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AN E-PROCUREMENT SYSTEM INTEGRATING NEGOTIATION AND MULTI-ATTRIBUTE AUCTION

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ABSTRACT

Uncertainty cost of the sellers is a big challenge the buyer(the government) encounters in public procurement setting. An implementation framework of an e-procurement system integrating multi-round negotiation and multi-attribute auction is proposed to help the buyer deal with the problem. A negotiation procedure is firstly introduced to make the sellers reveal their cost information little by little. Then the sellers with lower cost are screened out to participate in the subsequent multi-attribute auction. The research shows that the procurement mechanism is optimal from the perspective of not only the social surplus but also the buyer's payoff.

Keywords: *E-Procurement; Negotiation; Multi-Attribute Auction*

1. INTRODUCTION

With the rapid development of information and communication technologies, electronic procurement has become very popular and commonly used by companies and governments. For buyers, e-procurement can bring out faster purchasing cycle and lower administrative cost with the help of higher information transferring and processing efficiency than traditional procurement [1]. Electronic procurement platform allows the possibility to include many novel and useful features into the procurement process that were unthinkable in the past [2]. For instance, Teich et al. [2] develop a Negotiation-Auction system for online trading of multiple units of a good in a multi-attribute environment.

Despite many similarities, public procurement differs from private one by many aspects. Public procurement has policy implications not only with respect to setting laws and directives that promote competitiveness, fairness, equity, and transparency in public contracting but also in advancing other policy goals such as social welfare [3]. Competition between suppliers must be introduced into rewarding contracts and selecting providers in public procurement under the regulation rules. So the use of auctions is advocated by public authorities to prevent corruption [4]. Multi-attribute auction considers attributes such as quality, lead time, warranty, etc., in addition to the price. The winner determination in multi-attribute auction depends on underlying the bid evaluation mechanism. Che [5] develops a scoring function combining the attributes including the price to determine a score for each bid, and the bid with the highest score wins the reverse auction. David et al. [6] extend Che's work and analyze three auction protocols for the case of multi-attribute items, termed first-score sealed-bid, second-score sealed-bid, and sequential full information revelation.

Thus far, existing research on multi-attribute auction is mostly based on the assumption that all the sellers' cost parameters are independently and identically distributed, and the distribution is common knowledge [7, 8]. In practice the sellers' cost parameters may not be independently and identically distributed, and the buyer may not exactly know every seller's cost distribution. In this case the buyer must design a mechanism to make the seller reveal his cost information. We propose a mechanism combining some features of negotiation and multi-attribute auction for public procurement. In the mechanism high-efficient sellers are screened out by negotiation to compete for the contract and the final winner is determined by multi-attribute auction. In order that the complicated decision situations in our mechanism can be handled automatically, we set up an implementation framework of the e-procurement system, which can trigger gains not only in procurement efficiency but in user-friendliness.

The rest of the paper is organized as follows. In

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section 2, we describe the framework of the e-procurement system integrating negotiation and multi-attribute auction. In section 3, we discuss the procurement mechanism upon which the e-procurement system works. Section 4 represents a numerical example. Section 5 is the conclusion and future research.

2 THE FRAMEWORK OF THE E-PROCUREMENT SYSTEM INTEGRATING NEGOTIATION AND MULTI-ATTRIBUTE AUCTION

In this section we propose an implementation framework of electronic procurement system combining the features of negotiation and auction. The hybrid system is quite suited for such a case that the buyer's information on the sellers' cost is so obscure that single auction mechanism cannot perform well enough. Firstly the buyer and the sellers engage in multi-round negotiation, by which the buyer can gradually learn more about the sellers' cost information. On the basis of the new knowledge, the buyer raises his price in sequence until at least one seller accepts the price he offers. If only one seller is willing to accept the offer, which must own the lowest cost parameter, he wins the contract. If two or more sellers accept the offer, a multi-attribute auction is employed to determine the final winner by a scoring function.

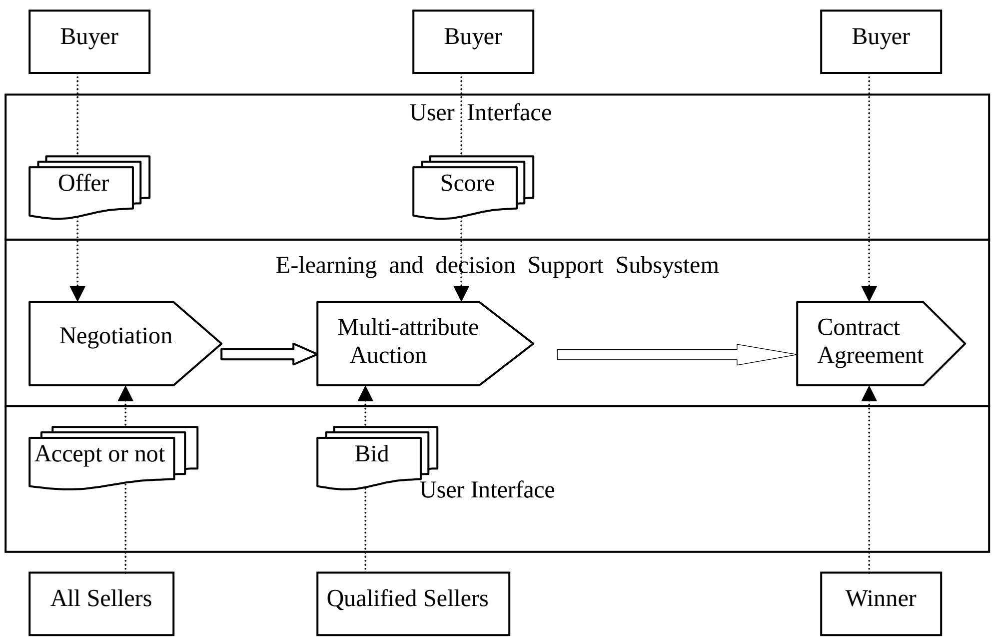

Figure 1: The Overview of E-procurement System

Figure 1 illustrates the main function and process of the e-procurement system. As the figure shows, the advantage of such a system lies in that the complicated information processing can be fulfilled automatically by background e-learning and decision support subsystem. Based on the information renewal rules and established equilibrium, the e-procurement system can figure out the price for the buyer to offer in negotiation and the tender for the sellers to bid. In addition, the processing outcome such as the sellers' cost parameters distribution in negotiation stage and the bidders' score in auction stage can be displayed, and input of data and instruction such as the sellers' bid can be implemented through friendly user interface[9].

3 PROCUREMENT MECHANISM COMBINING NEGOTIATION AND MULTI-ATTRIBUTE AUCTION

Automation of the procurement system depends on the game rules and the equilibrium strategies of the buyer and the sellers in negotiation and auction. In this section we develop a mechanism integrating a negotiation model and an auction model to find out the equilibrium in procurement scenarios.

3.1 Negotiation model

The negotiation model consists of one buyer(the government) and n sellers. The buyer wishes to procure an indivisible product with quality q from one of the sellers. Both the buyer and sellers

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are risk-neutral and acting non-cooperatively to maximize their respective expected payoffs from the game. The utility function of the buyer $u(q)$ is continuous, increasing and concave in q, i.e., $u_q > 0$, $u_{qq} \le 0$. The seller's cost $C(q,\theta)$ is determined by the quality q and his cost parameter θ. $C(q,\theta)$ is continuous, increasing in quality q and cost parameter θ and convex in q, i.e., $C_q(\cdot,\cdot) > 0$, $C_\theta(\cdot,\cdot) > 0$ and $C_{qq}(\cdot,\cdot) \ge 0$. In this paper we suppose $C(q,\theta) = \theta c(q)$. θ reflects the efficiency of the seller. Cost parameter θ_i of seller i is his private information and is assumed to be a random draw from the uniform distribution over $[\underline{\theta}_i, \overline{\theta}_i]$ $(i = 1, 2, \cdots, n)$. Suppose $u(q) - C(q,\theta) > 0$, which assures it possible that the trade is simultaneously profitable to two parties.

If the transaction is reached, then the total joint surplus at the time is $u(q) - \theta c(q)$. Given the quality q, the lower the seller's cost parameter θ, the higher the total joint surplus. We can see that it is the most beneficial to choose the seller with the lowest cost parameter as the provider from the perspective of the society.

Unlike the relative literature on information structure, we assume that the cost parameters of the sellers may not be identically distributed. It means $\underline{\theta}_i$ may not be equal to $\underline{\theta}_j$ and similarly $\overline{\theta}_i$ may not be equal to $\overline{\theta}_j$ $(i, j = 1, 2, \cdots, n, i \ne j)$. Suppose that initially the buyer even doesn't know the exact value of $\underline{\theta}_i$ and $\overline{\theta}_i$, and but only knows the minimum of all the cost parameters $\underline{\theta} = \min\{\underline{\theta}_i\}$, and the maximum $\overline{\theta} = \max\{\overline{\theta}_i\}$ $(i = 1, 2, \cdots, n)$. Every seller doesn't know others' cost parameters distribution range either. Since the cost information is so obscure that traditional multi-attribute auction mechanism can not bring about maximal payoff for the buyer any more. Therefore the buyer needs to design a new mechanism.

At the outset of the negotiation the buyer declares he wishes to procure a product with quality q_0. The buyer has the power to offer a price, and the sellers can only choose to accept the price or not. Although there are many sellers participating in the negotiation, we can regard it as a one-to-one game because in e-procurement system one seller cannot observe others' actions and the sellers make decision dispersedly and independently.

Following Muthoo [11], we assume the seller takes the strategy as follows: the seller with cost parameter θ would accept the price only if the price the buyer offers in any round satisfies

$$p^B \ge \theta c(q_0) + \alpha[u(q_0) - \theta c(q_0)] \qquad (1)$$

where $\theta c(q_0)$ is the cost the seller provides the product and $u(q_0) - \theta c(q_0)$ is the joint surplus from the trade. Thus $\alpha[u(q_0) - \theta c(q_0)]$ represents the minimal profit in the current period the sell wishes to obtain from the trade. α represents the minimal share of the joint surplus that the seller wants, and the seller will reject a share less than α. We call α the seller's accepting threshold value. After a price is rejected, the buyer can obtain some new information on the seller's cost parameters, then by which he offers a new price to increase the chance of being accepted.

The buyer takes the strategy as follows: when in the buyer's belief the infimum of the seller's cost parameter set $\{\underline{\theta}_i\}$ is λ, the buyer offers

$$p^B(\lambda) = \lambda c(q_o) + \beta[u(q_0) - \lambda c(q_o)] \qquad (2)$$

Similarly we call β the buyer's offering threshold value. The values of α and β reflect respectively the bargaining power of the sellers and the buyer. We assume that the strategies of the buyer and the sellers are common knowledge and they always stick to the strategies. If the aforementioned strategy of a party is optimal given another party's equilibrium strategy, then in any sub-game, the party has no incentive to deviate from the equilibrium.

After offering a price p, the buyer waits the seller to accept or not. As long as at least one seller is willing to accept the price, negotiation ends up. If no supplier accepts the offered price, the buyer can make a judgment that $p < \alpha u(q_0) + (1-\alpha)\theta_i c(q_0)$ $(i = 1, 2, \cdots, n)$. So he has to offer a higher price in next round. Let $\overline{p}$ denotes the highest price that has not been accepted, we can conclude $\lambda = \inf\{\theta : \overline{p} < \alpha u(q_0) + (1-\alpha)\theta c(q_o)\}$. The seller's action helps the buyer and other sellers learn some new knowledge.

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If the price $\overline{p}$ is rejected by all the sellers, then in the buyer's posterior belief the infimum λ of set $\{\underline{\theta}_i\}$ can be written as

$$\lambda = \frac{\overline{p} - \alpha u(q_0)}{(1-\alpha)c(q_0)} \quad (3)$$

If $\overline{p}$ is rejected by all the sellers, the buyer can know that all the cost parameters are more than λ. His belief on sellers' cost parameter is updated to be uniformly distributed over $(\lambda, \overline{\theta}]$. According to the established strategy, the buyer offers $\beta u(q_0) + (1-\beta)\lambda c(q_0)$ in next round. Obviously the price is increasing round by round. In our paper time proceeds in discrete rounds, indexed by k.

In the buyer and the seller's equilibrium strategies the two threshold values satisfy $\alpha = \beta\delta$, where δ is the same discount rate of the buyer and the sellers[11].

δ represents the depreciation degree of the product's value as time elapses and determines the patience of the buyer and the sellers in negotiation. It becomes apparent that $\beta > \alpha$, or else the buyer and the sellers can never reach an agreement.

Theorem 1 The optimal threshold values in the buyer and the seller's equilibrium strategies can be written as

$$\alpha^* = 1 - \sqrt{1-\delta} \quad (4)$$

$$\beta^* = \frac{1-\sqrt{1-\delta}}{\delta} \quad (5)$$

The conclusions in Theorem 1 are as the same as [11] and can be proved by the same method. It can be seen that the equilibrium strategies of the buyer and the sellers only depend on the discount rate δ. $\frac{\partial \alpha^*}{\partial \delta} > 0$ and $\frac{\partial \beta^*}{\partial \delta} > 0$ imply that the more the discount rate is, the stronger the bargaining power of the seller is and the weaker that is of the sellers. The existence of discount rate makes the seller certainly accept the buyer's offer in some round.

Theorem 2 (1)The price the buyer offers in k th round can be written as

$$p_k^B = [1 - \frac{(1-\beta)^k}{(1-\alpha)^{k-1}}]u(q_0) + \frac{(1-\beta)^k}{(1-\alpha)^{k-1}}\underline{\theta} c(q_0) \quad (6)$$

(2)If the seller i accepts the offer in k th round, then we can judge that his cost parameter θ_i is distributed over $(\lambda_{k-1}, \lambda_k]$, where

$$\lambda_k = [1 - \frac{(1-\beta)^k}{(1-\alpha)^k}]\frac{u(q_0)}{c(q_0)} + \frac{(1-\beta)^k}{(1-\alpha)^k}\underline{\theta} \quad (7)$$

The offer sequence of the buyer is given by Eq. (6) and the buyer renews his belief according to Eq. (7). Considering $\frac{u(q_0)}{c(q_0)} \geq \overline{\theta}$, there exists at least one seller bound to accept the price in negotiation stage.

3.2 Auction Model

If only one seller accepts the buyer's offer in negotiation stage, then the seller wins the order without subsequent auction. If there are two or more sellers willing to accept in one round, then the buyer uses sealed first-score multi-attribute auction to determine the only winner. If in k th round m sellers together accept the price and the negotiation ends, we can judge that the sellers' cost parameters is independently and identically distributed on $(\lambda_{k-1}, \lambda_k]$ and the distribution is common knowledge.

For simplicity, we consider quality as one-dimensional attribute. As in the classic model of Che [5] and David et al. [6], the seller bids a pair of (p^S, q). The seller's expected payoff is $v(p^S, q) = (p^S - \theta c(q))\Pr ob(win | p^S, q)$, where $\Pr ob(win | p^S, q)$ is the winning probability of bid (p^S, q). The buyer evaluates bids using an openly announced scoring function consistent with his payoff given by

$$S(p^S, q) = u(q) - p^S \quad (8)$$

where $u(q)$ denotes the utility of the buyer. Finally, the winner is the seller that scores highest among all the bidders according to the pre-announced scoring rule. The buyer and the winner trade according to the winning bid in the end.

Theorem 3 In the first-score sealed multi-attribute auction, a seller with cost parameter θ will choose the optimal quality q^* according to

$$q^* \in \arg\max_q [u(q) - \theta c(q)] \quad (9)$$

See [6] for a similar result. From Theorem 3, we can see that every seller's bidding quality q^* makes the joint surplus maximal when the seller

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wins finally.

Theorem 4 In the first-score sealed multi-attribute auction, the optimal strategy of the seller is to bid the price given by

$$p^{S*}(\theta) = \theta c(q^*(\theta)) + \int_{\theta}^{\lambda_k} c(q^*(t))(\frac{\lambda_k - t}{\lambda_k - \theta})^{m-1} dt \quad (10)$$

Che [5] and David et al. [6] have proved that in such case the winner is the seller with the lowest cost parameter. By the Envelop Theorem we can argue that the winner's bidding quality will maximize the total social surplus. In public procurement the seller cares only about his profits, but the government cares about total surplus, which includes the profits of the seller. Therefore some scholars fear that this leads the government to "over pay" for quality [11]. The first-score sealed multi-attribute auction mechanism makes the fear unnecessary, because the mechanism can maximize not only the social surplus but also the buyer's payoff.

4 NUMERICAL EXAMPLE

In this section we present a numerical example to explain the equilibrium in the procurement model. Assume $\delta = 0.900$, $\underline{\theta} = 0.100$, $\overline{\theta} = 0.500$, $\theta_1 = 0.250$, $\theta_2 = 0.300$, $\theta_3 = 0.350$, $\theta_4 = 0.400$, $\theta_5 = 0.450$, $u(q) = \sqrt{q}$, $C(\theta, q) = \theta q$. To maximize the expected joint surplus, the buyer chooses $q_0 = 2.778$ in negotiation stage. According to proposition 1, we can get $\alpha^* = 1 - \sqrt{1-\delta} = 0.684$, $\beta^* = \frac{1-\sqrt{1-\delta}}{\delta} = 0.760$. The lowest prices that the five sellers are willing to accept are respectively 1.360, 1.403, 1.447, 1.491 and 1.535 according to Eq. (1). After the essential data are put in, the e-procurement system returns the buyer's offer series and the seller's cost information series according to $p_k = 1.667 - \frac{0.240^k}{0.316^{k-1}} \times 1.389$ and $\lambda_k = 0.600 - 0.760^k \times 0.5$.

Table 1: The Buyer's Offer And The Sellers' Reaction In Negotiation Stage

k	1	2
Buyer's offer p_k	1.334	1.414
Seller 1	Reject	Accept
Seller 2	Reject	Accept
Seller 3	Reject	Reject
Seller 4	Reject	Reject
Seller 5	Reject	Reject

Table 1 lists the buyer's offer and the sellers' reactions in the first and the second rounds. From the table we can see that in the first round the buyer offers a price 1.334 and all the sellers reject. In the second round the buyer raises the price to 1.414 and seller 1 and seller 2 accept the offer, so negotiation ends. The two sellers are qualified to bid in subsequent multi-attribute auction. The sellers 3, 4 and 5 quit the system due to too high cost.

From Eq. (7), we get the sellers' cost parameters distribution $\theta_{1,2} \in (0.220, 0.311]$ and $\theta_{3,4,5} \in (0.311, 0.500]$. Table 2 demonstrates the two sellers's bid and theirs scores. The seller 1 finally wins the order. The joint surplus is 1.000 and the seller 1 can get 0.103 when the agreement is reached.

Table 2: The Sellers' Bid And Score In Multi-Attribute Auction

	Bid	*Score*	Win or not
Seller 1	$(1.103, 4.000)$	0.897	Win
Seller 2	$(0.848, 2.778)$	0.819	Not

5 CONCLUSIONS

In this paper we set up the structure of an e-procurement system integrating negotiation and multi-attribute auction, which is specially made for such a circumstance that the cost parameters of the sellers may not be identically distributed. An e-learning subsystem makes the sellers' cost information clearer to the buyer from their past actions in negotiation stage. Based on the established Bayesian equilibrium, the decision support subsystem helps the buyer offer in negotiation stage and the seller bid in auction stage through a friendly user interface. The

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e-procurement system proposed in this work can simplify the complex game and bring convenience and openness to the public procurement process. In this work, we assume that the buyer fixes the quality of the product and the seller chooses to accept or not simultaneously throughout negotiation. In future studies we can consider other offering patterns and bargaining order.

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