



A risk-averse competitive newsvendor problem under the CVaR criterion



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ABSTRACT

We study a risk-averse newsvendor problem with quantity competition and price competition. Under the Conditional Value-at-Risk (CVaR) criterion, we characterize the optimal quantity and pricing decisions under both quantity and price competition. For quantity competition, we consider two demand splitting rules, namely proportional demand allocation and demand reallocation. Although competition always leads to overstocking, interestingly it does not necessarily lead to a profit loss in certain competitive environments, such as demand reallocation, by avoiding/reducing overstocking that results from competition under the risk-neutral criterion. For price competition, we consider both additive and multiplicative demand. We find that the order quantity, sale price, and the expected profit decrease in the degree of risk aversion. Further, both high price sensitivity and competition intensity force decision makers to lower their prices. However, high price sensitivity always reduces the order quantity while competition can have the opposite effect.

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1. Introduction

The newsvendor problem, as one of the fundamental problems in supply chain management, is an one-time business decision in which a monopolist vendor orders inventory before a one period selling season with stochastic demand. The standard newsvendor problem has been widely studied and extended to more complex models. We refer interested readers to [Khouja \(1999\)](#), [Petruzzi and Dada \(1999\)](#) and [Qin et al. \(2011\)](#) for detailed reviews of the newsvendor problem and its extensions.

To reflect the situation in real markets, one major extension of the newsvendor problem is the replacement of the monopolist vendor by a set of competing vendors. A key element of the competitive newsvendor problem relates to how competition affects inventories and pricing. The two main research streams are quantity competition and price competition. In recent years, a number of papers have been devoted to competition analysis in the standard (risk neutral) newsvendor problem. They find that the quantity competition always leads to inventory overstocking (e.g., [Lippman and McCardle, 1997](#); [Cachon, 2003](#)) and that price competition leads to lower equilibrium prices and higher stock levels in all firms (e.g., [Chen et al., 2004](#)). An overview of the key results is provided in [Section 2.1](#).

Ordering and pricing decisions based on quantitative models in industrial practice and academics are often based on minimizing the expected cost or maximizing the expected profit, which implies the concept of risk neutrality of the decision maker. Nowadays, supply chains become more vulnerable to uncertainties. Besides the expected profit, decision makers focus more on risk or potential loss. Hence, the assumption of risk neutrality seems to be inadequate for contemporary supply chain management. In view of this, many researchers have called for models that deviate from the risk neutral assumption. For example, [Tsay \(2002\)](#) suggests that various players should be allowed to have different attitudes towards risk sensitivity. Recent empirical findings provide further support for the importance of incorporating risk preferences in business practices. After a survey of 1500 executives from 90 countries, a McKinsey research report ([Koller et al., 2012](#)) points out that the decision makers demonstrate extreme levels of risk aversion regardless of the size of the investment, even when the expected value of a proposed project is strongly positive. Through an experimental study, [Schweitzer and Cachon \(2000\)](#) show that the ordering decisions reflect risk aversion for high profit products. Motivated by these arguments, research on risk-averse models with different objective functions to reflect risk preferences has become an important stream.

Expected utility, mean-variance, and VaR/CVaR are the three main research streams of modeling risk averseness in inventory and pricing problems. For the framework of expected utility, although any concave increasing utility function (e.g., logarithmic

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utility function and loss-averse utility function) could reflect risk-averse behaviour, the main challenge is how to explicitly specify the utility function for a decision maker. Note that a utility function represents both the degree of the diminishing utility in wealth and the decision makers' attitude toward risk. However, these two aspects are inseparable from the utility function (e.g., Levy, 2006). Therefore, expected utility is not a dedicated risk measure and cannot be implemented in practice. The framework of mean-variance introduced by Markowitz (1952) is to address the trade-off between the expected return (mean) and the variation of return (variance). However, the mean-variance criterion suffers an inherent theoretical flaw in which both upside and downside variations from the mean are seen as risk. Although variance is still suitable for the case where the outcome distribution is close to a symmetric distribution, profit distributions of inventory models are asymmetric in general (e.g., Ismail and Louderback, 1979), which implies that variance may not be a reasonable risk measure. The above argument leads to the use of a downside risk measure to replace the variance. CVaR, as one important downside risk measure, is the conditional expected profit below the amount VaR, where VaR is defined as the maximum profit at a specified confidence level. The CVaR criterion is also a coherent risk measure that has some desirable structure and computational characteristics compared to the VaR criterion. Further, as Choi and Ruszczyński (2008) point out, CVaR represents a trade-off between the expected profit and a certain risk measure, which means that CVaR takes into account both the expected profit and the risk. Because of its numerous advantages, the CVaR criterion has been widely applied both in theoretical study and in practice. We review the key results of the newsvendor problem under the CVaR criterion in Section 2.2.

This paper differs from the previous literature on risk-averse newsvendor models in three ways. First, although several researchers (e.g., Wang, 2010) have recently considered risk-averse competitive newsvendor problem under a utility criterion, the aforementioned drawbacks of the expected-utility framework hinder practical implementation. Therefore, we replace the utility criterion by the CVaR criterion that has not been studied in the literature yet. Second, the literature has only explored the price competition in risk-neutral newsvendor games (see Chen et al., 2004), and studied the pricing and quantity decisions of a risk-averse newsvendor without competition (see Chen et al., 2009). The effect of risk averseness in pricing competition has not been investigated yet. Third, the literature on the competitive-newsvendor problem assumes that the newsvendors are identical (e.g., Wang, 2010; Chen et al., 2004). The effect of heterogeneity in the newsvendors on the competitive problem is still unknown.

To fill these research gaps, we study the risk-averse competitive newsvendor problem, using CVaR as the risk measure and considering both quantity competition and price competition. For quantity competition, two types of demand splitting rules (proportional allocation and reallocation) are proposed. We show that there exists a unique Nash equilibrium for both competition types. We find that risk averseness decreases the newsvendor's order quantity and may lead to inventory under stocking. Further, although competition leads to a higher total order quantity than that of integrated newsvendors (single newsvendor problem), the total profit of competing newsvendors may not always decrease. Specifically, the total profit of risk averse competitive newsvendors may be higher than that of integrated newsvendors in the demand reallocation problem. For price competition, the risk averse competition equilibrium has a lower retail price and a lower order quantity. Meanwhile, the total profit of competing newsvendors is always lower than that of integrated newsvendors. Moreover, we show that the equilibrium selling price decreases with both the elasticity of demand and the proportion of a newsvendor's unsatisfied customers that switch to a competitor (intensity of price competition). The equilibrium order quantity decreases with the elasticity of demand, but first rises and then drops

with the competition intensity. For the heterogeneous newsvendors, the newsvendor with a higher degree of risk aversion intends to adopt a more conservative strategy (e.g., a higher price and a less order quantity), which results in a smaller market share.

The remainder of this paper is organized as follows. In the next section, we review the literature on the competitive newsvendor problem and on the risk-averse newsvendor problem. Section 3 introduces the model setting. Section 4 considers the quantity competitive newsvendor model. In Section 5, we consider the pricing competitive newsvendor problem. Section 6 discusses the effects of risk aversion and competition. Section 7 discusses the heterogeneous competitive newsvendor problem and presents numerical results. Finally, Section 8 concludes the paper.

2. Literature review

The newsvendor literature is surveyed from two aspects: competition and risk aversion.

2.1. The competitive newsvendor problem

For quantity competition, Lippman and McCardle (1997) consider a competitive newsvendor problem in which the total demand is allocated among competing newsvendors under certain demand splitting rules. Cachon (2003) considers the same newsvendor problem with a proportional demand allocation rule, i.e., the supplier allocates demand among the newsvendors proportional to their orders. Both studies find that quantity competition leads to overstocking. Wang (2010) extends the newsvendor problem with a proportional demand allocation rule to a game setting where multiple newsvendors are loss averse under a utility criterion. They show that loss aversion leads to a decrease in the newsvendors' total order quantity and may lead to a lower total inventory level of the decentralized supply chain than that of an integrated supply chain. By using the same utility criterion as in Wang (2010) and under a demand reallocation rule, Liu et al. (2013) consider the competitive loss averse newsvendor problem in which two substitutable products are sold to two identical retailers. They show that the order quantity of each retailer is increasing in the loss aversion coefficient and increasing in the substitution rate.

For price competition, Chen et al. (2004) investigate the price-dependent competitive newsvendor problem in which the firm uses the price to compete for demand. They find that competition leads to lower equilibrium prices and higher stock levels for all firms. Zhao and Atkins (2008) study a similar pricing competitive newsvendor problem. They also find that the competitive equilibrium has higher safety stocks and lower retail prices. Further, they show that retail prices and safety stocks strictly increase with the proportion of a newsvendor's unsatisfied customers that switch to a competitor, but strictly decrease with the intensity of price competition.

2.2. The risk-averse newsvendor problem

Modelling risk-averse newsvendor problems has received considerable attention in recent years. Utility functions (e.g., Lau, 1980; Agrawal and Seshadri, 2000; Chen et al., 2007; Choi and Ruszczyński, 2011), mean-variance (e.g., Chen and Federgruen, 2000; Wu et al., 2009) and VaR/CVaR are the three main research streams. We refer interested readers to Jammernegg and Kischka (2012) for summaries of the ordering policies of newsvendors with various risk preferences. Here, we review the key contributions on the CVaR approach, which is one of the most important financial risk measures. CVaR is a coherent risk measure with attractive computational characteristics and consequently is widely used in the financial fields. For more

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