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Optimal decision making in multi-product dual sourcing procurement with demand forecast updating

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ABSTRACT

In this paper, we will investigate a buyer's decision making problem in procuring multiple products, each treated as a newsvendor, from two markets. The contract market has a long lead time, a fixed wholesale price and resource constraints. While the spot market has an instant lead time and a highly volatile price. The purchasing decision at the spot market can be made near the beginning of the selling season to take the advantage of the most recent demand forecast. The buyer needs to determine the purchasing quantity for each product at the two markets to maximize the expected profit by trading off between the resource availability, demand uncertainty and price variability. The procurement decision making is modeled as a bi-level programming problem under both a single resource constraint and under multiple resource constraints. We show that this bi-level programming problem can be formulated as a single-level concave programming problem. We then develop a sequential algorithm which solves for a linear approximation of the concave programming problem in each iteration. This algorithm can be used to solve a real world problem with up to thousands of kinds of products, and is found to be highly efficient and effective.

1. Introduction

Uncertainties in supply and demand often result in massive risks for a business. Consider the demand uncertainty as an example, according to Cachon and Swinney [1], many European apparel retailers were estimated to generate 30–40% of theirs sales at marked-down prices. Similarly, Nintendo experienced lost sales in excess of $1 billion due to unsatisfied demand on the Wii video game system during the 2007 holiday season [2]. Moreover, a business often experiences exposure to supply uncertainty. For example, in October 1999, Dell Computer suffered a $470 million earnings shortfall from the effect of DRAM (dynamic random-access memory) prices on gross margins. This shortfall triggered a 13% drop in its stock price [3].

In the real practice, a business more often than not offers multiple kinds of products rather than single product to satisfy various customers' demands. Hence, its procurement function is to match closely various demands with respective supplies at low costs [4]. To reduce the gaps between supply and demand and to hedge supply chain risks, multiple-channel sourcing is often adopted. As Ghemawat and Nueno [5] reported, Zara procures products from dual distinctive markets. Less expensive products are outsourced in Asian facilities with a long lead time to get competitive prices. The majority of Zara's designs are produced in costly European and North African factories with a short lead time in order to pursue the perishable fashion. Similarly, Hewlett-Packard purchases electronic components from both contract markets and spot market.

A significant feature of the spot market is that it provides some flexibility to react to demand uncertainty with a short lead time. Hence, at the spot market, the purchasing decision may be made near the beginning of the selling season. Compared to the ordering decision at the contract market with a long lead time, more demand information could be collected and better demand forecast can be achieved. However, to our best knowledge, most of the existing works on the procurement portfolio with a spot market focus only on the single product case, and none takes forecast update into account.

Therefore, motivated by the need to incorporate the forecast update into procurement portfolios and to extend the single product case to multiple products case, we investigate the optimal multi-product dual sourcing procurement policy with Bayesian forecast update. The buyer has two options for procurement: either from a wholesale contract market or from a real spot market. At the wholesale contract market, a fixed wholesale price contract is approved by both the buyer and the seller, and orders

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must be placed early before the selling season. In contrast, at the spot market (in which the supply prices are highly volatile) orders may be placed near the beginning of the selling season. In the period between the two procurement decisions, demand forecast can be updated by Bayesian rule, through which the forecast gets much more accurate than before.

The paper is organized as follows. Section 2 reviews the three streams of research related to our study. In Section 3, we describe our problem in detail and model the problem under both single resource constrained scenario and multiple resource constrained scenarios. Furthermore, we present some analysis on the structure properties of the models. In Section 4, we provide an efficient and effective iterative/sequential approximate linear programming method, which can be used to solve thousands of products like large-scale problems. Further, we prove the convergence of this algorithm. Section 5 numerically illustrates the models and the algorithm with various scale problems. Section 6 discusses some extension of our study. Section 7 concludes with a summary.

2. Literature review

There are three streams in the literature that are relevant to our research: the procurement portfolio of contract market with a spot market, the demand forecast updates with two or more ordering opportunities and the multi-product newsvendor problem with constraints. We will give a brief review for each one of them.

2.1. Research on procurement portfolio of contract market with spot market

As a risk management tool to hedge supply and demand uncertainties, the procurement portfolio of contract markets with spot market has received more detailed attention. The central question is to maximize profit or reduce procurement risks by searching an optimal structure of sourcing portfolios in various scenarios, such as single period or multiple periods.

Recently, there is a rich body of literature that addresses procurement portfolio. Readers may refer to Haksöz and Seshadri [6] for an excellent review and discussions on this topic. However, our problem has two distinct characteristics from the existing works. We consider demand forecast updates before buying at the real spot market and multiple products with some resource constraints.

Martínez-de Albéniz and Simchi-Levi [7] develop a portfolio contract framework for a *single* product in a multi-period environment, through which a buyer trades off between price and flexibility to maximize the expected profit; their results indicate that portfolio contracts not only increase the buyer's expected profit but can also reduce the financial risk.

Chen and Liu [8], Zhang et al. [9] consider procurement strategies for a *single* product on dual supply markets, i.e., a long-term contract market and a spot market where there is no quantity limitations but fluctuating spot prices. Unlike our problem where there are some resource constraints for the orders, when ordering from contract market, the buyer is required to purchase at least a fixed quantity at a fixed wholesale price. Boyabatlı et al. [10], Martínez-de Albéniz and Simchi-Levi [11], Serel et al. [12], Wu et al. [13], Bonser and Wu [14], Serel [15] consider a procurement portfolio including the capacity option contract according to which a buyer needs to pay reservation price in advance. This differs from our problem, where only a fixed price wholesale contract is involved.

Sequentially, some extensive studies have been done as follows. Shi et al. [16] extend the objective function of Martínez-de Albéniz and Simchi-Levi [7] from a risk-neutral one to a risk-averse one. Dropping the assumption of independence between spot price and demand, Fu et al. [17] propose a shortest-monotone path approach to obtain the optimal procurement solution when demand and spot prices are random and possibly correlated. Martínez-de Albéniz and Simchi-Levi [11] investigate a single period portfolio procurement problem with competitive behavior among the suppliers. Seifert et al. [18], Milner and Kouvelis [19] incorporate the online B2B exchanges into the procurement portfolio.

Except for Boyabatlı et al. [10], which addresses two products with substitution at a contract market and a spot market, multiple products have not been involved in this stream of works. Moreover, none of them incorporates forecast update into decision making before buying at a spot market. Our study may complement these works.

2.2. Research on demand forecast updates with two or more ordering opportunities

Choi and Sethi [20] present a comprehensive survey on this kind of related works. However, this category of works often concerns only on a single product, in which orders are placed to a same supply source. Our study may complement these works by considering multiple products with resource constraints and multiple supply sources.

Fisher and Raman [21] were the first to model the two-stage production problem with information update. In their work, unlike our model, the product costs are kept the same through the two periods, and there is a capacity constraint in the second period.

Gurnani and Tang [22] model the two-stage ordering problem by considering the unit cost in the second order is uncertain and could be higher (or lower) than the unit cost at the first order. Unlike our model, multiple products and resource constraints are not taken into account.

Donohue [23], Chen and Xu [24], Chen et al. [25], Cheaitou et al. [26], Zhou and Wang [27] extend the two ordering policy with demand forecast updating from a single buyer to the whole supply chain. However, only a *single* product is concerned in their works.

Sethi et al. [28–31] study the single-period and multiple-period two-stage ordering problem with an information update. Similarly, only a *single* product is concerned in their works.

Choi et al. [32] investigate an optimal two-stage ordering policy for a seasonal product in which the ordering cost in the first stage is known but is uncertain in the second stage. Only the case of single product with normal distribution is modeled in their works. By contrast, we model multiple products with the general demand distribution and present a normal distribution example.

Miltenburg and Pong [33,34] study the problem of ordering multiple style goods with two ordering opportunities. During the time between the two ordering opportunities, new information on the demand is collected to revise the demand forecasts by Bayesian rule. Unlike our problem, the first ordering opportunity has a low unit cost and the second ordering opportunity has a certain higher unit cost than that of the first opportunity. In this paper, we present two interactive ordering decisions, while Miltenburg and Pong [33,34] only propose two *independent* ordering decisions, which lead to a *suboptimal* decision. Another difference is only two products are illustrated in their numerical example. We provide thousands of types of products in our numerical analysis.

Özer and Wei [35] study a supply chain in which a retailer faces a newsvendor problem with a forecast update. They show that the advanced order can send better demand information to the manufacturer and benefits the supply chain in terms of the profit and risk.

Further, Özer and Wei [36] consider a credible information sharing problem in a supply chain under asymmetric forecast information, and develop two contracts to detect and signal forecast information respectively. Unlike our problem, there is

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