Review on the Theory of Multi-Attribute E-Auction

Anshi Xie*, Yijun Li*** and Wenjun Sun

Abstract

As an old price-discovering mechanism, auction entered the economics literature relatively recently. The full flowering of theory came only at the end of the 1970s. But this old mechanism plays a significant role in the Internet era. The development of e-commerce has given auction newfound vitality. Meanwhile, e-auction is rapidly becoming a new business mode. But in the area of b2b e-business, most procurement processes concern with the price, which is the only attribute in the decision making process. It is necessary to study multi-attribute auction in which we conduct auction with more attributes. In other words, the mechanism should automate multilateral negotiations on multiple attributes of a deal. The objective of this paper is to give an overall review of auction theory and multi-attribute auction. We will provide comprehensive categorization auction type for the first time and identity future research opportunities in the field of multi-attribute e-auction. We will present the direction for the potential research the last section of this paper.

Keywords: Multi-attribute decision-making; E-auction; Auction theory; Multi-attribute auction; Mechanism design

1. Introduction

The word “auction” comes from the Latin “augere”, which means “to increase”. People often exchange commodities that are not commonly used. Auction has been received as a scientific subject by researchers for no more than half of a century. Vickrey, who has been regarded as the pioneer in the field of auction theory, started his research from the point of view of game theory. His seminal paper, “Counterspeculation, auctions and sealed tenders” [44], which was published on the Journal of Finance in 1961, is the most important paper in this field. Because of this work, Vickrey was rewarded the Nobel Price in Economic in 1996.

Auction on the Internet which we call it e-auction is a relatively recent phenomenon. With the rise of the Internet, the application to electronic

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commerce is immediate. Internet-based auction differs from traditional ones in that they bend the rules of time and space. Participants do not need to be in the same place, to participate at the same time, or even to leave the convenience of their homes to aggressively bid and win items halfway around the world. This is a regular occurrence at the online auction site. Auctioneering (or procurement) has been increasing at an explosive rate. Enterprises today are looking closely at the potential of Internet reverse auction technology to help keep procurement costs down. These attitudes are influenced, in part, by reports of 25 to 50 percent savings in multimillion-dollar procurements. In reality, many firms are still struggling to define an appropriate

Conventional auctions only automate negotiation on the price. But it would be comfortable to have procurement, the attribute of a deal include the delivery period, credit degree, ending deadline, quantity, etc. A service can be characterized by its quantity, supply time, and the risk involved, etc. In the commercial deal, an item can be characterized by size, weight, supply date, etc. Auction is efficient protocols for reaching agreements among agents, and they can also be used when the issue to be considered is associated with multi-attributes. There are many difficulties in studying multi-attribute auction. In this paper, we address these difficulties and provide a detail review of auction theory and multi-attribute auction.

The rest of this paper is organized as follows: we start in section 2 with an overview of classification scheme for auction theory and mainly discuss the Vickrey auction mechanism; Section 3 describes the multi-attribute e-auction; Section 4 presents our evaluations on potential research directions.

2. Auction Theory

As an old price-discovering mechanism, auction entered the economics literature relatively recently. Two papers have been regarded as initial references [21,44]. The full flowering of theory came only at the end of the 1970s. A very readable introduction to the state of this field by the late 1980s is in McAfee and McMillan [32]. Another helpful introductory article is Maskin and Riley [31]. Why should we study auction? McAfee and McMillan explained that auction theory provided one explicit model of price making. A less fundamental but more practical reason for studying auction is that auction is of considerable empirical significance. The value of goods exchanged each year by auction is huge. This fact in itself indicates that some theoretical study of auction is warranted. More over, as will be seen, the theory of auction is closer to applications than is most frontier mathematical economics [20]. Next, we will give an overview on this topic from
three perspectives: definition, schemes and economic models.

2.1 Definition

Oxford Dictionary defines an auction as a “public sale in which articles are sold to maker of the highest bid”. This definition describes the English auction, which cannot reflect the essence of auction. An authoritative definition is given by McAfee and McMillan [32] as follows: an auction is a market institution with an explicit set of rules determining resource allocation and prices on the basis of bids from the market participants.

2.2 Basic Auction Schemes

This section will give the reader a brief overview of the auction schemes.

Although there are various kinds of auction classifications, there appears to be no unified forms. Here we briefly summarized each classification and discussed them from traditional classifications.

A. According to the traditional view, we can divide auctions into “outcry auction” and “sealed-bid auction”. Outcry auction includes the ascending-price auction (English Auction) and the descending-price auction (Dutch Auction). Sealed-bid auction includes the first-price sealed-bid auction and the second-price sealed-bid auction. It should be pointed out that it was Vickrey who first defined the second-price sealed-bid auction. As such, the second-price sealed-bid auction is usually also called the Vickrey auction. Jason and Margolis [23] presented an nth price mechanism, which, however, didn’t receive any recognition from other researchers.

B. According to the market structure, we divide auctions into single auction and double auction. Single auction is a “one to many” auction in nature. Either buyer or seller monopolizes the market resource and holds the market. Double auction differs from single auction in structure. Double auction is “many to many”. Both sides are related through supply and demand. An environment where vendors and buyers meet with the goal to sell and buy goods is commonly called a market. As there are many different interpretations of what a market is, such an environment should rather be called a market framework. Figure 1 shows an example of such a framework. There are four cases presented: 1. One vendor and one buyer directly negotiate in the classical sense; 2. Multiple vendors and one buyer are engaged in a
reverse auction; 3. Multiple buyers and one vendor are engaged in a classical auction (English, Dutch, Vickery, etc.); 4. Multiple buyers and vendors trade in a market.

C. According to the value form, we divide auctions into common-value auction and private-value auction. In certain auction, because of the information asymmetry, only that buyer knows one buyer’s valuation of a product; not all buyers may agree on a product’s value; buyers may value a product differently for different reasons. We call this auction private value auction. The main commodities for this auction type are paintings, Egyptian thimbles, and Victorian snuffboxes etc. In a common-value auction, the actual value of (or any known measure of) the goods is the same for all buyers. Buyers start with different estimates or private information about the following aspects of the goods: quality of the goods, remaining economic life of the goods, and some “measure” of the goods. In a common-value auction, buyers can receive meaningful information about the product’s “true value” from other buyers’ bids. The typical commodity for this auction is mineral rights. In a private-value auction, buyers rarely get any information about the product’s “true value” from other buyers.

D. According to the status of buyers and sellers, we can divide traditional auctions into forward auction and reverse auction. In reverse auction, sellers bid for a buyers’ business. The seller that makes the lowest bid wins the auction. Just as there are open and sealed bid auction in the “regular” auction format—there are open and sealed bid formats in reverse auction too. The new e-procurement system is a typical rever-
Table 1 Regular Auction and Reverse Auction

<table>
<thead>
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<th>Regular auction</th>
<th>Reverse auction</th>
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<tr>
<td>English</td>
<td>Open/Ascending/Highest price wins</td>
<td>Open/Bids goes down/Lowest bid wins</td>
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<tr>
<td>Dutch</td>
<td>Open/price fall/highest bid wins</td>
<td>Open/Price rises/Highest bid wins</td>
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<tr>
<td>First price Sealed Bid</td>
<td>Sealed highest bidder wins</td>
<td>Sealed lowest wins</td>
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<tr>
<td>Vickrey auction</td>
<td>Highest bidder wins and pays the next bidder’s bid</td>
<td>Lowest bidder wins and receives the next bidder’s bid</td>
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Advanced Auctions

Advanced auctions are distinct from traditional auctions, such as English, Dutch, Sealed First price, and Vickrey, etc. Advanced auctions market mechanisms with multidimensional parameters, such as resource allocation, prices, time, and utility, etc, on the basis of bids from the market participants. The advanced auctions are a subset of auction. Followed by this definition, multi-unit auction [28], multi-item auction, combinatorial auction [22], multi-attribute auction [6,9,11,12,34], AKBA, i-Budle, AUSM, RSM, etc, are all advanced auction. Limited by the length of this paper, we give a brief introduce of multi-unit auction, multi-item auction, combinatorial auction. Multi-attribute auction will be mainly discussed in next section.

2.3.1 Multi-Unit Auction

Multi-unit auction is of great practical importance, and have been used to selling units of bandwidth in computer networks and satellite links, MWs of electric power, capacity of natural gas and oil pipelines. These auctions can be homogeneous or heterogeneous. In a homogeneous auction a number of identical units of a good are to be auctioned. In the simplest multi-unit auction, each buyer wants only one unit. The auction mechanisms above can be generalized. For example, in a simultaneous auction of $k$ units, all bidders could make closed sealed-bids, and the $k$ objects could be awarded to the $k$ highest bidders. In a first-price auction each bidder would pay his own bid. In a generalization of the Vickrey auction the $k$ highest bidders would pay the value of the highest losing bid. It can be shown that the revenue-
equivalence theorem still holds for these auctions. Note that in the first-price auction the successful bidders pay differently for the same thing; we call this a discriminatory auction. By contrast, the Vickrey auction is called a uniform auction, because all successful bidders pay the same. A uniform auction is intuitively fairer, and also more likely to reduce the winner’s curse.

2.3.2 Multi-Item Auction

Simply speaking, the multi-item auction is in the case that one bidder buy more than one commodity. When we study multi-item auction, we should suppose: the quantity of items to sell is fixed as well as the quantities requested by the buyers. These two assumptions are not valid for many situations where auction is used. Lengweiler [25] for example proposes an auction model, where the available quantity is not fixed. The approach proposed here is inspired from Lengweiler’s model, and it is based on an English auction with multiple items, private evaluations and variable requested quantities.

2.3.3 Combinatorial Auction

Combinatorial auction is special case of multi-item negotiations in which items are traded in bundles. Hence, the bids submitted to the auctioneer are combined offers to sell, buy, or simultaneously sell and buy several different items. Combinatorial auction has received much attention in the literature, with the early works mainly focusing on solving the allocation problem. However, recent contributions by Abrache et al. [1] have emphasized that the design of combinatorial auction is a multi-faceted problem, involving many challenging issues.

These advanced auctions cannot be sorted into traditional classifications. These advanced forms of auctions can be categorized by several different dimensions of the goods (as illustrated in Figure 2).

If Figure 3, x-axis stands for attribute, y-axis stands for item and z-axis stands for unit. Node 1 describes single-item, price-only, single-unit offers. Node 2 describes single-item, price-only, multi-unit offers. Node 3 is multi-item, price-only, fixed-quantity offers. Bundle offers are allocated by combinatorial auction. Node 4 describes pure multi-attribute offers having a single item. These offers are often used in multi-attribute reverse auction and in RFQs. Node5 to 8 describe combinations of the dimensions. For example, Offer Node 6 describes fixed-quantity offers where qualitative attributes and quantity of goods are negotiable.
Researchers proposed other auction forms, such as asymmetric auction, multi-stage auction [37], volume-discount auction, and multi-stage extended Vickrey auction. The classifications mentioned above cover most of these advanced auctions, so we do not discuss them any further.

2.3.4 Auction Model

Auction model had not been paid much attention until Vickrey published his paper on the *Journal of Finance* in 1961. Since then, scholars realized that auction theory research was very important but scarce.

Generally, we study the auction model with the following assumptions:
① One item; ② All bidders and sellers are risk neutral; ③ All bidders are symmetric; ④ Commodities have private values; ⑤ Only bids decide the payment price; ⑥ All bidders are non-cooperate game; ⑦ Sellers are auctioneers and there is no transaction cost in the auction process. Researchers call the above assumptions the *Independent private-value model*.

Based on these assumptions, two aspects of auction should be studied: One is from the point of view of the auctioneers; the other is from the point of view of the bidders. From the point of view of the auctioneers, how to design an optimal auction is the most critical issue. The schemes mentioned above can all been regarded as the auction model. As the schemes mentioned above, English auction is the most popular form but Vickrey auction has most academic value. Vickrey proposed his classical auction model—second-price sealed-auction—through analyzing traditional auction mechanisms. The remarkable character of the Vickrey auction is that the best strategy for bidders is to “tell the truth”. This mechanism is inspirit-consistent because the highest bidder wins and pays the next bidder’s bid, so it is a Pareto-optimal allocation mechanism.
What advantage does the Vickrey auction have over other auction mechanisms? It is shown clearly in the following figure:

In case 1, the highest bid is $M=B$, where $M$ is higher than his preferred price $P$, the second highest price is lower than $P$, so bidder will win the bid. The net surplus is $(P-M)$. It is unnecessary for the bidder to bid higher prices than $P$. In case 2, the bidder bids $M$, which is higher than his preferred price $P$. The bidder wins the bid, but he must pay $M$, which is higher than $P$. So he will lose $(M-P)$, which he should gain. In case 3, the bidder bids $M$ which is higher than his preferred price $P$. But since he did not bid the highest price, he will not get the bid. So it is the same situation as when he bids $P$.

In case 4, the bidder’s bid is the highest one $M=b$. But his preferred price $P$ is higher than $M$ and $M$ is higher than $M$. He can win the bid at the price of $M$. The net surplus $(M-M)$ will not increase for his low-bid strategy. In case 5, bidder’s bid is $M$, which is not the highest bid. He can win the bid when he bids at his preferred price $P$. He lost the opportunity of getting the net-surplus $(P-M)$ for his low-bid strategy. In case 6, for his bid $M$ is lower than the highest price $M$, he lost the bid. It is thus shown clearly that the second-price mechanism can effectively avoid the problem of shill bidding.

Hereinbefore, we introduced how to design an optimal mechanism from auctioneers’ perspective by way of Vickrey auction. From the viewpoint of the bidders, we should design competitive project (competitive bidding).
Generally, competitive bidding should consider three questions as follows: (1) How to determine the winning probability; (2) How to evaluate cost; (3) How to determine the numbers of bidders.

Research in the field of competitive bidding began 60 years ago [21]. Friedman first presented his competitive bidding model in the famous journal, *Journal of Operation Research*. He also presents significant findings on competitive bidding in his doctoral thesis. Other researchers have investigated the theory and application of competitive bidding based on Friedman’s model. However, Friedman’s model (1) and Gates’ model (2) are the most classical.

\[
\prod_{i=1}^{n} \int_{r_i}^{\infty} f_i(r_i) \, dr_i \\
1/(1 + 1/\sum_{i=1}^{n}(1 - P_i) / P_i)
\]

where,
\[
r_i = b_i / c \cdot r_i \text{ is the ratio of bid to cost;}
\]
\[
f_i(r_i) \text{ is the density function;}
\]
\[
P_i \text{ is the winning probability.}
\]

In the 1960’s, Casey and Shaffer, Morin and Clough modified Friedman’s model. Morin and Clough [35] presented a discrete probability model and were the first to perform a computer simulation.

Capen, Clapp and Campbell presented a common value model and at the same time presented the question of Winner’s Curse—bidders will conceal their true value due to fear of deception. Wade and Harris [47] presented the local market definition on the basis of Friedman’s model and extended his model.

In the 1980’s, Carr [13] put forward a theory for general competitive bidding. He dealt with the problem of market environment and cost changing. In the 1990’s, several kinds of symbolic logic methods enriched the diversity of competitive bidding model. Alan [2] provided a structure method that applied the multi-criteria decision making technology. Their method mainly reflected the importance of preference. Other algorithms, such as liner utility and AHP, have also been applied to the competitive bidding model.

The price is the unique strategic dimension in the previous auction models. However, in many situations, it is necessary to conduct auction on multiple attributes of a deal. For more than 50 years, multinational corpora-
tions have been selling industrial and commercial products, with annual sales of $5 billion and $3.4 billion in annual spending, according to the most recent figures. Although the firm is an industry leader and innovator, it has a tradition of minimizing risk and moving forward in a well-planned and deliberate manner. In 1997, its senior management decided the firm should become an early adopter of electronic procurement techniques, such as catalog systems and reverse auction, with the aim of reducing costs and eliminating traditional time-consuming, paper-based competitive bidding practices. Over the next three years, multinational corporations’ needs changed as managers and staff learned more about how best to do reverse auction. In parallel, the field of online reverse auction and e-procurement matured as well. The reverse auction or the e-procurement is the concretely representation of multi-attribute e-auction to some extend, so we offer a review of multi-attribute e-auction in the next section.

3. Multi-Attribute E-Auction

3.1 E-Auction

Internet allows direct contact between buyers and sellers, and provides a suitable and popular place for conducting auction, which are usually called e-auction or auction online. We define e-auction as a web page, which displays information about a good or service with the intent to sell it through a competitive bidding procedure to the highest bidder. In fact, e-auction is an application environment of auction, so we cannot study e-auction as a separate research field. Most literature on e-auction is about its role in enterprise [2,18,24,48].

There are many differences between traditional auction and e-auction. E-auction gives bidders increased convenience both geographic and temporal. These increased conveniences can also benefit the seller by creating a larger market for auctioned good. Furthermore, search engines and clickable hierarchies of categories for browsing make it more convenient for a bidder to find the goods she is looking for.

The earliest e-auction Web sites are Onsale and eBay which opened in 1995. It was the first to take advantage of the technologies offered by the Web, including the use of automated bids entered through electronic forms, and search engines and clickable categories to allow bidder to locate their items of interest. In the past several years, two large Web-based companies, Yahoo! and Amazon, have announced their own person to person auction services very much like eBay’s. It will be interesting to see whether these
well-funded later entrants will be able to take business away from eBay. E-auction is potentially rich sources of study both for economic theorists and for empiricists.

Various forms of auctions exist on the Internet. Hunsberger[22] has suggested a simple but equally sensible classification. According to him, there are only two main categories of Internet auction: long-term and live auction.

3.1.1 Long-Term Auction

A long-term auction is characterized by a fixed time scale with a certain starting date and a predetermined deadline. It may well last for several weeks. The auction house restricts itself to offering the digital platform for presenting the items and to providing the rules governing the transaction in its standard terms and conditions.

3.1.2 Live Auction

Live auction is much closer to conventional auction in the analogue world. They are restricted to a shorter period of time and are under constant control by an auctioneer. Throughout the entire auction the bidders will be informed on their screens about the starting price and the current status of the bids. Finally, the auctioneer will hammer down the item in almost traditional form according to s. 156 Civil Code. Live auction highlight the enormous degree of interactivity modern communication techniques already in use. It is conceivable, however, that in the near future live auction might even be held in the form of a ‘video conference’.

In electronic auction, we can have readily available items and face global market; we can easily access information and have a large scale of operation; we have flexible duration and can compete with other auctions and retailers. The advantages mentioned above indicate that electronic auction will ultimately and inevitably replace traditional auction.

But in the area of b2b e-business, most procurement processes concern price, which is the only attribute in the decision making process. Traditionally, these types of negotiations are resolved through bilateral bargaining or sealed-bid tenders, where a buyer asks for bids in unstructured or semi-structured format and then the buyer manually selects one or more of these bids. A tendering procedure allows the sale to be determined by a variety of attributes involving not only price but quality, time, contract term, and supplier reputation. So other attributes should be considered in the e-procure-
ment process. In other word, the mechanism should automate multilateral negotiations on multiple attribute of a deal. We call this auction mechanism “multi-attribute” e-auction. The evolution of multi-attribute auction is based on the theory of multi-attribute decision-making, which we will now briefly introduce.

3.2 The Basic Theory of Multi-Attribute E-Auction

Multi-attribute decision making problem (MADM) is one branch of the multi-object decision making problem. If the decision variables in multi-object decision making problem are dispersed and the preparative project is limited, we call this problem a multi-attribute decision-making problem. In 1957, Chruchman, Ackoff, and Arnoff solved “the problem of choosing the enterprise investment policy” using simplified weigh methods. This was regarded as the first practice in the field of multi-attribute decision making problem. Since then, multi-attribute utility theory became a popular approach under the condition of fuzzy environment. Barret and Easton extended the multi-attribute decision making theory along the line of multidimension theory. Hwang and Yoon summarized the results of those researchers.


Research on multi-attribute decision-making problem in China started in the early 1980’s [16, 36]. Researchers have summarized for more than 10 approaches. Value scoring was the first approach to be widely accepted. Recently, other approaches, such as the weight sum approach, the weight product approach, TOPSIS (Technique for Order Preference by Similarity), relative position estimate ELECTRE (Elimination et Choice Translating Reality), PROMETHEE, LINMAPk, and contrast coefficient emerged. Shuling Liu’s doctoral paper[28], Research on multi-attribute decision making theory, method and applications is the most significant theoretical literature in the field of multi-attribute decision making in China hitherto. The author presented 14 new multi-attribute decision making methods and extent juncture and separator method based on attribute. He particularly designed a new propinquity distance from ideal point and derived a new method named “measurement sort by angle”. The method was compared with TOPSIS and received good results. The latest important literature to emerge on this topic
is *Theory and method of decision making* by Chaoyuan Yue [50], in which he summarized 7 multi-attribute decision methods and showed the results of an experimental research combined with graduate evaluation system.

Similar to classic auction theory, multi-attribute can also be divided into open-cry and sealed-bid auction. In a first-score sealed-bid auction, the winner gets a contract awarded containing the attributes $X_j$ of the winning bid. Alternatives with the same overall utility are indifferent and the first of those bids is the winning bid. In a second-score sealed-bid, auction we take the overall utility achieved by the second highest bid ($S_{\text{max}} - S_{\text{max}-1}$) into a monetary unit. Consequently, the winning bidder can charge a higher price. In the first-score and second-score sealed-bid schemes, the auction closes after a certain pre-announced deadline. In a multi-attribute English auction, bids are made public and the auction closes after a certain amount of time elapses in which no one submits a bid.

Having analyzed the multi-attribute decision making theory and classifications of multi-attribute auction, we will address three basic issues in multi-attribute e-auction: winner determination, security, protocols and strategies.

3.3 Winner Determination in Multi-Attribute E-Auction

Several studies have looked at multi-attribute auction [6, 11, 34]. Che studied how to design competition in government procurement by using a model of two-dimensional auction [14]. It includes two attributes: price and quality. Laffont and Tirole described many issues involved in procurement negotiations, ranging from the costs of setting up a tender to evaluating the bids in such a process. Branco derived an optimal auction mechanism to be used when the bidding firms’ costs are correlated [11]. Bichler, Kaukal and Segev [8] use a similar utility function approach and discuss a Web-based multiple prototype of multidimensional auction system. Teich [43] discussed Web-based multiple issue auction algorithms in cases where quantity is an issue as well as quantity is not one of the issues. Contrary to Che, Branco, and Bichler et al, they did not attempt to develop a scoring rule but instead accepted bids in the issue space itself. Teich&Wallenius [41] elaborate on their multiple unit auction algorithms and describe a Java-based web implementation of their algorithms. Sandholm [39] describes his web-based experimental auction site, which includes options for combinatorial auctions, agents, and a price/quantity graph bidding mechanism. Maes, Guttman and Moukas [30] also discuss the use of agents for use in web-based auction and markets. In the next section, we will introduce some classical models of multi-attribute e-auction.
3.3.1 Che’s Model

Che [14] generally analyzed and designed multi-attribute e-auction model and proved REM (revenue equivalence theorem). Che designed an optimal scoring rule based on the assumption that buyers know the sellers’ probabilistic distribution of cost parameter.

Che first considered two attributes: price and quality (marked as p and q, with quantity fixed). He regarded quality as one-dimension attribute (in fact, quality includes many attributes such as capability and performance etc).

The buyer’s utility function derived from contract:

\[ U(q, p) = V(q) - p \]  

where: \( V' > 0, V'' < 0 \)

\[ \lim_{q \to 0} V'(q) = \infty, \lim_{q \to \infty} V'(q) = 0 \]

The winner provider’s revenue gained from the contract:

\[ \pi_i(q, p) = p - c(q, \theta_i) \]  

In the cost function \( c \) the unit cost is expressed as \( \theta \), which is private information. \( \theta \) is assumed to be independently and identically distributed. Losing firms earn zero profits and trade always takes place, even with a very high \( u \). Che investigated what an optimal auction in this case should look like. In Che’s model, an optimal multi-attribute auction selects the firm with the lowest \( \theta \). The winning firm is induced to choose quality \( q \) that maximizes \( V(q) \) considering the costs.

The shortcoming of Che’s model is obvious. The costs are assumed to be independent across firms. In the context of procurement auction, one might expect that the costs of the several bidders would not be independent.

3.3.2 Bichler’s Model

Based on multi-attribute utility function, Bichler [6] presented an extend model. He took the weight of attributes into account. In his model, an attribute \( x' \) is said to be independent of \( x' \) if preferences for specific outcomes of \( x' \) do not depend on the level of attribute \( x' \). It is fair to say that preferential independence holds for many situations. Based on his preconditions, a bid received by the auctioneer can be described as vector \( Q \) of n relevant attribute index by i. A vector \( x_j = (x_{j1}, ..., x_{jn}) \) can be specified where \( x_{ji} \) is the level of attribute I in bid \( b_j \). In the case of an additive scoring function \( S(x) \),
the buyer evaluates each relevant attribute $x_j$ through a scoring function $S_j(x_j)$. The overall utility $S(x_j)$ for a bid $b_j$ is then given by the sum of all individual scorings of the attributes. For a bid $b$ that has values $x_1, ..., x_n$ and weights $w_1, ..., w_n$ on the $n$ relevant attributes, the overall utility for a bid is then given by:

$$S(x_j) = \sum_{i=1}^{n} w_i S_j(x_i)$$

(5)

In these cases, the first bid is the winning bid. The multi-attribute English auction, which has been known as the first-score open-cry auction, works in the same way. However, all bids are made available to the participants during an auction period. In a second-score sealed-bid auction, he took the overall utility achieved by the second highest bid $S_{max-1}$ and transformed the gap to the highest overall utility ($S_{max} - S_{max-1}$) into implied volatility. Consequently, the winning bidder can charge a higher option price. In the first-score and second-score sealed-bid schemes, the auction closes after a certain pre-announced deadline. In a multi-attribute English auction, bids are made public and the auction closes after a certain amount of time elapses in which no one submits a bid.

3.3.3 Other Models

Branco [11] derived an optimal auction mechanism for the case when the bidding firms’ costs are correlated, but the initial information of firms is independent. This is somehow equivalent to the common value approach in classic auction theory. He shows that when the quality of the item is an issue, the existence of correlations among the costs has significant effects on the design of optimal multi-attribute auction. Therefore, unlike in Che’s independent-cost model, optimal quality cannot be achieved solely through the bidding process.

Using the basic tool of consumer theory, Teich [43] showed that if the procurer decides on a budget for the project, which became known to all agents, and does not value any savings, the problem of designing optimal multidimensional auction will be equivalent to the design of one-dimensional auction. But in his model, it is unclear whether the assumptions of a preset budget and, especially, valueless savings are appropriate in most procurement situations.

Cripps and Ireland assumed that the procurement agency required the bids to pass a certain quality threshold in order to be eligible to enter the auction. The procurer, under the assumption that objectively better projects
have a greater probability of being accepted, subjectively conducts the quality test. But their methods were limited to the comparison of three alternative mechanisms and the identification of optimal reserve prices in the context of a very simple model, leaving open a complete characterization of optimal mechanisms.

Mishra and Veeranmant [34] mapped the producer-consumer economy to an “outsourcing” economy in which multi-attribute negotiations were done. Dekrajangpetch [19] applied interior-point linear programming algorithm to auction method.

Burmeister designed an approach to bundle relevant combinations of attributes into packages [12]. The whole procedure can be a multi-round auction. Each round consists of the three steps: announcements at the beginning of a round, bidding, and evaluation of bids. This method can solve the problem of multi-attribute partially. But this approach cannot overcome the disturbance of individual factors.

The model mentioned above can only partly solve the problem. It is often found that in some instances, we observe good results in laboratory environments. But the results of practical applications are not ideal. So the problem of winner determination will be the main issue in multi-attribute e-auction recent years. There are also many researchers devoted to finding effective methods to solve these problems.

3.4 Security

Unlike the many dot-COM companies that vanished along with the burst bubbles in 2000 and 2001, online auction sites are among the most successful Internet businesses and are here to stay. In the last several years, online auction sites have brought auction to the general public. But online auction has also attracted most of the online frauds, which were ranked as the number one type of Internet frauds during the last three years. In 1999, online auction frauds accounted for 87% of reported incidents of Internet frauds, up from 68% in 1998. Indeed, online auction seemed to attract fraud. Between 1998 and 1999, fraud related to online auction soared by 76% while frauds related to other types of online transactions plummeted by 44%. In the year 2000, the volume of auction related fraud increased by 23% and accounted for 78% of the reported incidents. Considering that there are millions of items listed on eBay across thousands of categories on any given day and the eBay community transacted more than $5 billion in annualized gross merchandise sales in 2000, online auction transactions that involve
fraud can be plentiful as well. Statistical data support this prediction. In fact, among the 35 million Americans participating in online auction, 41% of online auction buyers reported having a problem. Economists have been studying auction for over forty years, yet no one has predicted the volume of online auction and the variety of fraudulent behavior observed in current online practices.

From the viewpoint of mechanism, there is little literature on Internet e-auction security. Among these literatures, Srividhya [40] analyzed the problem mentioned above from the viewpoint of how to design an efficient auction protocol. He thought that a good auction protocol should have: ① anonymity; ② security; ③ privacy; ④ separable. He designed a sort of security protocol and solved the security problem in Internet transmission using BAN logic.

### 3.5 Design of Protocol and Strategy

E-auction has already turned to be one of the most popular mechanisms in electronic commerce. Many basic principles and ideas for the design of multi-agent Artificial Intelligence systems developed form the mechanism design literature. Much of the research in mechanism design has been devoted to the study of auction [31,33]. The Internet is a computational setting with flexible software that is used by relatively sophisticated users. In multi-attribute auction, buyers buy the goods from a set of potential sellers according to some bidding rules and rules for determining the auction’s outcome.

McAfee and McMillan [32] proposed the question which auctioneers should consider in protocol and design: ① What is the best form of selling mechanism to use in any particular set of circumstances? ② Should the seller impose a reserve price? ③ Can sellers design the auction so as to achieve price discrimination among the bidders? ④ Is it ever in the seller’s interest to require payment from the unsuccessful bidders? ⑤ Whether it is feasible to make payment depend not only on the bid but also on something correlated with the true value of the item? ⑥ Should the seller release any information he has about the item’s true value? ⑦ What can the seller do to counter collusion among the bidders? Since then, researchers have design the optimal mechanism based on above question.

In recent years, researchers have designed the protocol and strategy of multi-attribute auction with partial question solved in multi-attribute environment. David and Kraus [17] suggested two main protocols for the
multi-attribute auction. The first is a variation of the first-price sealed-bid auction, and the second includes four possible variations of the English auction protocols. They describe each protocol in detail and find stable and beneficial strategies for the buyer agent and for the seller agents.

Many issues also remain unsolved in the mechanism design. What should the buyer reveal at the start of an auction? Should it be all preferences, only part of them, or false preferences? How does the amount or the type of the announced preferences influence the auction results? Should the buyer be committed to the preferences it announces and should the seller agent be committed to its proposed bid? What should the winner selection criterion include? How should a seller agent formulate its bid considering the various attributes? What should the optimal bid/bids of each seller be given the protocol, and its beliefs? Assuming that an ascending protocol is used, how can a bidder suggest a better bid than the current best bid, if it does not completely know the buyer’s preferences?

All the problems mentioned above form the basic frames of mechanism design. The goal of mechanism design is double-win both for bidders and auctioneers. The design of mechanism will also be the important aspect of multi-attribute e-auction.

4. Perspectives on Future Research

Auction theory has developed for about a half century, but the theoretical framework has not been solidly formed. The intrinsic characters limit the development of auction theory. Most studies on auction have been conducted in laboratory environments. But auction model should be supported by data. This makes the conclusions of auction theory highly speculative and there is a large distance between theory and practice. Meanwhile, many researchers devote themselves to designing optimal auction mechanisms, which plunges auction theory studies into further mistakes. The research based on bidders is not profound. This also weakens the explanatory ability of auction theory.

From the viewpoint of decision-making science, both parties in the auction process confront complex decision problems. The business strategy should be further researched. Variety and unconformity in markets is the starting point and critical problem of auction theory.

Several other urgent problems exist that must be addressed. For example, how auction affects living performance; How to model double auction; The competition and consistency between auction and other business mecha-
nisms etc. In recent years, more and more researchers design optimal auction mechanisms using static and dynamic Game analysis. But Game analysis is a symmetric trade-off contract to an asymmetric trade-off in a practical world. Thus, an in depth studies on how to make good use of Game theory is also a worthwhile topic.

Most business activity on the Internet is limited to publicity the business opportunity and catalog based sales, but it will rapidly expand to include negotiations or commodities being traded. These negotiations are currently conducted by human intermediaries through various forms of auctions, bidding systems for awarding contracts, and brokerages. Trading on the Internet allows a business to reach a larger number of potential customers and suppliers in a shorter time and with a lower cost than is possible with other models of communication, and to settle business transactions with lower cost overhead in a shorter time. It is important to investigate the psychological and emotional aspects of behavior of people in an auction and factor the results in the design of auction.

Moreover, in the environment of e-commerce, multi-attribute e-auction has not been given much attention. More and more multi-national enterprises have begun cutting costs using e-procurement. Auction is efficient protocols for reaching agreements among agents, and they can also be used when the issue considered is associated with multi-attribute. However, several difficulties arise when trying to implement traditional single-attribute auction protocols for multi-attribute. The lag of e-procurement theory is incomprehensible. In the field of auction theory, how to design a simplified and efficient optimal auction mechanism will also be the hotpot. Furthermore, multi-attribute e-auction will certainly have great influence on the recombination of enterprise supply chain, the shortening of the procurement cycle, and procurement cost saving. Designing and analyzing e-auction based on supply chain is also an important research field.

Though the research on auction is fairly insufficient, the recent achievements in the field of auction theory make auction an important part of economics. Because of the practical significance of e-auction, which is shown in resolving problems in national debt, e-commerce, and government procurement, auction theory have gradually become the theoretical foundation of industry economics, finance, information economics and other subjects.
References


