Invited Review

Multi-attribute online reverse auctions: Recent research trends

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This paper provides an updated overview of the rapidly developing research field of multi-attribute online reverse auctions. Our focus is on academic research, although we briefly comment on the state-of-the-art in practice. The role that Operational Research plays in such auctions is highlighted. We review decision- and game-theoretic research, experimental studies, information disclosure policies, and research on integrating and comparing negotiations and auctions. We conclude by discussing implementation issues regarding online procurement auctions in practice.

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1. Introduction

Since the late 1990s E-commerce has been changing the way firms do business. E-commerce can be described as business transactions that occur via open-networks, such as the Internet.

Online procurement (reverse) auctions play an important role in E-commerce. The basic principles of such auctions originate from the concept of dynamic pricing and a bidding process to set the prices and determine the allocation of goods/services being auctioned. Auctions always follow a pre-defined set of rules. Two-attribute sealed bid reverse auctions, known as $A + B$ auctions, have been extensively used by US Government agencies over two decades. Online reverse auctions have also been used by a number of large corporations in business-to-business transactions. Many of them have saved millions of dollars through online reverse auction usage in comparison to traditional procurement approaches (for example, Brunelli, 2000; Hohner et al., 2005; Metty et al., 2006a, 2006b). It is not uncommon that auctions are run as price-only. Such auctions may not be binding, since buyers want to consider other attributes besides price (ex post). This is not ideal and may lead to problems, since bidders cannot be sure if and when they win an auction.

Despite high expectations, online reverse auctions have also faced criticism and in some cases such auctions have been discontinued after a few initial successful years (Emiliani & Spec, 2005; Gupta, Parente, & Sanyal, 2012; Tassabehji, Taylor, Beach, & Wood, 2006). One of the criticisms is that online reverse auctions only concentrate on the interests of the buyer, while ignoring the interests of the suppliers. Buyers may also exhibit resistance to change for various reasons (Peng & Calvi, 2012). It is true that long-term relationships between buyer and supplier can be damaged, if price is the sole priority of the buyer (Jap, 2007). Gupta et al. (2012) analyze the reasons why initially successful procurement auctions for health insurance contracts in the US were discontinued in early 2000. The authors conclude that the fault lay with the design and implementation of the auction mechanism. The bidding was price-only. How the different attributes were weighted by the buyer was not explicitly told to the sellers. Another concern was that full disclosure of bids might have hindered bidder participation. In order to overcome this criticism, new auction mechanisms that take non-price attributes, such as quality, delivery and payment terms explicitly into consideration have been suggested. Also in multi-attribute settings, it is important to provide incentives to losing bidders to maintain their future interest in a business relationship (Ray, Jenamani, & Mohapatra, 2013).

Several commercial software vendors provide platforms for conducting such auctions (e.g., Perfect, Ariba, CombineNet (acquired by SciQuest), Bravo Solution, Epicor, Digital Union, TradeExtensions, 2013).

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The Mars Inc. procurement auctions were discontinued after a few years.

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and Negometrix) known as Multi-Attribute Online Reverse Auctions (MAORAs).

In the academic literature, quite a bit of attention is being paid to MAORAs. The objective of this paper is to gain a deeper understanding of MAORAs and how to implement them. This is achieved through a state-of-the-art literature review of articles published in academic journals. Only in exceptional cases have we cited conference papers. We have used both google scholar and web of science (ISI) with a variety of keywords to aid us in finding all recent and relevant references. Our focus is on recent trends in this research, mainly iterative reverse auctions. We deal with issues such as buyer–seller relationships and information revelation, among others. We only briefly comment on the state-of-the-art in practice. The auctions that we discuss are primarily targeted for human users and not software agents, although many of the auction formats allow humans to use a (computerized) proxy. Our paper builds upon Teich, Wallenius, Wallenius, and Koppius (2004).

The rest of the paper is organized as follows. To lead the way to more complex multi-attribute auctions, the two-attribute A+B auctions are briefly covered in Section 2. Section 3 presents a classification of online multi-attribute reverse auctions. A general description of MAORAs is provided in Section 4. Important preference elicitation schemes are reviewed in Section 5. Research trends in MAORAs over the last decade are described in Section 6. The paper concludes in Section 7. A short glossary is provided to aid the reader with the terminology.

2. A+B auctions

A+B auctions, also known as cost/time auctions, are two-attribute sealed bid procurement auctions, where bidding takes place on cost (A) and time to deliver (B). Such auctions have been described by Ellis and Herbsman (1990), Herbsman and Ellis (1992), and Herbsman (1995). The A part of the equation is the bidder’s cost and the B part is the estimated time, which is then multiplied by the Road User Cost (RUC) in highway construction projects. The RUC incorporates attributes such as “traffic delays (time, distance) and agency costs, such as inspection, and other elements” (Herbsman, 1995). The winner of the auction has the “lowest combined bid” which incorporates the actual cost of the project (A) plus the cost of the time of the project (B × RUC). If the project is not completed by the contractor’s time estimate, then the contractor may be penalized by the number of days late × RUC, and likewise, if the project is completed early, there may be an incentive, i.e. days early × RUC (Herbsman, 1995).

Herbsman (1995) claims that these cost/time bidding systems have been used since around 1980 by early users such as the US Army Corps of Engineers. In 1991, the US Federal Highway Administration encouraged the states’ Departments of Transportation to begin experimenting with these auctions (Herbsman, 1995). The success of the A + B auctions in highway construction projects is pretty clear. Herbsman (1995) compared 101 projects using this bidding system to projects where only the lowest bid was awarded. He concluded that in most cases there were savings in construction time costs without additional project costs themselves. More recently, Gupta, Snir, and Chen (2014) report similar results based on 38 projects of the Minnesota Department of Transportation. Additionally, similar results were reported by Lewis and Bajari (2011) based on over 1300 projects awarded by the California Department of Transportation.

3. A classification of online multi-attribute reverse actions

An auction is a common name for transactions where the price is discovered through a competitive bidding process. An auction determines how the winner is determined, how the payments of the winning bidder(s) are determined, and how the bid information is collected from the bidders. Auction literature recognizes four basic mechanisms, which are most commonly used: the English auction, the Dutch auction, the first-price sealed-bid auction, and the second-price sealed-bid auction (also known as the Vickrey auction). These basic mechanisms are special cases of the generic mechanism. For a discussion and definitions see Milgrom (2004), Parsons, Rodriguez-Aguilar, and Klein (2011), Teich et al. (2004).

The basic mechanisms, although originally defined for single item and price-only auctions, can be extended to more complex settings, e.g., settings with multiple attributes. Interestingly, most auction mechanisms used in practice contain elements of one or more of the four basic mechanisms. Teich et al. (2004) provide a comprehensive classification of auction situations based on 18 characteristics. The first four characteristics concern the number and nature of the good(s)/services to be auctioned. Characteristics 5–14 deal with the auction rules and format. Characteristics 15–18 are related to the nature and composition of bids.

(1) Number of items of a good/service auctioned
(2) Number of goods/services auctioned
(3) Nature of goods/services (homogenous, heterogeneous)
(4) Number of attributes
(5) Type of auction (forward, reverse)
(6) Nature of auction (one-round or progressive)
(7) English vs. Dutch auction (ascending vs. descending price)
(8) Who can participate (by invitation vs. open to anybody)?
(9) Are agents used or not?
(10) Price paid by winner (first price, second price, etc.)
(11) Is price discrimination applied (yes or no)?
(12) Do constraints exist (explicitly, implicitly)?
(13) Is there a follow-up negotiation?
(14) Is a value function elicited for the buyer?
(15) What is the nature of bids (open cry, semi-sealed, sealed)?
(16) Dimensionality of the bid vector (1, 2, or n-dimensional)
(17) Are bids divisible?
(18) Are bundle bids allowed?

We concentrate on the online single-lot (contract) and not-single lot reverse English auctions with multiple attributes. A single-lot auction often refers to a contract, for example building a bridge or a highway stretch (with specified qualifications). The single-lot auction typically has multiple units of a product supplied by only one supplier. The not-single-lot auction includes multiple winners in the event. Hence the key demarcating feature is the number of winners.

4. A generic description of MAORAs

We consider a situation where the buyer makes an announcement that she would like to organize an auction for contracts or acquire a given quantity of a good/service and asks (invited) suppliers to submit their bids based on k attributes of the item. A bid vector consists of k dimensions. This usually includes price and the level of each of the other attributes. If quantity is relevant, it should be treated separately, since it is by nature different from the other attributes. A contract usually defines such terms.

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5 If one compares this list with that provided in the Teich et al. (2004) article, one notices that consolidation has taken place in the marketplace. Moreover, several companies who were early players, no longer are in business.

6 Negotiations are not considered as auctions, although auctions may incorporate features of negotiations.

7 Strictly speaking, homogenous goods do not have quality differences. However, they may be of interest for MAORAs because of differences in delivery terms and warranties. A contract usually defines such terms.
the buyer prefers better levels in the non-price attributes. In cases of non-price attributes, such as color, where there is not a natural order regarding what is considered "better", the auction owner should specify the preference order.

MAORAs allow for each bidder to iteratively submit several bids. Each bid is assessed by the buyer. If a scoring rule is used, the assessment can be based on it. The scoring function assigns each bid a score, based on which the bids can then be ranked. The concept of a scoring function is similar to that of the value function (utility function). Commonly used scoring functions are additive or quasi-linear (Beil & Wein, 2003; Bichler, 2001; Chen-Ritzo, Harrison, Kwasnica, & Thomas, 2005; Kersten, 2014; Parkes & Kalagnanam, 2005). Interestingly, Kersten (2014) shows that reverse auctions may cause a significant loss of social welfare in case utility functions are not quasi-linear.8

All the bidders with ‘active’ (winning) bids at the end of the auction are obliged to deliver their respective amounts of the item with the agreed upon technical specifications and delivery terms.

A reservation price is usually applied by the MAORA owner, above which she is not willing to pay. The MAORA owner can apply different reservation prices for different quantities. In addition, relevant attributes of the MAORA must be specified. Moreover, the size of the bid decrement must be specified by the MAORA owner9 – and whether a fixed bid decrement is applied throughout the MAORA.

The European Union has adopted a new public procurement directive stating that buyers must provide weights for the attributes (a scoring function) or lexicographically order the attributes (Article 55 in 2004/17/EC and Article 53 in 2004/18/EC; see also Kersten, 2014). Buyers need to make sure that the scoring function reflects their preferences. Bausa Peris et al. (2013) identified and studied 28 e-procurement platforms in the European Union. They also provide guidelines for best practices.

5. Preference elicitation schemes

Several scholars have developed tools which support the decision making process in a MAORA, from the point of view of the bidder. We list some such tools:

- “Suggested price” (to make bid ‘active’) and information on “bid status” (Teich, Wallenius, Wallenius, & Koppius, 2001, 2006)
- Eliciting “bid taker’s preferences”, providing information on “current best bid” and “bid status” (Bichler, 2000; Chen-Ritzo et al., 2005; Strecker, 2010; Strecker & Seifert, 2004)
- “State of competition” measure and “how to improve the bids” (Koppius & Van Heck, 2003)

Because eliciting buyer’s preferences is central to MAORAs, we review some common schemes for accomplishing this. For additional information, please consult Butler, Dyer, Jia, and Tomak (2008), who present useful preference elicitation models (AHP, conjoint analysis, and multi-attribute utility assessment) that can be used in E-commerce, including reverse auctions.

5.1. Scoring functions

Scoring functions simply refer to the use of weights to aggregate multiple attributes to a single composite score. Technically, a scoring function is simply an additive linear utility (or value) function over the different attributes. This is probably the most common preference elicitation scheme used in practice (see the EU directive previously mentioned). But how do we estimate the weights for price, quality, deliver terms, etc. in such a linear function? We suspect that in many cases in practice, the buyer is just asked to furnish such weights. There is literature, however, which demonstrates that it is preferable to estimate such weights based on linear comparisons of bid vectors (Korhonen, Silvennoinen, Wallenius, & Örnni, 2012). Simply put the value difference between alternative vectors b1 and b2 (including price, and assuming that b1 is preferred over b2) greater than or equal to ε, and maximize ε. This operation maximizes the minimum value difference among the pairwise comparisons. Alternatively, one could use one of the value function estimation techniques, such as the mid-value splitting technique explained in Keeney and Raiffa (1976).

5.2. ‘Pricing out’

According to Keeney and Raiffa (1976, p. 125), in many contexts (though not in all) it is natural to ‘cost out’ or ‘price out’ all non-price attributes. This has the great advantage of simplifying the bids to price and quantity (if quantity is relevant). Teich et al.’s (2001, 2006) NegotAuction system is based on ‘pricing out’ all non-price attributes.

To price out, single out some base case profile x∗ (where x refers to the vector of non-price attributes) and ask:

Starting from the profile x0, how much would you be willing to pay to change x0 to the base case x∗. If the number of vectors x0 to be compared is limited, we could rank the vectors in terms of ‘willingness to pay’.

The procedure tremendously simplifies, if the following two assumptions hold: (1) The monetary attribute considered jointly with any other (single) attribute is preferentially independent of the complementary set of attributes. (2) The monetary tradeoffs are functionally independent of the monetary level. Then we can ‘price out’ each attribute separately.

We illustrate with a simple example. Assume that a product being procured has three levels of quality: A, B, and C (A best). In ‘pricing out’ the quality dimension, the buyer would simply be expected to let the suppliers know, how much (more) she would be willing to pay for better quality levels (A and B) compared with the baseline quality C. The answer would be per unit. (The underlying assumption is that there would be industrial quality standards, such as ISO; or quality would have to be carefully defined by the buyer.) Similarly, we could ‘price out’ differences in delivery terms. If the acceptable delivery time for a component is 4 weeks, and some of the suppliers could deliver in 2 or 3 weeks, the buyer would be expected to let the suppliers know how much more (if anything) she would be willing to pay (per unit) for goods delivered in 2 or 3 weeks. In a similar fashion, we could ‘price out’ all non-price attributes.

6. Recent research trends

MAORAs, by taking non-price attributes into consideration, are designed to deal with the limitations rooted in online reverse auctions which have only focused on price. With MAORAs, the buyer and suppliers hope to save time and money through a more effectively structured process. In addition, in MAORAs, the rules and procedures are clearly specified, based on which bids submitted by suppliers are evaluated. MAORAs can be implemented for single unit, multiple unit, or even multiple item, auctions.

We classify recent research dealing with MAORAs into four groups:

1. Decision- and game-theoretic contributions
2. Experimental economic performance comparisons between different auction formats
3. Testing different policies on information disclosure
4. Comparing negotiations and auctions and integrating them

Different studies use different performance metrics. Some use allocational efficiency, some Pareto efficiency, some efficiency as in the connection with the number of bids.
Multiple Criteria Decision Making (MCDM) literature sense. We try to be careful regarding what the authors mean by economic performance of auctions. The glossary at the end of the paper provides the necessary definitions.

Combinatorial (multi-item) auctions are a very active area of research, attracting scholars from different fields (operations research, computer science). Classic examples of such auctions are the FCC auctions for radio bandwidth. In such auctions the bidders bid for a combination of goods/services (a bundle), utilizing synergies in production. However, because of the amount and specificity of this research we leave it outside the scope of our paper. Combinatorial auctions have been reviewed by De Vries and Vohra (2003), Cramton, Shoham, and Steinberg (2006), and Leskelä (2009), among others.

6.1. Decision- and game-theoretic contributions

6.1.1. Early work

Staschus et al. (1991), while working at the electric utility company PG&E, published an article on a multi-attribute auction formulation to evaluate bids from suppliers. The framework was programmed into a Lotus 1-2-3 spreadsheet, and shared with the potential suppliers. All attributes were ‘priced out’ for the suppliers, so they could easily evaluate their own bids. It is not clear from the paper whether these “bids” were collected by sharing an emailed file, and whether there was competitive, iterative bidding, or if this was simply a framework they built and it was never applied in practice. However, we believe this was the first paper published in an academic journal on multi-attribute auctions.

Herbsman and Ellis (1992) developed a simple multi-attribute reverse auction system for highway construction projects, although their system is generic and can be used in any multi-attribute reverse auction setting. They suggested using ‘pricing out’ all attributes besides cost and simply adding up the ‘priced out’ values. They go into detail, how one should measure non-cost attributes in the highway construction context, which is obviously a critical aspect. The authors also suggest using weights to add up different attributes. However, if they have been ‘priced out’, there is no need to use weights.10

Another pioneer in multi-attribute auctions is Che (1993), who in a theoretical paper investigated design issues for two-dimensional (price and quality) single lot auctions. In Che’s model there is one important assumption, namely that costs are independent across suppliers. Branco (1997), among others, has challenged this assumption and studied an optimal auction mechanism for single unit procurement auctions where the costs of suppliers were assumed to be correlated.

We divide the literature in this section into single-lot (or contract) versus not-single-lot auctions.

6.1.2. Single-lot or contract auctions

Che’s auction model has been further developed by Beil and Wein (2003). The buyer is assumed to know only the form of the suppliers’ cost functions, but does not possess information on the specific parameter values. The buyer uses the bids iteratively to learn about the suppliers’ cost functions, and in the final round maximizes her/his scoring function.

Also inspired by Che (1993), Parkes and Kalagnanam (2005) develop an iterative reverse auction mechanism for the special situation of linear, additive cost structures (for suppliers) and a linear, additive utility function for the buyer. The authors show that this kind of iterative mechanism brings about an equilibrium outcome for the modified Vickrey–Clarke–Groves (VCG) auction.

Narasimhan, Talluri, and Mahapatra (2008) study reverse auctions from the suppliers’ perspective. Suppliers are required to infer the unknown preferences of the buyer in order to be able to bid. A number of multi-attribute models for developing effective bidding strategies from a losing supplier’s perspective based on the past winning quotes are proposed. This approach takes a broad view towards strategic procurement. Also see Saroop, Sehgal, and Ravikumar (2007), who develop a two-phase auction mechanism that guides the bidding but limits the information disclosed about the buyer’s preference function.

Kostamis, Beil, and Duenyas (2009) compare two auction formats: open-cry reverse auction versus sealed bid auction. They use cost adjustments on non-price attributes (such as quality), bearing resemblance to the ‘pricing out’ mechanism. They show that if there are differences in cost adjustments and some suppliers have high cost adjustments, then one should use the open-cry (open-bid) auction instead of the sealed bid auction format.

Wang, Liu, Wang, and Lai (2010) propose two models for multi-attribute contract auctions where each bid is normalized, then using the weighted product method, each bid receives a score. The two models are compared on equilibrium bidding strategies, buyer’s revenue, and optimal auction design.

Perrone, Roma, and Nigro (2010) develop a project management approach to designing multi-attribute contract auctions for standardized engineering services procurement in the context of the automotive industry. The authors determine optimal suppliers’ bidding strategies and expected outcomes. A simulation was also conducted by the authors to study sensitivity issues.

Engel and Wellman (2010) develop multi-attribute auctions with generalized additive independent preferences to accommodate non-additive trader utility functions. In a simulation study they found that by allowing traders to express dependency among attributes they improve the economic efficiency of the event.

Karakaya and Köksalan (2011) develop an interactive approach supporting both the buyer and the bidders in a multi-attribute, single-item, multi-round, reverse auction environment. The authors estimate the parameter values of the underlying preference function of the buyer using his/her past preferences. The estimated preference function values are iteratively improved and the bidders are informed about them. Then the bidders update their bids and the auction continues, until no supplier profits from continuing the bidding.

Bellosta, Kornman, and Vanderpooten (2011) propose a general framework allowing for the definition of numerous Multiple Criteria English Reverse Auction mechanisms (MERA). Adopting ideas from the behavioral decision theory literature, they consider various preference models, allowing for intransitive and incomparable preference structures. According to the authors, such preference models are common in practice. The authors claim that their work is the first milestone, providing autonomous buyer and seller agents a way to interact. See also Yang, Liao, and Huang (2014), who elicit buyer’s preferences via binary comparisons, resembling ideas in MCDM. Shi (2013) proposes a sealed bid multi-attribute contract auction protocol that pays special attention to security issues, namely bid privacy and bidder anonymity.

6.1.3. Not-single-lot auctions

Following their earlier work (Teich, Wallenius, & Wallenius, 1999), Teich et al. (2001, 2006) develop the Negotiauction system, combining features of auctions and negotiations. They use the ‘pricing out’ technique, which is an established technique used by practicing decision analysts, where all other attributes besides price (and quantity) are priced out. The authors argue that this technique is simple and useful, making bids essentially two-dimensional (price and quantity). They also allow the buyer to introduce constraints on the attribute levels and the suppliers themselves. This process also allows price discrimination among the suppliers, without their knowledge.

10 The authors provide an interesting brief description of the long history of price-only auctions in the United States, and why historically one has wanted to award the contract to the lowest bidder. Obviously, both the Staschus et al. (1991) and Herbsman and Ellis (1992) models were from the pre-Internet era.
Sandholm (2006a) has introduced a commercial paradigm called ‘expressive commerce’, which he has also applied to sourcing. He also allows price discrimination and the insertion of constraints. Specifically, in his view, supply and demand should be expressed in much greater detail than in traditional online auctions, generating a Pareto efficient improvement in the allocation of goods. The allocation problem is very likely to turn into a highly complex combinatorial optimization problem. Algorithms for solving such a problem have been developed by the author (Sandholm, 2006b). Sandholm (2013) describes how his expressive bidding auctions have been implemented in hundreds of advanced auction events (most involving multiple items) at the company he founded, CombineNet.11

Bichler and Kalagnanam (2005) investigate issues related to ‘configurable offers’ in MAORAs. Configurable offers enable suppliers to specify optional values for each attribute, also using propositional logic statements, providing additional flexibility over fixed bids. Besides bringing about more flexibility in the specification of the bids, they make efficient information exchange among market participants possible. The authors also establish a multidimensional auction platform, which includes a generic Java Application Programming Interface (API) that can be used for different allocation mechanisms and an Extensible Markup Language (XML) schema, allowing for the definition of various kinds of bids. With such a framework, one is able to specify buyer preferences, allocation rules and supplier offerings. This approach has many similarities with the theoretical framework constructed by De Smet (2007), although he focuses on the single contract, with an example of mortgage loans.

Talluri, Narasimhan, and Viswanathan (2007) focus on the preference elicitation by combining Data Envelopment Analysis (DEA) with an integer programming model. The DEA model allows the buyer to specify inexact preferences for the attributes. The integer programming model solves the Winner Determination Problem for multisourcing reverse auctions.

Cheng (2008) presents a model for solving the sealed-bid, multiple-issue reverse auction problem by using a specific Multiple Criteria Decision Making approach. The process for constructing bids is formulated as a fuzzy multiple-objective programming problem. The supplier is assumed to be able to accurately estimate her production costs together with specific delivery dates. The Winner Determination Problem is considered a multiple-attribute decision problem, and is solved with the TOPSIS method (Technique for Order Preference by Similarity to Ideal Solution). A related reference is Chan, Shukla, Tiwari, Shankar, and Choy (2011), who use an evolutionary algorithm to solve the Winner Determination Problem formulated as a Goal Programming model. See also Kameshwaran, Narahari, Rosa, Kulkarni, and Tew (2007). Singh et al. (2011) describe the TOPSIS method approach, but in a single-lot context with sole sourcing.

Ray, Jenamani, and Mohapatra (2011) develop a multi-attribute procurement methodology for the case of a limited supplier base. They propose awarding a small part of the contract to all of the participants as an incentive to keep them as suppliers, but also propose a penalty scheme to keep all participants honest. Their simulation study shows that their proposed mechanism provides higher utility to the buyer compared to the case where no incentives are provided.

Rao, Zhao, and Ma (2012) in their auction mechanism focus on homogenous, divisible goods, incorporating multiple attributes. The result may involve multiple sources. The mechanism is based on using the minimum bid increment method and the suppliers are assumed to provide their actual cost structures truthfully to improve the efficiency of the allocation. They also present an example about auctioning coal for a power plant. See also Rao and Wu (2012).

Synthesis: The approaches presented do not in general assume explicit knowledge of the buyer’s value function or the suppliers’ cost functions. Instead, there is a Multiple Criteria Decision Making literature focusing on developing iterative (interactive) schemes to learn these functions over time. The single-lot or contract auctions are sole-sourced, whereas the multi-unit auctions developed can either be sole-sourced or multi-sourced. The Winner Determination Problem is more complex in case of multiple unit auctions, resulting in a need to use optimization algorithms.

6.2. Experimental economic performance comparisons between single-attribute versus multi-attribute auction formats13,14

Among the first researchers to experimentally investigate MAORAs was Bichler (2000). In his study, the Vickrey and the English auction consisting of bids with one and two attributes were examined. He showed that the overall utility achieved in a multi-attribute format was higher than in the single attribute auction. Additionally, the efficiency was similar in both auction formats, measured via the percentage of auctions where the highest value holder wins the item.

An economic performance comparison between a three-attribute, reverse English auction and a corresponding price-only auction is conducted by Chen-Ritzo et al. (2005). Their research is implemented in the laboratory context and the findings show that the economic performance is influenced by bidder experiences and that the dominant strategy expectation in these auctions is not realized. Their multi-attribute auctions have the special characteristic that the bidders do not know the scoring function of the buyer but are given information regarding it. The main finding of the paper is that the multi-attribute mechanism results in higher utility for both suppliers and the buyer compared to the price-only auction. The findings further show that allocational efficiency varies tremendously (from 25 to 75 percent) among inexperienced bidders, depending on their capability to use the buyer’s preferences elicited. As for experienced bidders, allocational efficiency is achieved in three of the four settings. In addition, it is observed by the researchers that 100 percent Pareto efficiency is earned by inexperienced participants; however this level is not far from the theoretical maximum.

A comparison of buyer-determined and price-based multi-attribute mechanisms has been conducted by Engelbrecht-Wiggans, Haruvy, and Katok (2007). Under both mechanisms, bidders bid based on price, but in the buyer-determined mechanism, the buyer is free to select the bid that maximizes her surplus, while in the price-based mechanism, the buyer commits to awarding the contract to the lowest priced bidder. The authors show that the buyer-determined mechanism is able to increase the welfare of the buyer in cases where there is adequate competition from a large number of suppliers. In situations where the number of suppliers is insufficient and there is a low correlation between cost and quality, the buyer is better off with the utilization of the price-based mechanism.

Synthesis: Note that all auction formats discussed in this subsection are single unit or single lot. Obviously the multi-attribute and single

11 CombineNet has recently been acquired by SciQuest. See the press release link http://investor.sciquest.com/releasesdetail.cfm?ReleaseID=788431.
12 XML is a markup language similar to HTML; however, XML was designed to transfer data, not to display it.
13 A laboratory study has been conducted by Strecker and Seifert (2004) to compare a multi-attribute reverse English auction and a multi-attribute reverse second score sealed-bid (Vickrey) auction. In the English auction variant, instant information feedback is provided to the bidders, whereas the Vickrey auction is viewed as a one-shot, sealed-bid procedure. The authors confirm that the multi-attribute reverse English auction is very likely to result in a higher allocative efficiency and buyer’s surplus than the multi-attribute Vickrey auction. This result is in line with earlier experimental findings in multi-attribute reverse auctions (Bichler 2000). The authors strongly recommend that buyers should apply the English auction format when implementing a multi-attribute auction for e-procurement.
14 Asker and Cantillon (2008), in a theory paper, show that scoring auctions (multi-attribute auctions using a scoring function) dominate over several other types of auctions, for instance price-only auctions with minimum quality thresholds.
attribute auction methods tested are different as well as their computer interfaces. Likewise the performance measures are different, for example, some focus on allocational efficiency, some on Pareto efficiency and others on revenue or cost equivalence among auction methods. At any rate, the common finding is that the multi-attribute auction generates higher utility than the price-only auction format (there are exceptions though, e.g., Engelbrecht-Wiggans et al., 2007), although we may not fully understand the circumstances when this is true.

6.3. Testing different policies on information disclosure

Information feedback in auctions can range from full transparency, to no transparency (Gupta et al., 2012). In full transparency all bids are disclosed to all bidders (although not typically the identity of the bidder). In case of no transparency (also called sealed-bid auctions), the bids are not disclosed to other bidders. Koppius and Van Heck were one of the first to systematically study the impact of different information disclosure policies on multi-attribute auctions. Two different policies on information disclosure used in a three-attribute English reverse auction with multiple rounds and four bidders have been explored by Koppius (2002) and Koppius and Van Heck (2003). The findings show that allocative efficiency is substantially increased if more information on the buyer’s preferences and the bidders’ submissions is disclosed. At the same time, this kind of information policy is very likely to reduce the number of Pareto improving bids left when the auction ends. Nevertheless, it is surprising that the number of Pareto efficient outcomes is not influenced by this kind of information policy. As for the restricted information policy, 21 percent allocative efficiency and 63 percent efficiency regarding actual gains realized from trading are achieved which can be considered rather low. In addition, under the restricted information policy, among the total outcomes, only some 30 percent are Pareto efficient.

Preference revelation in MAORAs has been investigated in a laboratory study by Strecker (2010). In this study, procurement via a multi-attribute reverse English auction in cases of non-disclosure and full disclosure of buyer’s preferences in the form of a scoring rule are compared. In situations where the scoring rule is kept secret, bidding can be considered as an unguided, exploratory process in which bidders are expected to follow an ad hoc, trial-and-error strategy. Strecker confirms that preferences revealed by the buyer are likely to result in higher allocational efficiency and Pareto efficiency of auction outcomes and can thus be considered to be in line with earlier experimental evidence (Koppius & Van Heck, 2003). Finally, the author concludes that attracting more suppliers to compete in an auction increases the level of competition that is likely to elevate revenue for the auctioneer in standard price auctions and is thus likely to elevate utility for the buyer in MAORAs as well.

Adomavicius, Gupta, and Sanyal (2008, 2012) investigate feedback schemes for multi-attribute procurement auctions. Specifically, novel feedback schemes for multi-attribute auctions are developed by the authors aimed at protecting the buyer’s preference information from the suppliers and suppliers’ cost schedule from the buyer and other suppliers. A laboratory experiment to study bidder behavior and profit implications under three different feedback regimes is conducted. The results indicate that bidders are able to earn more profit if they can extract more information about the state of the auction. Furthermore, bidding behavior is shown to be much influenced by the nature and type of feedback.

Haruvy and Katok (2013) have conducted an experimental study to investigate the impact of two issues on the auction outcome: (1) the impact of bidder quality and the effect of this quality transparency, (2) the effect of price visibility. One managerial implication of their study is that one should prefer sealed bid auctions over open bid auctions, because these generate higher levels of buyer surplus. However, if open bidding is used it is better to avoid revealing the identity of bidders to other bidders.

In a laboratory experiment, Gwebu, Hu, and Shanker (2012) show that by reducing information asymmetry and by releasing “certain information” the auction owner reduces bidder drop out rates. They also obtained better results, i.e. higher utility bids for the buyer by releasing additional information. Gwebu (2009) showed that it is important to build decision support tools to facilitate every stage of the bidding process.

Synthesis: Clearly, the more information is revealed in particular about the buyer’s preferences, the better the auction outcome. However, there is a need to strike a balance between disclosing too little or too much information due to privacy issues (Gupta et al., 2012, see also Greenwald, Kannan, & Krishnan, 2010).

6.4. Comparing negotiations and auctions and integrating them

6.4.1. Comparing negotiations and auctions

Bulow and Klemperer (1996) compare price-only auctions versus negotiations from an economics standpoint. They conclude, under a set of assumptions, that if there is an auction (in a forward auction) there has at least one extra serious bidder to appear in an auction event, then generally one should not negotiate but directly begin an auction.

Kersten, Pontrandolfo, Vahidov, and Gimon (2012) discuss an on-going project involving an experimental comparison of auction and negotiation mechanisms. The experiments take place in an e-business context which resembles real-life e-procurement situations (transportation service procurement). Kersten, Vahidov, and Gimon (2013) study different concession-making patterns in experimental multi-attribute negotiation and auction settings. In the auction settings concession-making behavior is more likely to lead to Pareto-optimal behavior. However, they also suggest that because of greater transparency of negotiations, these lead to “better” agreements. See also Pontrandolfo, Wu, Moramarco, and Kersten (2010).

Pham, Zaitsev, Steiner, and Teich (2013) conducted a laboratory study with human subjects using the NegotiAuction system of Teich et al. (2001, 2006). They placed subjects in three modes, namely all bidders in the ‘auto mode’ (auction), all bidders in the ‘manual mode’ (negotiation) and some bidders in the ‘auto’ and some in the ‘manual mode’, in the same mixed event. For buyers, cost savings and allocational efficiency were highest in the mixed event on average. For suppliers, profits were highest on average, in pure ‘auto (auction) mode’ events.

6.4.2. Integrating auctions and negotiations

As we have previously stated, it is not uncommon in practice for auctions to focus on price, and once the auction event has ended, begin a negotiation between the buyer and the top suppliers regarding other attributes. This is, however, not the best way to conduct auctions/negotiations. There is a growing number of non-economists who see value in better integrating negotiations with auctions. Examples include research on the NegotiAuction system (Teich et al., 2001, 2006; see also Subramanian’s book 2010), and the studies of Benyoucef, Alj, Vézeau, and Keller (2001), Shakun (2005), David, Azoulay-Schwartz, and Kraus (2006), Chen, Kersten, Neumann, and Vahidov (2009), Chen and Tseng (2010), Huang, Kaufman, Xu, and Zhao (2011), Kersten et al. (2012, 2013) and Hindriks, Tykhonov, and de Weerdt (2012):

Benyoucef et al. (2001) develop a system that could handle multiple simultaneous negotiations, where the negotiations are linked to one another. They compare their system to synchronized auctions and provide an example of putting together a vacation package.

There exist several papers which discuss hybrid auction-negotiation mechanisms, yet focus on a single attribute (price). We do not discuss such papers in depth. An example is Engelbrecht-Wiggans and Katok (2006).
Shakun (2005) describes a multi-issue, multi-bilateral negotiation, where buyers and sellers conduct pairwise multi-attribute negotiations, followed by an optional auction.  

David et al. (2006) have extended the traditional MAORA auction mechanism, by allowing for negotiation on non-price attributes. Three auction protocols for sourcing of multi-attribute items are discussed: a variation of the first price, sealed-bid protocol, a variation of the second price, sealed-bid protocol, and a variation of the English auction protocol. The authors develop a specific model for these protocols and identify optimal and stable strategies for both the bidders and the buyer. In addition, the auctioneer’s/buyer’s expected payoff is examined in order to give suggestions regarding an optimal scoring rule.  

Cheng (2008) develops a bi-level distributed programming method for the sealed-bid reverse auction problem, combining aspects of negotiations. In his model, the buyer represents the upper level decision maker.  

Chen and Tseng (2010) have developed a hybrid negotiation-credit-auction (NCA) that separates the design elements of a contract in a negotiation round involving multiple attributes from an auction round, where an English reverse auction provides competition among the potential contractors. The authors claim that their NCA mechanism provides a balanced result between efficiency and utility maximization.  

Huang et al. (2011) study the efficacy of post-auction negotiations. They compare a fixed quality mechanism where the quality is set by the buyer for the auction to a negotiable quality mechanism. A bonus stage follows, where quality can be improved. They find that negotiation improves the supply chain’s surplus and generates the possibility of Pareto optimal improvements over price-only auctions.  

In Hindriks et al. (2012) model, multiple round bilateral negotiations are conducted with each of the sellers. They propose three variants of their method, one where offers are restricted in each round, another where the winning offer is announced in each round and the third where the seller is told only if they are the winner or not in that round. They show, experimentally, that the outcomes of the negotiations approximate Pareto-efficient auction outcomes.  

Synthesis: The hybrid aspects of integrating auctions and negotiations together are still in a developing stage. Subramanian (2010) discusses many real-world examples of such integration without the use of systems. However, there have not been many examples of using hybrid methods and systems in practice, although it is fairly common to conduct an auction first and end it in a follow-up negotiation with one or more of the bidders.

6.5. Implementing online procurement auctions in practice – a learning process

Online procurement auctions were expected to dramatically change the way companies select their suppliers. Despite high expectations, many challenges in implementing such auctions in practice remain. There are interesting papers by Hur, Hartley, and Mabert (2006) and Schoenherr and Mabert (2007), which discuss real-world implementation issues. We briefly comment on both papers. Note that strictly speaking both papers deal with price-only auctions. However, it is clear that companies surveyed in the papers consider other attributes in addition to price. We feel that useful lessons for MAORA auctions can be learned from these two studies. See also Elmaghraby (2007).

The first paper describes how e-auctions were adopted and used in five large US companies, representing diverse industries. Interviews with supply managers revealed that implementing e-auctions is a learning process – and a challenge for companies. However, it can be of great advantage. The authors talk about five “enabling practices”, namely building e-auction competencies, organizing for knowledge management, creating a holistic sourcing process, focusing on Total Cost of Ownership (TCO), and experimenting with different e-auctions. The first question an organization faces is whether it should develop its own competence in the area, or whether to resort to out-sourcing. Normally organizations start by outsourcing, but at some point switch to developing in-house competencies. Another lesson is that e-auctions should be integrated into the organization’s TCO strategy. In other words, sourcing decisions should consider all costs, including transportation, service, warranty, as well as buyer’s switching (of suppliers) cost (in other words, multiple attributes). The organization should learn from the auctions. Not all auctions are successful. The organization should study the aspects which make the auctions successful and learn from these. Furthermore, one needs to tailor the auctions according to situational characteristics where appropriate!

The Schoenherr and Mabert (2007) paper discusses five most common myths regarding online reverse auctions. They are:

1. Reverse auctions are only about the price
2. Reverse auctions are suitable only for commodities
3. Reverse auctions damage the buyer-supplier relationships
4. Over time, savings in repeat reverse auctions will decrease
5. Reverse auctions are a passing fad

They provide convincing evidence challenging each myth. They also provide best practices how to overcome the myths when using online procurement auctions. The data is based on 30 case study companies.

7. Conclusion

We have discussed the latest academic developments in multi-attribute online reverse auctions (MAORAs). We believe that price-only reverse auctions have limitations and multi-attribute online reverse auctions (MAORAs) can overcome them (also see Gupta et al., 2012). A bid-taker determines the attributes of an item she wants bidders to submit bids on, such as price, quality, warranty, and delivery time, to name a few. Each bid submitted gives the bid-taker a certain level of utility, with higher levels of utility being preferred to lower levels. After several rounds of bidding, the contract to supply the auctioned items is awarded to the bidder(s) who is (are) able to submit a combination of attribute values which generates the highest level of utility for the bid-taker (in theory).

Recently presented MAORA mechanisms have several common features. Firstly, they assume that the buyer’s preferences can be represented with an implicit or explicit utility function (scoring function). Related to the above, almost all research on MAORAs assumes that scoring functions are additive or quasi-linear in order to allow easy modeling of a buyer’s preferences. Thirdly, care is taken by mechanism designers, what information should be revealed to other bidders/the bid-taker. If a mechanism suggests revealing too much sensitive information, say about the cost structure of bidders, it is not likely to be used in practice. However, the auction benefits from revealing the buyer’s preferences. Although there is evidence that MAORAs are superior to the price-only online reverse auctions, there are a number of questions that need to be answered. First, taking scoring functions as given has been criticized by several researchers over the years. It is difficult to elicit one’s preferences in a form which can be converted into an accurate utility or value function. As we have discussed, there are alternative ways to elicit the buyer’s preferences.

A common further limitation of MAORAs is that they pay too much attention to competition from the same-side-of-the table dynamics (supplier side), but ignore competitive pressures from the across-the-table dynamics (supplier–buyer interactions) (Subramanian, 2010). Another interesting future research question would be to survey the extent to which MAORAs are being used in practice and to try to understand why some auctions have been successful, while others have not.
We would like to conclude by highlighting the importance of two areas of auctions for OR modeling. The first concerns combinatorial auctions and bidder support for them (Leskelä, 2009; Sandholm, 2013). The second is about analyzing and developing good bidding strategies for online auctions. There exist some studies dealing with bidding strategies, but since they do not generally discuss problems with multiple attributes, we do not elaborate them further in this paper (Puro, Teich, Wallenius, & Wallenius, 2011).

References


Glossary

A+B auctions: Two-attribute auctions, where bidding takes place on cost (A) and time to deliver (B); extensively used in the US Department of Transportation (DOT) highway construction contracts.

Allocative efficiency: The sum of the producer and consumer surplus resulting from the auction, divided by the sum of the producer and consumer surplus, which would be realized if the bidders with the highest valuations received the contract.

The bid decrement: The desired reduction in price (or total cost) from one bid to the next.

Pareto optimality (efficiency): The auction outcome is Pareto optimal (efficient) if and only if there is no other outcome that is preferred by all parties.

Price discrimination: Buyer pays different prices for different suppliers for the same good/service.

Pricing out: Eliminating attributes by expressing them in monetary units.

Quasi-linear utility function (of the buyer): Nonlinear utility (or value function) of all attributes except price minus price \( u - p(k) - p \), where \( p \) represents price, and \( x \) the vector of all other attributes besides price.

Winner determination problem: Given a set of bids, determining who wins the auction.

(For additional definitions, see Teich et al. 2004.)