Risk-averse multi-product selective newsvendor problem with different market entry scenarios under CVaR criterion

Mohammad A.M. Abdel-Aal *, Shokri Z. Selim

Department of Systems Engineering, King Fahd University of Petroleum and Minerals, 5067, Dhahran 31261, Saudi Arabia

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ABSTRACT

We study the CVaR risk-averse Multi-Product Selective Newsvendor Problem (MPSNVP). The MPSNVP involves the integration of the procurement decisions with the market selection decisions. Prior to the demand realization, the decision maker has to select markets (from available markets) to serve, and decide the order quantity for each product, in order to maximize profit under CVaR risk criterion. The products are procured from an external supplier with a lower purchasing cost relative to the local suppliers. It is assumed that the realized demand for each product should be satisfied; and in the case of shortages, the firm expedites from a local supplier with a higher purchasing cost. Specifically, three cases of the MPSNVP are discussed: flexible, full and partial market entry problems. The mathematical models result in binary nonlinear programs. We propose solution algorithms to these models. In addition, we transform the obtained programs into conic quadratic mixed integer programs. The computational tests show that the proposed solution algorithms outperform the state-of-the-art commercial solvers. In addition, the paper provides managerial insights into the effect of the risk aversion level along with the number of products and market pool size.

1. Introduction

Traditional models of supply chain planning used to treat planning decisions separately. Those models do not optimize the entire supply chain, because of the conflict between planning decisions, and the drastic changes in the dynamic business environment. One can notice a proliferation of recent research trend on integrating different planning decision. A crucial topic in supply chain planning is inventory planning. Newsvendor problem is one of the well-known classical problems in inventory management literature. The decision maker of the classical newsvendor problem has to decide on the order quantity to be procured, in order to maximize (minimize) the total expected profit (cost). The procurement decision has to be taken prior to the realization of the actual demand. Upon demand realization, either leftover inventory or stock-out will occur at the end of the selling period. The decision maker should consider both of these possibilities during the decision-making process.

Another stream of literature that is closely related to inventory planning problems is the demand or market selection problems. This type of problems considers demands characteristics, and allows the supplier to select the markets to serve. Related papers on deterministic demand selection models and their variants include (Charnsirisaksul, Griffin, & Keskinocak, 2004; Geunes, Shen, & Romeijn, 2004; Shu, Li, & Huang, 2013; van den Heuvel, Romeijn, Wagelmans, & Kundakcioglu, 2007). For stochastic demand selection, see (Bakal, Geunes, & Romeijn, 2008; Carr & Lovejoy, 2000; Chahar & Taaffe, 2009; Lin & Ng, 2011; Taaffe, Geunes, & Romeijn, 2008).

Taaffe et al. (2008) integrated the classical newsvendor problem and the problem of market selection in a single problem known as the Selective Newsvendor Problem (SNVP). Consequently, the SNVP considers a firm that aims at maximizing its expected profit from selling a single product in a set of potential markets. The decision maker of the SNVP has to identify the optimal quantity to be manufactured or purchased from a supplier, as well as select the set markets to serve. The modeling of this problem relies on the benefit of risk-pooling effect by gathering the demand of multiple markets and ordering a single order quantity. Eppen (1979) and Chen and Lin (1989) studied and displayed the risk-pooling effect and its benefits in inventory management. Several studies were performed to extend the SNVP. Taaffe, Romeijn, and Tirumalasetty (2008) discussed the case where the demand follows discrete probability distribution with all-or-nothing orders in single and multiple periods. A two-stage stochastic integer
program model was developed. The authors; then, proposed a tailored cutting plane algorithm on the bases of the L-shaped method for solving the stochastic integer program.

Taaffe and Tirumalasetty (2005) introduced the risk aversion concept into the SNVP. They provided two risk models; one of them is related to the critical predefined profit level and the other is related to minimizing the worst case profits of a given demand. The authors proposed heuristic procedures for solving each model of the two resulting stochastic integer programs.

Chahar and Taaffe (2009) extended the all-or-nothing model of Taaffe et al. (2008) to the risk aversion case. They applied the well-known conditional value-at-risk (CVaR) and the mean-CVaR approaches to control the demand risk.

Waring (2012) studied the effect of the value-at-risk (VaR) as well as the CVaR and the mean-CVaR as risk measures on the optimal decisions and profit of the SNVP. She also evaluated the effect of the fluctuations of the risk preference levels on the SNVP performance.

Lin and Ng (2011) developed a robust optimization technique to solve the minimax regret SNVP model in the case of limited information about the probability distribution of the markets demands. The authors developed a linear time solution method and another algorithm based on integer programming to obtain an approximate solution. Then, they compared their results with those of the worst-case model in terms of risk-related criteria and mean profit.

Traditionally, the classical newsvendor problem and the SNVP are modeled to obtain the maximum expected profit or, equivalently, the minimum expected cost. This modeling approach is suitable for risk-neutral decision makers. However, there are decision makers with risk-taking preferences and others with risk-aversion preferences. In this kind of companies (Chahar & Taaffe, 2009), in addition, in real world, companies might be concerned with achieving a predetermined target of profit or avoiding a certain level of losses due to demand uncertainty; risk-aversion preference is suitable for decision-makers in the real world is always consistent with the loss aversion preferences (Xinsheng, Zhiqing, Rui, Min, & Ping, 2015). Practically, not all companies have financial resources to support potential losses due to demand uncertainty; risk-aversion preference is suitable for this kind of companies (Chahar & Taaffe, 2009). These facts motivate the study of risk aversion preferences of decision makers and the consequences of these preferences. Decision theory and financial engineering provides well-established studies considering the risk preferences of decision makers.

In recent years, researchers have focused on the risk-averse newsvendor problem and have provided different approaches to incorporate risk-aversion to the newsvendor problem. Atkinson (1979) studied the risk-aversion attitude of a manager, and showed that, such a manager will order a smaller quantity than a risk-neutral manager will. Some of the researchers explored the utility function to model the risk-aversion in the newsvendor problem (Bouakiz & Solbel, 1992; Choi & Ruszczyński, 2011; Lau, 1980; Shu, Wu, Ni, & Chu, 2015). Other studies maximized the probability of achieving a predetermined profit (Lau & Lau, 1988; Lau, 1980). Another approach to incorporate risk-aversion to the newsvendor problem is to optimize the mean-variance function of the newsvendor model (Choi & Chiu, 2012; Choi, Li, & Yan, 2008; Wu, Li, Wang, & Cheng, 2009). The recent trend in the risk-averse newsvendor literature is focusing on the use of risk measures, such as VaR (Jammernegg & Kischka, 2012; Özler, Tan, & Karaesmen, 2009; Wen & Qin, 2013; Wu, Zhu, & Teunter, 2013), CVaR (Ahmed, Çağnak, & Shapiro, 2007; Chahar & Taaffe, 2009; Gotoh & Takano, 2007; Jammernegg & Kischka, 2012; Xinsheng et al., 2015; Xu & Li, 2009; Xu, Meng, & Shen, 2013), spectral measures of risk (Fichtinger, 2010), and law invariant measures of risk (Choi & Ruszczyński, 2008; Choi, Ruszczyński, & Zhao, 2011).

The common approach to treating risk aversion is through utility function. However, several studies state that expected utility is not a dedicated risk measure and is difficult or even impossible to be implemented in practice (Ahmed et al., 2007; Choi & Ruszczyński, 2008; Wu, Zhu, & Teunter, 2014). Arzter, Delbaen, Eber, and Heath (1999) introduced four coherency axioms, when a risk measure satisfies these axioms; it is known to be a coherent measure of risk. Gotoh and Takano (2007), Choi et al. (2011) justified the utilization of coherent risk measures; such as CVaR, as a strong alternative to utility function approach in expressing the risk-aversion preferences of decision makers and demonstrate that optimizing the CVaR never conflicts with optimizing the expectation of any risk-averse utility function by stating that:

- Expected utility models as well as coherent risk measures are convex and consistent with stochastic dominance.
- Coherent risk measures satisfy the axioms of Translation Equivariance and Positive Homogeneity.
- For expected utility models, Translation Equivariance and Positive Homogeneity axioms typically do not hold.

Choi et al. (2011) stated the following “For a multi-product newsvendor, the Translation Equivariance axiom implies that adding a constant gain is equivalent to changing the vendors performance measure by the same amount; the Positive Homogeneity axiom guarantees that one obtains the same solution when considering the total profit or the profit rate (i.e., average profit per product), and when one changes the currency in which the profit is calculated.” The above arguments demonstrate that implementing coherent risk measures to model risk aversion attitudes of the multi-product newsvendor problem can be more attractive than implementing the expected utility approaches due to the appealing properties of coherent risk measures.

Pflug (2000) proved that CVaR is a coherent risk measure. The appealing property of CVaR; and in fact all coherent risk measures, is that it is consistent with the stochastic dominance conditions and this leads to convex optimization problems (Ahmed et al., 2007; Ogryczak & Ruszczyński, 2002).

Practically, companies with newsvendor structures such as electronics, fashion, airline, food industry, etc., sell more than one type of product (Lau & Lau, 1995). This fact motivates the extension of the SNVP to consider the case of SNVP with multiple products.

The study in this paper tries to fill the gap in the literature by considering the problem of selling multi product types in a set of potential markets. The paper presents the real features of the companies with newsvendor structures, which sell more than one type of product (Lau & Lau, 1995). We take risk preferences of decision makers into consideration. This paper studies the CVaR risk-averse SNVP with multiple products, termed as the CVaR risk-averse Multi-Product Selective Newsvendor Problem (MPSNVP). The risk-neutral MPSNVP was studied in Abdel-Aal, Syed, and Selim (2016) and Strunka, Romeijn, and Wu (2013). The MPSNVP is concerned with a newsvendor who sells several products in several markets. It is assumed that the realized demand of each product should be satisfied and, in the case of shortages, the firm expedites from a local supplier with a higher purchasing cost. The decision maker of the risk-neutral MPSNVP selects a set of markets to cover from among all potential markets, and at the same time, he determines the optimal order quantities of each product to be purchased from an external supplier, in order to maximize profit. Strunka et al. (2013) studied the risk-neutral preference of the multi-product selective newsvendor problems. The authors discussed two cases of the single period inventory problem; the flexible and full market entry cases. For the first case, an optimal polynomial solution procedure is proposed, while, for the second case a solution procedure which is exponential in the number of products is proposed.
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