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Procurement decision making mechanism of divisible goods based on multi-attribute auction

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ABSTRACT

Multi-attribute auction enables negotiation on several attributes in addition to the price such as quality, quantity, time of delivery and service levels. Most of the existing multi-attribute auction mechanisms are designed by considering a unique good or indivisible multiple goods. This paper focuses on designing a multi-attribute auction mechanism for addressing the decision making problem of multi-attribute and multi-source procurement of a kind of homogeneous continuous divisible goods (such as coal, oil, electricity and gas). The suppliers' optimal bidding strategies are discussed, and a bidding method named the minimum bid increment method is proposed to simulate the overall process of suppliers' multiple rounds of bidding. Theoretical analysis shows that our auction mechanism is an efficient mechanism, and satisfies the incentive compatibility conditions and the individual rationality conditions. Moreover, a multi-attribute auction example about the steam coal procurement is given to show how to implement our multi-attribute auction mechanism.

1. Introduction

With the emergence of procurement economy and the rapid development of e-commerce, especially the extensive use of online procurement, considering the price as the sole criterion to procure goods cannot meet the needs of real procurement decision making. In practice, the competition and negotiation in the procurement involve many other dimensions in addition to the price (Che 1993, Rao et al. 2012, Chen and Chen 2005, Liu and Wang 2009, Rao and Zhao 2011, Bichler and Kaukal 1999). For example, in the supply chain management domain, contracts are typically composed of multiple negotiable attributes, such as the supply time, the quantity of items delivered, the duration of the product's warranty and the price. This kind of procurement under the multi-attribute information environment is called a multi-attribute procurement. However, Microeconomics and Game Theory cannot provide powerful tools for the multi-attribute procurement decision making. Therefore, to seek feasible methods for the multi-attribute procurement decision making becomes more important.

In the multi-attribute procurement, the suppliers will submit the supply information to the buyer after the buyer announcing the purchasing information. Then the buyer will select the optimal suppliers and allocate the allowable supply quantities of the procurement goods to them according to the submitted information. The buyer's objective is to maximize his utility and the total efficiency of resource allocation. However, each supplier's submitted information is the private information. It is complicated and asymmetric. So the facticity of this information cannot be guaranteed, and the goal of utility maximization is difficult to achieve. Therefore, the buyer must create an incentive and competitive trading environment to induce suppliers to announce their actual costs truthfully. In order to solve this problem, we propose an optimization mechanism for procurement decision making based on multi-attribute auction theory in this paper.

Multi-attribute auctions are defined as a kind of market mechanisms, which enable automated negotiation on multiple attributes of a deal (Bichler and Kaukal 1999, Bichler 2000). This feature is especially useful in procurement auctions where buyers negotiate with multiple suppliers over heterogeneous or homogeneous goods. Many scholars have studied on multi-attribute auctions. Thiel (1988) gave a partial analysis on multi-attribute auctions. He showed that the problem of designing optimal multi-dimensional auctions will be equivalent to the design of unidimensional auctions. A thorough analysis of the design of multi-attribute auctions has been provided by Che (1993). He derived a two-dimensional version of the Revenue Equivalence Theorem (RET). Che also designed an optimal scoring rule based on the

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assumption that the buyer knows the probability distribution of the supplier's cost parameter. Branco (1997) extended Che's work. His analysis was based on Che's independent cost model and derived an optimal auction mechanism for the case when the bidding firms' costs are correlated. The works of Che and Branco were among the first considering multi-dimensional auctions. But both were studying auction design only in a two issues context, i.e., price and quality.

Mishra and Veeraman (2002) first brought multi-attribute auctions into the area of procurement economy. He proposed a reverse auction algorithm for the outsourcing economy and proved that this reverse auction algorithm achieves nearly efficient allocation and the final prices are also nearly competitive. Later, Beil and Wein (2003) focused on the buyer utility-maximization in multi-attribute auctions, i.e., optimal auction design. The paper suggested an inverse-optimization based approach that allows the buyer via several changes in the announced scoring rule, to learn the suppliers' cost functions and then determine a scoring rule that maximizes the buyer's utility within an open ascending auction format. Parkes and Kalagnanam (2005) provided an iterative auction design for an important special case of the multi-attribute allocation problem with special (preferential independent) additive structure on the buyer value and seller costs. This design also has excellent information revelation properties that are validated through computational experiments. This paper also developed Auction NonLinear and Discrete for the more general nonlinear case—a particularly simple design that solves the general multi-attribute allocation problem, but requires that the auctioneer maintains prices on bundles of attribute levels. Parallel to these works, David and Kraus (2006) extended Che's model for more realistic electronic commerce applications, where the reverse auction considers multiple non-price attributes. For this case he analyzed the first-score, the second-score and the English auctions.

In multi-attribute auctions, the problem of winner decision is a research hotspot. Dekrajangpetch and Sheble (2000) developed and used an extended algorithm of interior-point linear programming (IPLP) to solve the problem of supplier selection. Similarly, Yan and Yuan (2012) established a multi-attribute reverse auction model based on the linear programming theory. Moreover, Falagario et al. (2012) addressed the decision problem of supplier selection by applying an extension of the DEA (Data Envelopment Analysis) methodology, and used the cross-efficiency evaluation for selecting the best supplier among the eligible candidates. For these studies, a common focus is to design optimization algorithms to determine the winner, but these algorithms only apply to determine a unique winner in general, that is not a good solution to the procurement decision problem involving multiple winners.

In recent years, scholars have focused on the research of multi-attribute auction theory combined with practice. Perrone et al. (2010) provided a project management approach for multi-attribute auction design for standardized engineering services procurement in the context of new product development in automotive industry. They argued that price and time based auctions can also work as a mechanism to increase the reliability of engineering planning in that they allow involvement of suppliers in determining variables such as duration and cost of a given activity which are to be used to construct and manage the whole project plan. Strecker (2010) studied the effects of information revelation on allocational and Pareto efficiency in a multi-attribute reverse English auction, and designed a computer-based laboratory experiment to observe differences between two information revelation policies with respect to the buyer's utility and suppliers' profits. The results suggest that revealing the buyer's preferences increases allocational efficiency. Karakaya and Köksalan (2011) introduced an interactive approach to provide aid both to the buyer and the sellers for a multi-attribute, single-item, multi-round, reverse auction. The experiments show that the mechanism supports the sellers well and the winning bids are very close to the bids that would have been obtained under full information. Ray et al. (2011) proposed a novel multi-attribute relationship-preserving reverse auction mechanism for a limited supplier base. The mechanism enables healthy competition among the suppliers by retaining them in the supplier base. The simulation study interestingly shows that a buyer derives higher utility by using the proposed mechanism as compared to the existing mechanism where no incentive is provided to the suppliers. Liu et al. (2012) analyzed multi-attribute procurement auctions with risk-averse suppliers. They showed that as the number of suppliers increases or the suppliers become more risk-averse, the equilibrium bidding price decreases under the first-score auction but remains the same under the second-score auction.

These are all the important research results on multi-attribute auctions in the past few years. However, most of results are obtained by considering the multi-attribute auctions for a unique good or indivisible multiple goods. The research on the multi-attribute auctions for divisible goods which aims at the characteristic of homogeneousness and continuity is not sufficient and in-depth. In addition, the winner (winning bidder) in the most multi-attribute procurement auction mechanism given by existing literature is unique. In this paper, the procurement decision making problem of homogeneous continuous divisible goods (such as coal, oil, electricity and gas) is studied, and a procurement decision making mechanism is presented based on multi-attribute auction. In this optimization decision making mechanism, other attributes in addition to the price are considered further, such as quantity, development cycle, delivery time, different quality parameters, service quality and suppliers' reputation. Different from the existing multi-attribute auction mechanism, the winner in our auction mechanism can be more than one, and each winner will supply multiple quantity goods to the buyer.

The rest of the paper is organized as follows. In Section 2, we give some basic assumptions and definitions. Section 3 gives the whole process to design a procurement decision making mechanism of divisible goods based on multi-attribute auction. Section 4 gives an application example about the steam coal procurement to show how to implement our procurement decision making mechanism. In Section 5, a conclusion summarizes our work and gives directions for future researches.

2. Basic assumptions and definitions

It is supposed that one buyer wants to buy Q_0 units of a homogeneous continuous divisible good. The buyer faces $n \geqslant 2$ potential suppliers, numbered $1,2,\ldots,n$. The set of suppliers is denoted as $N = \{1,2,\ldots,n\}$. Supplier i ($i = 1,2,\ldots,n$) submits the trading information including price, quantity, quality, and so on to the buyer. Then the buyer will allocate the goods to the winners according to the submitted information by the suppliers. The allowable supply quantity to supplier i is denoted as q_i^*, which satisfy

$$\sum_{i=1}^{n} q_i^* = Q_0.$$

where $q_i^* \geqslant 0$, $i = 1,2,\ldots,n$.

The buyer's objective is to maximize his utility and the total efficiency of resource allocation. In order to achieve this objective, the buyer must design an incentive and competitive trading environment to induce suppliers to announce their actual costs truthfully. Next we present an incentive optimization mechanism for procurement decision making of divisible goods based on multi-attribute auction.

If we regard the Q_0 units of a divisible good as an auctioned good, and regard the buyer as the auctioneer, and the n suppliers