Evaluation of an Online Multidimensional Auction System: A Computer Simulation Investigation

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Abstract Through computer simulations, this paper evaluates the performance of an online multidimensional auction system with negotiation support and especially focuses on investigating the efficacy of two design features of online multidimensional auction system on its performance: sellers' feedback and post-utility scoring method. The performance of the auction system is measured by joint gain and speed of convergence. The simulation results demonstrate that the use of sellers' feedback and post-utility scoring method lead to better bargaining outcomes as measured by the buyer's total utility and the number of auction rounds. The research results provide important theoretical implications about the role of information feedback in auction design.

1. Introduction

Although auctions have been studied by economists for a long time, only recently has the online multidimensional auction mechanism received attention from researchers as an efficient way of resolving one-to-many bargaining problems [Bichler 2000]. Among the early studies on multidimensional auctions [McAfee & McMillan 1988], Che [1993] studied design competition in government procurement by developing a model of two-dimensional auctions, where firms bid on both price and quality, and bids are evaluated by a scoring rule set by a buyer. Branco [1997] further extended Che's model by incorporating the impact of costs' correlations on the design of multidimensional auction mechanisms. According to his analysis,

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when the costs of the several bidders are not independent, the buyer has to use a two-stage auction; in the first stage the buyer selects one firm, and in the second stage, he or she bargains to readjust the level of quality to be provided. Bichler [2000] provided the first experimental analysis of multidimensional auctions. He showed that the utility scores achieved in multidimensional auctions were significantly higher than those in conventional auctions. Strecker and Seifert [2002] report on a computer-based laboratory experiment in a sole sourcing scenario of a single, indivisible object and investigate whether a multi-attribute reverse English and a multi-attribute reverse Vickrey auction institution lead to identical outcomes with respect to the buyer's utility, suppliers' profits and allocational efficiency. The results show no significant difference in suppliers' profits.

This research focuses on investigating the efficacy of two design features of online multidimensional auction system on its performance: sellers' feedback and post-utility scoring method. The performance of the auction system is measured by joint gain and speed of convergence. The joint gain is operationalized by a utility score achieved by the buyer and/or seller [Bichler 2000] and the speed of convergence can be measured by the number of rounds taken in the multi-round auction.

The remainder of this paper is organized as follows. Section 2 explains the use of sellers' feedback and the post utility scoring. Section 3, 4, and 5 proposes the hypotheses, experimental design, and experiment setting respectively, Section 6 gives the results of simulation and the final section discusses the conclusions and future research issues.

2. Multidimensional Auction with Seller's Feedback and Post-Utility Scoring

2.1. Use of sellers' feedback

In the conventional procurement auction, buyers search current market conditions (i.e., product feature and price) and create Request for Quotes (RFQs) to initiate the auction. Therefore, the buyers' aspiration levels are determined by the search results. In case the buyers fail to properly assess the market conditions when they initiate auctions (e.g., the buyers' requirement is set too high for a given budget), the auctions lead to failure, causing extra cost and time. Furthermore, the buyers do not receive any useful information to adjust their RFQs when the auctions fail. Therefore, the buyers must initiate another round without knowing which requirement is set too high within a given budget. Such a situation occurs due to incomplete information inherent in the auction process. Economists have argued that incomplete information leads to less efficient bargaining outcomes [Strecker & Seifert 2003].

We argue that this can be resolved by providing the buyers with information on market conditions. Our system is designed to foster more efficient outcomes by providing sellers' cost information to buyers. However, exposing detailed cost information can be a sensitive issue for sellers. Therefore, revealing sellers' cost information should be minimized to provide just enough information so that the buyers can initiate the next round of the auction with a more reasonable RFQ.

2.2 Post-utility scoring method

Buyers sometimes do not have perfect knowledge on their utility functions before they see the alternatives from sellers. Our system allows buyers to determine their preference structure after alternatives for all the issues have been determined, that is, after collecting offers from all the sellers. Buyers evaluate offers based on their utility functions, and utility functions are composed of the relative importance of issues and individual utility scores for each issue.

3. Hypotheses

We hypothesize that a buyer using MAMENS would achieve better bargaining outcomes than those using a conventional multidimensional auction system (Note: Throughout this paper, conventional multidimensional auction systems refer to the multidimensional auction systems built based on the proposed multidimensional auction mechanism but not having the two unique design features of MAMENS). It is also hypothesized that an increased number of sellers will lead to better bargaining outcomes for the buyers regardless of the trading mechanism. More specifically, the following formal hypotheses are proposed.

H1: Using the post-utility scoring method of the MAMENS system will lead to more joint gain than not using it.

H2: An increased number of sellers will lead to more joint gain regardless of utility scoring method.

H3: Providing buyers with sellers' cost information in the MAMENS system will lead to a quicker speed of convergence.

H4: An increased number of sellers will lead to quicker speed of convergence regardless of the existence of sellers' cost information.

H5: Providing buyers with sellers' cost information in the MAMENS system will lead to more joint gain than not providing it.

H6: An increased number of sellers will lead to more joint gain regardless of existence of the sellers' cost information.

4. Experimental design

In order to test the hypotheses, two independent experiments were conducted using computer simulation as in Bichler [2001]. Details of the computational platform used for the simulation is presented in the following sections. While holding other variables constant, each experiment employed two independent variables: the treatment and number of sellers. In each experiment, there were three groups with a different number of sellers (3, 5, and 7). The computer simulation ran 30 sessions for each group under the two conditions: one with treatment and the control group without treatment. Except for the treatment, all the parameter values were the same within the experiment.

Experiment I

Hypotheses 1 and 2 (the effect of the post-utility scoring method) were tested in Experiment I. A buyer initiated the multidimensional auction with a maximum level of price threshold (i.e., 100) in order to avoid the failure of first round bargaining due to a tight budget. Sellers were assigned randomly to the two conditions: MAMENS (with the post-utility scoring method) and conventional multidimensional auction system (without the post-utility scoring method). To investigate the effect of the post-utility scoring method, the mean values of the buyer's total utility (i.e., joint gain) from both conditions were compared using ANOVA test.

Experiment II

In Experiment II, hypotheses 3, 4, 5, and 6 (i.e., the effect of sellers' feedback) were tested. In this experiment, unlike in Experiment I, a buyer initiated the multidimensional auction in each trading session with an unreasonably low level of price threshold (i.e., 68), purposefully causing the failure of first round bargaining. After the failures of each round, the buyer relaxed one requirement per round in order to increase the chances of receiving a satisfactory offer in the next round. The auction continued to run new rounds until the buyer found a satisfactory offer.

There were two treatments in Experiment II to illustrate relaxing requirements: MAMENS (with sellers' feedback) and conventional multidimensional auction system (without sellers' feedback). The buyer using MAMENS relaxed the requirement that was most cost-causing to the majority of sellers. On the other hand, the buyer using the conventional multidimensional auction system relaxed the requirement that was personally least important.

Investigating the effect of sellers' feedback is more complex than investigating the effect of the post-utility scoring method. The number of rounds taken to reach agreement as well as the mean value of the buyer's total utility is used as a measure of effectiveness of the two systems. The number of rounds would reveal the efficiency of the negotiation support capability whereas the buyer's total utility

value would show the quality of the final bargaining outcomes. These two dependent variables were compared using ANOVA test.

5. Experiment Setting

5.1 Task

The task used in the experiments is digital camera trading. The hypothetical digital camera trading game involves two issues in addition to the price: resolution (number of pixels) and delivery time (number of days). The total cost of a camera depends on only two factors: the cost of resolution and delivery time. Each trading session involved one computer-simulated buyer and various numbers of computer-simulated sellers (3, 7, and 11). To investigate the research questions in Experiment I, we run the computational platform with two different modes to calculate the overall utility to the buyer: ***MAMENS mode*** (with post-utility scoring) and ***conventional auction mode*** (without post-utility scoring). In Experiment I, the winning offers determined by the two different modes are compared. In Experiment II, only MAMENS mode is used because the experiment's focus is not the effect of different utility scoring methods.

5.2 Parameters

The computational platform involves a number of parameters that are considered to affect the bargaining outcomes. In order to focus on testing the research questions, some of the parameters are intentionally manipulated or held constant by the researcher, while others are randomly assigned by the computer (Table 1).

Table 1. Parameters used in the computer simulation

Parameter name	Parameter value used in the simulation
Number of sellers	3,7,11
Number of issues	3
Number of trading session runs	30
Buyer's price threshold	100 in Experiment I , 68 in Experiment II
Value weight	54:23:23 (Price: Resolution: Delivery time)
Cost weight	Random number between 0.2 and 0.8

Number of sellers

Most previous bargaining experiments used a fixed number of bidders because of the cost for human subjects. Bichler [2000] used four sellers in his multidimensional auction experiment. We, however, use different numbers of sellers for each experiment in order to investigate the effect on the bargaining outcome of a

changing the number of sellers. For each experiment the computational platform runs the same simulation with three different group sizes: 3, 7, and 11 respectively.

Number of issues

A multidimensional auction can involve many issues, although price is the main concern for the buyer. Throughout the simulation the number of issues is being held to three - price, delivery time, and resolution - in order to focus specifically on the current research questions.

Number of trading sessions

For each study, the computational platform runs 30 trading sessions in order to provide sufficient data for the statistical analysis. Each session might include several trading rounds if the buyer cannot find the winning offer in the first round. Otherwise, one session of bargaining will include only one trading round.

Buyer's price threshold

In the simulation, the buyer has a price threshold or a budget limit that the sellers' offers cannot exceed in order to be accepted. Therefore, it can be assumed that the lower the price threshold the less the chance of finding an offer that fulfills the RFQ. Different buyers' price thresholds are used for each experiment. In Experiment I, the purpose is to examine the effect of the utility scoring method and therefore subsequent bargaining rounds are not performed. Therefore, buyers hold the highest possible threshold (100) in order to avoid impasse in the first round. In Experiment II, on the other hand, the threshold is set significantly lower (68), in order to make it harder for sellers to fulfill the RFQ within the price threshold. The threshold of 68 was chosen because it was the value that led to impasse in the first round of bargaining in the pilot testing of the simulation. However, as the buyer keeps relaxing requirements in subsequent rounds, sellers can also reduce the total cost, increasing the chance of fulfilling the RFQ within the price threshold.

Value weight

The relative importance of issues can affect the bargaining outcomes of multidimensional auctions [Bichler 2000]. Therefore, it is important to balance the weight distributions and keep them constant. The pilot experiments of this study sought to use perfectly balanced weight distribution (e.g., 34:33:33). However, it was determined that there was a difference between the weight for price and the other two issues. Price is a *continuous attribute* in terms of determining utility score while the other two issues are *discrete attributes*. The pilot experiments showed that the weight on the price tends to be under-represented compared to the other weights due to the different utility scoring method. In other words, if all three issues have the same weight, the impact of price change is less than those of the other two. This simulation, therefore, put more weight on the price. However, the same weight distribution, (54:23:23), is used throughout the entire simulation.

Cost weight
Unlike the buyer who has three value weights, sellers have only two cost weights: one for resolution and the other for delivery time. The cost weight is randomly determined by the computer within the range of 0.2 and 0.8 adding up to 1.

6. Simulation results

6.1 Experiment I: The effect of the post-utility scoring method

In Experiment I, for all groups, the utility scores achieved by the buyer in the post-utility selection treatment were significantly above those achieved by the conventional method. Using a two-way ANOVA (α=0.05), the null hypothesis of revenue equivalence between the post-utility scoring method and the conventional method was rejected, and the hypothesis 1 that MAMENS's post-utility scoring method would achieve higher utility scores than the conventional method was supported. Also, the number of sellers had a significant effect on the outcome. Therefore, hypothesis 2 was also supported. Although there was not a specific hypothesis related to the interaction effect, it was investigated using a two-way ANOVA test and no significant interaction effect was found. Table 2 shows the results of Experiment I.

Table 2. The results of Experiment I: Hypotheses 1 and 2 (ANOVA)

ANOVA test results (hypotheses 1and 2)			
Source of Variation	Df	F	P-value
Number of sellers	2	3.12	0.047
Treatment (post-utility scoring vs. conventional)	1	19.37	< 0.0005
Interaction	2	1.17	0.312

The buyer's total utility values achieved in the treatment of the post-utility scoring method were, on average, 3.27% in group 1(group size 3), 4.86 % in group 2 (size 7), and 7.62% in group 3 (size 11) higher than those achieved by the conventional method. Figure 1 shows the buyer's total utility value on average for each group.

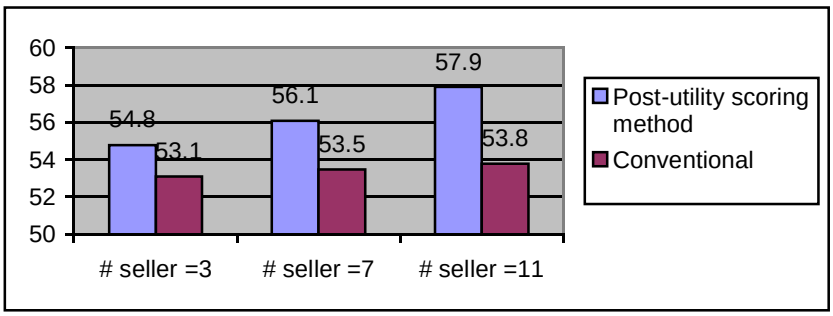

Figure 1. Average buyer's total utility value

6.2 Experiment II: The effect of sellers' feedback

In Experiment II, for all groups, the number of rounds taken by the buyer to determine the winner in the MAMENS system was significantly smaller than that of the conventional system. Using a two-way ANOVA test (α = 0.05), hypothesis 3 was supported: MAMENS leads to quicker agreement than the conventional system. The effect of the number of sellers was also significant. Therefore, hypothesis 4 was also supported. The interaction effect was not significant. Table 3 summarizes the results and Figure 2 shows the average number of rounds taken for each group and treatment.

Table 3. The results of Experiment II: Hypotheses 3 and 4 (ANOVA)

ANOVA test results (hypotheses 3 and 4)			
Source of Variation	df	F	P-value
Number of sellers	2	15.41	< 0.0005
Treatment (MAMENS vs. conventional system)	1	13.25	< 0.0005
Interaction	2	1.19	0.306

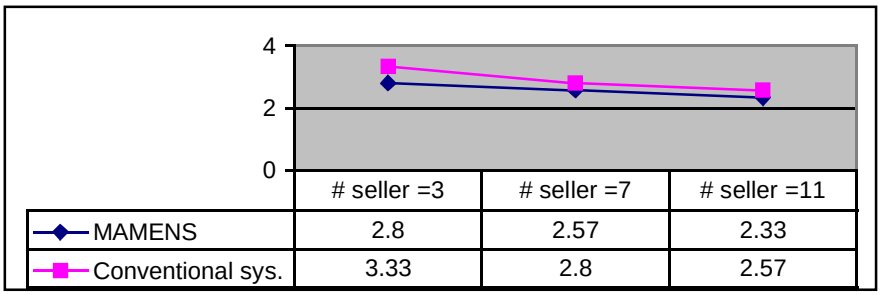

Figure 2. The average number of rounds taken for each group and treatment

For all the groups, the utility scores achieved by the buyer in the MAMENS system were also significantly above those of conventional system. Using an ANOVA test (α = 0.05), the null hypothesis of revenue equivalence between the

MAMENS system and conventional system was rejected, and hypothesis 5 was supported: MAMENS achieved higher utility scores than the conventional system. The effect of the number of sellers was also significant. The interaction effect was not significant. The results are shown in Table 4 and Figure 3 shows the buyer's total utility value for each group in Experiment II.

Table 4. The results of Experiment II: Hypotheses 5 and 6 (ANOVA)

ANOVA test results (hypotheses 5 and 6)			
Source of Variation	Df	F	P-value
Number of sellers	2	3.39	0.036
Treatment (MAMENS vs. conventional system)	1	17.20	< 0.0005
Interaction	2	1.24	0.291

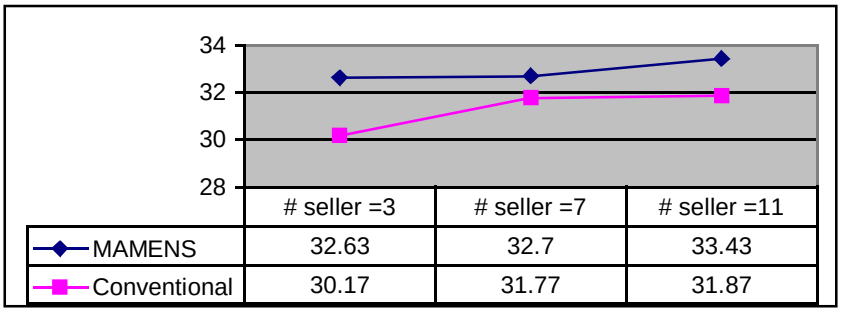

Figure 3. Buyer's total utility value in Experiment II

7. Discussions and Conclusion

The research results provide important theoretical implications about the role of information feedback in auction design. Koppius et al. [2000] argue that information feedback during an auction might have a significant impact on the performance of the auction mechanism and their proposition was made regarding the information feedback on improving a bid from a seller's perspective like in [Bodendorf et al. 1997; David et al. 2002]. Parkes [2002] considers auction design in a setting with costly preference elicitation and motivates the role of proxy agents situated between bidders and the auction, and maintain partial information about agent preferences and compute equilibrium bidding strategies based on the available information. The proxy agents can also elicit additional preference information incrementally during an auction. Parkes [2002] shows that indirect mechanisms, such as proxied ascending-price auctions, can achieve better allocative efficiency with less preference elicitation than direct mechanisms, such as sealed-bid auctions.

The simulation results presented in this paper validate the proposition from the buyer's perspective. Revealing information by a party can also tilt the information balance of power [Koppius et al. 2000]. Although this paper did not investigate this

issue in depth, it is suggested that a trusted third party can help the participants maintain a balance of power by regulating the degree of information feedback.

The research has several limitations. First, the computer simulation was conducted in a controlled environment to examine the effect of a limited number of factors. Therefore, the research results may turn out differently in real auction situations where various unexamined factors are involved that interact with each other. Second, although this study simulated realistic bargaining situations, some of the parameters were necessarily arbitrary. These limitations are inherent in computer simulation and can be overcome by a field study.

In addition to field experiments, there are several promising areas for future research. There needs to be further investigation on the impact of other variables on the performance of multidimensional auction mechanisms. Although this study investigates the effect of changing the number of bidders in the analysis of multidimensional auctions, there are still more variables that might affect the bargaining outcome in these multidimensional auctions. For example, the effect of the number of issues on the bargaining outcomes has not been thoroughly studied. Future studies need to look at such variables and their interactions by extending the simulation model presented in this study.

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