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A portfolio approach to multi-product newsboy problem with budget constraint ☆

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ABSTRACT

This paper investigates a portfolio approach to multi-product newsboy problem with budget constraint, in which the procurement strategy for each newsboy product is designed as portfolio contract. A portfolio contract consists of a fixed-price contract and an option contract. We model the problem as a profit-maximization model, and propose an efficient solution procedure after investigating the structural properties of the model. We conduct numerical studies to show the efficiency of the proposed solution procedure, and to compare three models with different procurement contracts, i.e., fixed-price contract, option contract, and portfolio contract. Numerical results are shown to demonstrate the advantage of the portfolio model, and sensitivity analysis is provided for obtaining some managerial insights.

1. Introduction

Multi-product newsboy problem with budget constraint is a classical inventory management problem, which was firstly introduced by Hadley and Whitin (1963). After Hadley and Whitin's seminal work, many researchers have investigated different models and solution methods for multi-product newsboy problems. Khouja (1999) presented a good literature review on these research. Due to the difficulty for solving large-scale problems, most recent works have focused on developing efficient solution methods, e.g., Lau and Lau (1996), Erlebacher (2000), Vairaktarakis (2000), Moon and Silver (2000), Abdel-Malek, Montanari, and Morales (2004). To address non-negativity constraints of the order quantities, Abdel-Malek and Montanari (2005) proposed a modified Lagrangian based method by analyzing the solution space. Zhang, Xu, and Hua (2009) provided an exact solution method for the problem with any continuous demand distribution. Zhang and Hua (2008) proposed a unified algorithm for solving a class of convex separable nonlinear knapsack problems, which include the singly constrained multi-product newsboy problem with box constraints. Zhang and Du (2010) studied the multi-product newsboy problem with limited capacity and outsourcing.

In the classical newsboy problem, the product is procured from the supplier with fixed-price contract. Under this procurement strategy, the retailer will undertake the salvage loss resulting from lower realized demand. To avoid this risk, the retailer always does not order enough inventories to maximize the supply chain's total profit under the fixed-price contract (Cachon, 2003). In order to maximize the supply chain's total profit, and share the risk raised from demand uncertainty with supply chain partners, some different contract types are used for encouraging the retailer to increase the order in supply chain management practice, such as buy back contracts, revenue sharing contracts, quantity flexibility contracts, sales rebate contracts and quantity discount contracts (Cachon, 2003). These contracts are labeled as "flexibility contract", in which a fixed amount of supply is determined when the contract is signed, but the amount to be delivered and paid for can differ from the quantity determined upon signing the contract. In comparison with fixed-price contracts, these flexibility contracts not only coordinate the supply chain, but also have sufficient flexibility (by adjusting parameters) to allow for any division of the supply chain's profit between suppliers and retailers. For more details of these flexibility contracts, please refer to Cachon (2003).

Option contract is one type of flexibility contracts (Martínez de Albéniz & Simchi-Levi, 2005), which is defined as an agreement between the retailer and the supplier, in which the retailer pre-pays a reservation cost up-front for a commitment from the supplier to reserve certain order quantity. If the retailer does not execute the option, the initial payment is lost. With option contract, the retailer can purchase any amount of supply up to the option reservation level by paying an execution cost for each unit purchased. In other words, option contract provides the retailer with flexibility to adjust order quantity depending on the realized demand, and hence the inventory risk can be lowered for the retailer by utilizing the flexibility of option contract.

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There are mainly two branches for the research on option contracts in supply chain management literature: one perspective is supply chain coordination with option contracts, e.g., Barnes-Schuster, Bassok, and Anupindi (2002), Wu, Kleindorfer, and Zhang (2002), Kleindorfer and Wu (2003), Wu and Kleindorfer (2005), Wang and Liu (2007), GomezPadilla and Mishina (2009), etc.; the other is on a single firm's optimal procurement decisions given particular contractual terms, e.g., Cohen and Agrawal (1999), Marquez and Blanchar (2004), Wang and Tsao (2006), Boeckem and Schiller (2008), etc. In these research, some combinations of different contracts, such as fixed-price contract and option contract, have been investigated.

In addition, some research on option contracts also took into account spot market since it is another source of supply for commodity products, e.g., Martınez de Albéniz and Simchi-Levi (2005), Fu, Lee, and Teo (2006), and Aggarwal and Ganeshan (2007). Spot market is a supply market in which products are sold for cash and delivered immediately. Contracts bought and sold on spot market are immediately effective. For some products, spot market can be used by the firm to purchase at any time; however, the product price on spot market is random. Over the last years, the emergence of the business-to-business trading exchange has transformed the procurement strategies, which provides spot market where buyers and sellers can trade products any time at online markets (Aggarwal & Ganeshan, 2007). As Carbone (2001) reported, 50% of Hewlett–Packard's procurement cost was spent on fixed-price contract, 35% in option contracts, and the remaining was left to the spot market.

Up to now, all the existing works on the combination strategies of different contracts focused on single product setting. We have not found any research on multi-product demand management with the combination of fixed-price contract and option contract. In this paper, we introduce a portfolio approach for managing multi-product newsboy problem with budget constraint, in which each product can be procured with a portfolio contract consisting of a fixed-price contract and an option contract. The dual contracts for each product in the problem make the optimal ordering decisions more challenging in multi-product setting. On one hand, the use of option contract for lowering the overage cost should be properly balanced against the additional cost of using the option contract since unit reservation plus execution cost of option contract is typically higher than unit cost of a fixed-price contract. On the other hand, the total budget should be well allocated to different products for signing the fixed-price contracts and option contracts.

The overall objective of the newsboy is to decide the optimal quantities of portfolio contracts for maximizing the total expected profit. We establish the structural properties for the optimal decisions of the proposed profit-maximization model, and develop an efficient solution procedure for the studied problem. Numerical results are shown to demonstrate the advantage of the portfolio model, and sensitivity analysis is provided for obtaining some managerial insights.

The rest of the paper is organized as follows: Section 2 describes the problem formulation. In section 3, the properties of the optimal solution are established, and an exact solution procedure is developed. Section 4 is dedicated to numerical studies for demonstrating the advantage of the portfolio contract model, and obtaining some managerial insights from sensitivity analysis. Section 5 briefly concludes the paper and provides some future research directions.

2. Problem formulation

We consider the following multi-product newsboy problem. A retailer sells n different products with stochastic demands over a single period, and each product can be acquired from the suppliers by signing a portfolio contract, which includes a fixed-price contract and an option contract. In the fixed-price contract, the retailer pay unit fixed cost for procuring each product; in the option contract, the retailer pay unit reservation cost up-front for a commitment from the supplier, then the retailer can pay unit execution cost for procuring each product under the commitment level. If retailer does not exercise the option, the initial payment is lost. The retailer has limited budget for signing the portfolio contracts. In the following, we use i to be the index of product $1,\dots,n$.

The cost parameters used in this paper are summarized in the following:

p_i, unit selling price for product i;
s_i, unit salvage value for product i;
c_i, unit procurement cost of fixed-price contract for product i;
v_i, unit reservation cost of option contract for product i;
w_i, unit execution cost of option contract for product i;
B, total budget available for signing the portfolio contracts.

To avoid the trivial case, we assume that $p_i > c_i > s_i$ for $i = 1,\dots,n$. Typically, the total cost of the option contract (reservation plus execution cost) is assumed to be larger than the cost of fixed-price contract, i.e., $v_i + w_i > c_i$, otherwise, the fixed-price contract is dominated by the option contract, and hence the fixed-price contract will never be engaged in the problem. We also assume that the reservation cost of option contract is smaller than the pure procurement cost of the fixed-price contract, i.e., $v_i < c_i - s_i$, otherwise, the option contract will be dominated by the fixed-price contract because the fixed-price contract always has lower costs whether the product can be sold or not. From these two assumptions, i.e., $v_i + w_i > c_i$ and $v_i < c_i - s_i$, we have $s_i < w_i$, which implies that the retailer will not have an opportunity to make profit by executing an option contract in order to obtain product salvage value.

The retailer makes quantity decisions of the portfolio contracts to fulfill n independent and stochastic demands. Let D_i denote the random demand for product $i = 1,\dots,n$, which has continuous probability density function $f_i(\cdot)$, cumulative distribution function $F_i(\cdot)$, and reverse distribution function $F_i^{-1}(\cdot)$. It is not uncommon to assume that all demands are non-negative, thus we can assume that $F_i(x) = 0$ for all $x < 0$, and $F_i(0) \geqslant 0$. This assumption does not rule out normal distribution as well as many other distributions with negative support values, since the distributions with negative support values should be approximated as non-negative demand distributions in practice (Zhang & Du, 2010).

The retailer's decisions are made in two stages. At the first stage, the retailer receives demand forecasts for all products, and determines a fixed-price contract quantity x_i, and an option contract quantity y_i to be signed. At the second stage, all demands are realized and the retailer exercises the quantity $\min((D_i - x_i)^+, y_i)$ of product i from the option contract to satisfy the demands for maximizing the revenue, where $(\cdot)^+ = \max\{\cdot, 0\}$.

We are ready to present profit-maximization model (denoted as problem P):

$$\text{Max } \pi(x,y) = \sum_{i=1}^{n} \pi_i = \sum_{i=1}^{n} E_i\left[\begin{array}{l} p_i \min(D_i, x_i + y_i) + s_i(x_i - D_i)^+ \\ -c_i x_i - v_i y_i - w_i \min((D_i - x_i)^+, y_i) \end{array}\right], \tag{1}$$

Subject to

$$\sum_{i=1}^{n} (c_i x_i + v_i y_i) \leqslant B, \tag{2}$$

$$x_i \geqslant 0, y_i \geqslant 0, \quad i = 1,\dots,n. \tag{3}$$