the actual selling season before any demand history is available (Fisher & Raman, 1996).

The length of lead time directly affects the forecast accuracy of uncertain demand (Perry, 1990). Reducing lead time can effectively enhance forecast accuracy and enable prompt response to unpredictable demand during the concentrated selling season of short life cycle products. Reduced lead time can substantially decrease forecast error as well. For instance, Blackburn (1991) reported that forecast error decreased from 40% to 20% when lead time was reduced from six to four months. Forecast error of demand will lead to inventory turbulence in practices: insufficient inventory results in high losses and low service level due to stockouts, or excess inventory results in markdowns and high disposal cost (Iyer & Bergen, 1997). Thus, decision makers need to formulate a strategy for matching the supply and demand of these products. Setting this strategy is more challenging than handling that of "functional" products, which have longer life cycles and stable, predictable demands. Lead time reduction can enhance forecast accuracy and ensure a quick response to changing customer needs. In the increasingly intense and competitive business environment, lead time reduction is an effective approach to respond quickly to unpredictable demand and minimize stockouts, forced markdowns, and obsolete inventory (Fisher, 1997).

Lead time can be reduced by various approaches. For example, a quick response system can compress lead time through information technology, such as electronic data interchange, point of sale, and bar coding (Cachon & Swinney, 2011; Fisher & Raman, 1996). Faster production processes, rapid logistics, collaborative planning, forecasting, and replenishment can also be conducive to lead time reduction. However, significant additional crashing costs may be associated with such reductions (Axsater, 2011). Most literature focused only on the benefit yielded by lead time reduction while

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disregarding the additional crashing cost involved in lead time reduction. To set an optimal lead time, decision makers need to balance carefully the benefit against the cost of lead time reduction.

Long lead time, great variety, and concentrated selling season for short life cycle products often increase the supply chain operational risk coming from demand uncertainty, shortages or excess supplies, and fluctuating environmental factors (Chiu & Choi, 2013). Traditionally, risk-neutral supply chain agents optimize the expected profit or cost. However, in practice, numerous contrary examples indicate that supply chain agents' decision-making behavior under uncertainty is not always geared towards optimizing expected profit or cost (Gan, Sethi, & Yan, 2005; Ma, Liu, Li, & Yan, 2012). The decision makers in a supply chain would have different kinds of attitudes towards risk. They can be avoiders of risk (risk-averse), lovers of risk (risk-seeking), or neutral to risk (risk-neutral) (Chiu & Choi, 2013; Choi, Li, & Yan, 2008). For example, when faced with unpredictable demand for short life cycle products due to long lead time, a risk-averse decision maker may make an overly conservative estimate of the market demand and order too few items, thus resulting in high losses and low service level due to stockouts. By contrast, a risk-seeking decision maker may make an overly optimistic estimate of the market demand and order too many items, thus resulting in forced markdowns and high disposal cost. Given this situation, incorporating the risk attitudes of supply chain agents into lead time reduction model is important in setting applicable and tailored decisions for a supply chain with short life cycle products.

In light of these critical issues, we study the optimal lead time decision problem in a short life cycle product supply chain with long lead time and short selling season. Our study contributes to literature on short life cycle products in two main aspects. First, our study is different from the extant literature that mainly focused on the benefits yielded by lead time reduction. We argue that though lead time reduction could lessen the retailer's demand forecast error, which can be as high as 40% to 100% (Fisher, 1997), it could also increase the supplier's additional crashing cost; thus leading to the increase of wholesale price. Therefore, to determine an optimal lead time, decision makers have to balance carefully the benefit against the cost of lead time reduction. Second, we incorporate the risk attitudes of supply chain agents into lead time reduction model, which is particularly important in a circumstance with high market demand uncertainty. To be specific, we consider a risk-averse supply chain consists of a risk-averse retailer and a risk-neutral manufacturer. The developed theoretical models enable decision makers to determine optimal ordering time, order quantity, and wholesale price by considering the effects of risk attitudes of supply chain agents and additional crashing cost for lead time reduction. Moreover, the results suggest that lead time reduction is conductive to improving supply chain efficiency as compared to the case without lead time reduction. In particular, the more risk-averse the decision maker is, as well as the larger forecast error is, the larger the improved efficiency will be. When the retailer is more risk-averse and the forecast error is larger, the retailer will tend to select a shorter lead time despite the higher wholesale price for a shorter lead time charged by the manufacturer. However, if the decision maker is mildly risk averse and the forecast error is small, he might not select to shorten lead time due to associated additional crashing cost. Our findings can provide new insights to practitioners with different risk attitudes under time-based competition environment.

The remainder of this paper is organized as follows: Section 2 reviews the literature related to our study. Section 3 analyzes the centralized and decentralized decision models for lead time reduction under CVaR criterion. Section 4 proposes a revenue sharing contract to achieve supply chain coordination. Numerical examples and managerial implications are given in Section 5. Finally, Section 6 summarizes the study. All proofs are presented in the Appendix.

2. Literature review

Lead time in inventory management is widely recognized as an important issue. There were two primary streams of studies focused on optimal lead time decision. One stream dealt with the optimal promised (quoted) lead time decision. The tardiness cost and holding cost due to the actual realized lead time later or earlier than promised lead time were considered. Yano (1987) was the first to use promised lead time as a decision variable. Researchers such as Hopp and Spearman (1993), So and Song (1998), So (2000), Liu, Parlar, and Zhu (2007), Wu, Kazaz, Webster, and Yang (2012) and Li, Lin, and Ye (2014) studied the issues related to promised lead time decision. Our study differs from these studies that we consider the optimal actual realized lead time decision, which can be reduced by additional crashing cost, instead of promised lead time decision. The other stream related to our model that considering additional crashing cost for lead time reduction dealt with the problem of multi-period products. Liao and Shyu (1991) first presented a continuous review model in which the order quantity was predetermined and lead time was the unique decision variable for multi-period products. Ouyang, Yen, and Wu (1996), Pan and Yang (2002), Ouyang, Wu, and Ho (2004), Chang, Ouyang, Wu, and Ho (2006), Lin (2009), Ye and Xu (2010), Li, Xu, and Ye (2011) and Li, Xu, Zhao, Yeung and Ye (2012) extended the model and developed new inventory models from different perspectives. A summary of this stream was given by Li et al. (2012). Our study differs from these studies that we consider the setting for short life cycle products where lead time reduction is conducive for enhancing forecast accuracy. Our model is also closely related to quick response system literature which found that lead time reduction can help to enhance forecast accuracy (Cachon & Swinney, 2011; Fisher & Raman, 1996; Iyer & Bergen, 1997; Lin & Parlakturk, 2012). However, the traditional quick response system literature did not consider additional crashing cost for lead time reduction. Specially, our study takes the risk attitudes of supply chain agents into consideration, which helps to make tailored decisions under uncertain environment with risks.

Risk management is not a new topic in the subject of inventory control area. Three major risk formulations were widely applied in related literature: mean–variance or mean–standard deviation, chance constraints or Value-at-Risk (VaR), and conditional VaR (CVaR). Each has its own strengths and limitations (see Chen, Sim, Simchi-Levi, & Sun (2003) for a detailed discussion). CVaR criterion measures "the average value of the profit falling below a certain quantile level, it takes into account both reward and risk" (Chen, Xu, & Zhang, 2009, page 1040), and has drawn a great deal of attention in the operation management field (see Rockafellar & Uryasev (2000), Rockafellar & Uryasev, 2002 for more details on CVaR). For example, Tomlin and Wang (2005) considered the optimal resource investments of mix flexibility and dual sourcing in unreliable newsvendor networks by using CVaR to measure risk. Gotoh and Takano (2007) adopted CVaR as the decision criterion in their study of a single-period newsvendor problem. Yang, Xu, Yu, and Zhang (2009) explored the use of revenue-sharing, buy-back, two-part tariff, and quantity-flexible contracts for coordinating supply chains with a risk-neutral supplier and a risk-averse retailer under CVaR framework. Ma, Zhao, Xue, Cheng, and Yan (2012) used CVaR as risk measurement to study the Nash-bargaining problem for the wholesale price and order quantity negotiation in a supply chain with a risk-neutral manufacturer and a risk-averse retailer. In this paper, we also use CVaR criterion to measure the performance of a risk-averse supply chain.