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Dynamic procurement management by reverse auctions with fixed setup costs and sales levers

Shuren Liu [a,*], Yimin Zhu [b], Qiying Hu [c]

[a] Business School, Xiangtan University, Xiangtan 411105, China
[b] Department of Mathematics and Science, Quzhou College, Quzhou 324000, China
[c] School of Management, Fudan University, Shanghai 200433, China

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ABSTRACT

In this paper, we study a dynamic procurement problem for a retailer with fixed setup costs and sales levers (such as pricing, advertising, etc.). The retailer runs a reverse auction with a procurement contract in each period. A number of potential suppliers bid for this contract, and the winner is the supplier with the highest bid and is given the decision right for the quantity produced and delivered. The demand is either realized by selling via Internet auctions and unmet demand is lost, or is a price-sensitive nonnegative random variable and all shortages are backlogged. We show the existence of the retailer's optimal procurement contract, under which the suppliers' Bayesian–Nash equilibrium bidding strategy is $(q(\cdot), Q(\cdot))$, similar to the classic (s, S) policy for the retailers in dynamic inventory control problems. However, the $(q(\cdot), Q(\cdot))$ strategy here is for the suppliers and is realized through the suppliers' marginal production costs and so consists of two random variables for the retailer.

1. Introduction

With the rise of electronic commerce, reverse auctions (i.e., procurement auctions) have become a primary way for firms to acquire goods and services. The main drivers of this phenomenon are factors such as the beliefs that auctions are an impartial way of setting price and that Internet makes auctions efficient [1]. An important thing is that dynamic procurement auctions are widely used in practice, e.g., by Huawei and ZTE, two world-leading telecom solutions and telecom equipment providers. Then, a question arises that how a procurement auction interacts with the inventory control problem. In details, what is the equilibrium for manufacturers (or retailers) and their suppliers in this interaction?

To answer the question, we study a dynamic procurement problem for a retailer facing uncertain demand in a multi-period setting. In each period, the retailer pays a fixed setup cost for running a reverse auction to determine how many units of the product are purchased with what price and from whom to purchase among a number of potential suppliers. It concerns the dynamic operations management addressing procurement decisions (when and how much to buy with what price and from whom), inventory control, and discovering prices.

In the classic stochastic inventory control problem, both retail price and purchasing cost are exogenous. Then, the classic problem is extended in two directions. In the first direction, retail price is endogenous. Federgruen and Heching [2] is a pioneering work on this direction. They combine dynamic pricing and inventory control when there is no fixed ordering cost

* Corresponding author at: Business School, Xiangtan University, Xiangtan 411105, China. Tel.: +86 731 52377861.
E-mail address: liushuren@xtu.edu.cn (S. Liu).

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and excess demand is backlogged. They show the optimality of a base-stock list-price policy. Hereafter, a number of papers on joint inventory-pricing control have been published. Yano and Gilbert [3] provide an extensive review on coordinated pricing and inventory control. Huh and Janakiraman [4] provide a sufficient condition for proving the optimality of (s, S) policies in stochastic inventory models with fixed ordering costs and multiple sales levers. Their sufficient condition can be applied to the models studied in [5–8] for the joint inventory-pricing control with fixed ordering costs for backordering and lost sales. Recently, under a general assumption on the random variable for demand, Lee [9] studies the joint inventory-pricing control when there are fixed ordering costs and excess demand is lost, and shows that an (s, S) policy is optimal for replenishment and the optimal price is determined based on the inventory level after the replenishment in each period.

Retail pricing can also be determined by Internet auctions, called (forward) auctions, i.e., a selling process where buyers compete to obtain goods or services by offering increasingly prices. The intersection of Internet auctions and operations management is a relatively new topic. Vulcano et al. [10] and Du et al. [11] consider sequential Internet auctions for selling a fixed quantity of a product. Chen et al. [12] study dynamic lot-sizing in sequential online retail auctions. They show that a threshold inventory-scrapping policy and a monotone staircase with unit jumps lot-sizing policy are optimal. van Ryzin and Vulcano [13] study the joint optimality problem on auctioning and ordering in an infinite horizon when there is no fixed ordering cost and they show the optimality of a base-stock reserve-price-auction policy. Furthermore, Huh and Janakiraman [14] and Liu et al. [15] study inventory control problems under Internet auctions and other sales channels when there are fixed ordering costs. They show the optimality of (s, S) policies.

The second direction on extending the classic stochastic inventory control problem is for purchasing costs. Fabian et al. [16] study an inventory model with stochastic purchasing prices. Kalymon [17] assumes that the purchasing price follows a Markov process and shows the optimality of (s, S) policies for a stochastic demand model. Recently, Yang and Xia [18] study a continuous-review acquisition problem when demand follows a compound Poisson process and the raw material price follows a discrete-state Markov process. They show that there is an optimal order-up-to policy. Berling and Martinez-de-Albeniz [19] study an inventory model where demand follows a Poisson process and the procurement price evolves as an Ornstein–Uhlenbeck process and derive an optimal policy as a base-stock policy. Kimitoshi and Katsushige [20] study an inventory model with fixed ordering costs where demand and spot price for purchasing follow a diffusion stochastic process and derive an optimal policy as an (s, S) policy.

However, since procurement cost often constitutes a large portion of a firm's total operating cost, selecting adequate suppliers with attractive prices is important for a firm in managing his supply chain. In practice, auctions are widely used, e.g., by Huawei and ZTE. Such auctions are called procurement (reverse) auctions. Gallien and Wein [21] address a problem of designing a multi-unit procurement auction for a monopsonistic retailer in capacity-constrained environments. Rachel et al. [22] consider a multi-unit Vickrey auction for a procurement supply chain setting. Tunca and Wu [23] study a procurement process selection problem for a large industrial retailer who uses reverse auctions for awarding procurement contracts. Chaturvedi and Martinez-de-Albeniz [24] study an optimal procurement design in the presence of supply risk. Li and Scheller-Wolf [25] compare performance of procurement auctions for push and pull contracts. Duenyas et al. [26] study simple auctions for supply contracts.

The joint scenario of reverse auctions and inventory control is a relatively new area. Chen [27] studies a single-period procurement problem, where a retailer wants to purchase from a number of potential suppliers who hold private information about their own marginal production costs. He shows that the supply contract auction is optimal when the purchase quantity is a decision variable and the price needs to be discovered. Farahvash and Altiok [28] also study a single-period multi-dimensional procurement auction, where the bids are multi-dimensional including information of price, shortage quantity, and lead time of suppliers.

There are differences between the two papers above. First, in [27], the auctions have two dimensions: price and quantity, which are aggregated into one dimension before suppliers' bids, while in [28], suppliers first submit their multi-dimension bids, which are then aggregated into one dimension. Second, Chen [27] makes one to use the revenue equivalence theorem to effortlessly establish the equivalence of different auction formats, whereas Farahvash and Altiok [28] are confined to sealed bidding. Finally, in [27], the optimal purchasing quantity in the newsvendor model can be determined analytically, while Farahvash and Altiok [28] use the Monte Carlo simulation method to get the optimal target inventory level.

Furthermore, Liu et al. [29] study a multi-period procurement problem by reverse auctions for a retailer with stochastic demand based on [27]. Farahvash and Altiok [30] also extend [28] to the multi-period case. The main differences are then inherited from Liu et al. [29] are based on [27] while Farahvash and Altiok [30] are based on [28] for the single-period setting. Moreover, a fixed setup cost for running a reverse auction is considered in [29] but not considered in [30]. Liu et al. [29] derive the optimal policy by analytical methods but Farahvash and Altiok [30] use simulation, although both are based on stochastic dynamic programming.

In this paper, we study a dynamic procurement problem by reverse auctions with fixed setup costs and uncertain demand which is sensitive to some sales levers. In each period, the retailer faces a number of potential suppliers, which may change with periods. The problem the retailer faces at the beginning of each period is to run a reverse auction to determine how many units of a product should be purchased from which supplier and at what price. The retailer should first present a procurement contract for the reverse auction and then all the suppliers make their bids. Each supplier is capable of producing the product with a constant marginal production cost and an unlimited capacity. The marginal production cost of each supplier is private and drawn independently from a common probability distribution function. All the retailers and suppliers are risk neutral, i.e., all of them are expected-profit maximizers. Moreover, the retailer faces uncertain demand which is sensitive to some sales levers. So, the retailer also should choose adequate sales levers. We show the existence of the retailer's optimal procurement contract and find