E-Business Oriented Optimal Online Auction Design

Anshi Xie

Yijun Li

Yong Li

E-Business Oriented Optimal Online Auction Design

Anshi Xie[1], Yijun Li[1], Yong Li[2]

[1]School of Management, Harbin Institute of Technology, Harbin 150001, China
[2] Bio-Chemical Engineering College, Beijing Union University, Beijing 100023, China
[1]Stanford@hit.edu.cn, [2]chestnut_ly@sohu.com

ABSTRACT

Online auctions, in the absence of spatial, temporal and geographic constraints, provide an alternative supply chain channel for the distribution of goods and services. This channel differs from the common posted-price mechanism that is typically used in the retail sector. In consumer-oriented markets, buyers can now experience the thrill of 'winning' a product, potentially at a bargain, as opposed to the typically more tedious notion of 'buying' it. Sellers, on the other hand, have an additional channel to distribute their goods, and the opportunity to liquidate rapidly aging goods at greater than salvage values. The primary facilitator of this phenomenon is the widespread adoption of electronic commerce over an open-source, ubiquitous Internet Protocol (IP) based network. In this paper, we derive an optimal bidding strategy in sequential auctions that incorporates option value assessment. Furthermore, we establish that our optimal bidding strategy is tractable since it is independent of the bidding strategies of other bidders in the current auction and is only dependent on the option value assessment

Keywords: online auction; optimal auction; mechanism design

1 INTRODUCTION

1.1 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.

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.

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 reverse auction system. Buyers are on a good wicket, and sellers bid for commodity.

1.2 Auction online

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.

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.

Business-to-consumer online auctions are heating up as an efficient and flexible sales channel. Along with the other two types of online auctions, namely consumer-to-consumer and business to business *auctions*, they represent a new class of mercantile processes that are ushering in the networked economy, but are not fully understood yet. Yong and Yum[51] have called for an extensive examination of the pervasive impact of advance electronic communication on the theory and practice of auctions. For a wide variety of goods sold over the Internet, consumers now have an interesting choice of mercantile processes to utilize to buy these goods. Broadly, these different processes can be broken into static posted-price mechanisms and dynamic interactive pricing mechanisms such as online auctions. In this context, online auctioneers are striving to find the correct strategic and tactical direction that ensures their long-term profitability. This involves optimizing existing as well as designing interesting new mercantile processes to sell their products. This paper is an attempt to analyze this emerging market structure with respect to the welfare of the different economic agents involved namely the *B2C* auctioneers (we implicitly assume the joint interest of the seller and the auctioneer, if they are different) and consumers. There already exists a vast body of literature dealing with the theory of auctions and optimal mechanism design. However, the majority of the work focuses on the analysis of single auctions and is carried out in isolation from the broader context of the markets in which these auctions take place. It should also be noted that despite the presence of a vast body of literature dealing with traditional auctions, one could not call these auctions 'mainstream' from a consumer's viewpoint. It is only after the synergetic combination of traditional auctions with Internet technology that this sphere of economic activity has blossomed into significance.

In the next section of this paper, we derive an optimal bidding strategy in sequential auctions that incorporates option value assessment. Furthermore, we establish that

our optimal bidding strategy is tractable since it is independent of the bidding strategies of other bidders in the current auction and is only dependent on the option value assessment.

2   OPTIMAL AUCTION DESIGN

What is the best auction design to use for a given selling situation? The work covered below all assumes a risk-neutral seller selling a single indivisible item to one of possibly several potential buyers.

In cases in which the bidder are risk-neutral, symmetric, and follow the IPV model, the Revenue Equivalence Therem holds(RET). The RET says that under certain conditions, the four major auction types-English, Dutch, First Price Sealed bid, and Vickrey auction will deliver the seller the same expected revenue. In this case, the optimal auction requires the seller to set a reserve price below which he will not sell the item. This price is set to mimic the expected bid of the second-highest bidder, and is strictly greater than the seller's reserve valuation. Moreover, the seller should go ahead and announce this reserve price before the auction begins.

Weakening the assumptions of the RET leads to changes in the optimal auction design. In cases where the bidders are risk-averse, but the assumptions of symmetry and IPV still hold, the Dutch and the First price sealed bid auctions. A seller should still optimal set a reserve price and possibly add an entry fee as well.

In cases where the bidders have affiliated values but remain risk-neutral and symmetric, sellers should use the English auction because the it yields the highest expected revenue, followed by the Vickrey auction, which is then followed by the Vickrey auction, which is then followed by the last-place tie between the Dutch and First price sealed bid. Moreover, a seller should still set reserve prices and entry fees; in fact, given a choice between two pairs which will attract the same set of bidders, it pays to choose the pair with higher entry fee and the lower reserve price. Side payments from the auctioneer to the bidders are sometimes optimal, but rarely used in practice.

Finally, when bidders are asymmetric, but remain risk-neutral and have IPV, the optimal auction format is highly variable.

The key is that auction mechanism design is theoretically well-grounded. There are different auctions are known to be optimal in different situations. Moreover, auctions for which truthtelling is the dominant strategy do exist and are quite feasible. Hence, an agents's best possible course of action could be carried out by a dumb agent simply telling the truth.

There are two important issues in the problem of optimal auction design. One is strategy. The other is protocol. Generally, researchers are focus on one issue.

In the next section, we mainly discuss optimal bidding strategy in different condition.

3   STUDY OF OPTIMAL BIDDING STRATEGY

In this section, we consider a sale of two identical objects through second-price sealed-bid auctions. If a bidder wins an auction, she will leave the game. If she loses the first auction, she will bid in another auction with probability of 1.Each bidder intends to buy at most a single object i.e., the utility of a second object is assumed to be zero. In future work, we intend to relax this assumption. However, we conjecture that this will not qualitatively change the results obtained here as long as marginal utility is diminishing i.e. the utility gained from the second object is smaller than that from the first. In this paper, we define *new bidders* to be those that have not bid in any auctions selling the same item before. *Seasoned bidders* are those for whom the current auction is their second auction. It is easy to understand that a new bidder's expected utility comes from both auctions. The first component of a bidder's utility is the difference between her reservation value and price in the first auction; the second component is the corresponding difference in the second auction multiplied by the probability of losing in the first auction, because only if she loses in the first auction will she receive utility in the second auction. Since we use bidder's expected payoff as her utility function, we are assuming risk-neutrality here. We assume that U1 is the utility from auction, r is reservation value, U2 is the utility from second auction and P is the probability of losing first auction, then,

$$U1 = \left| \begin{array}{l} 0, \text{ if she loses;} \\ r, \text{ if she wins} \end{array} \right.$$

$$U2 = \left| \begin{array}{l} 0, \text{ if she loses} \\ r, \text{ if she wins} \end{array} \right.$$

In the rest part of this paper, we will assume independent, private valuation, as in the private value model. We will also assume that within the same auction, there are two types of bidders –new bidders and seasoned bidders. We assume, mostly for ease of notation, that bidders of the same type adopt the same type of bidding function (strategy). From private-value model, we know that seasoned bidders would bid their reservation values. Hence, we take the following assumption: New bidders adopt the same type of bidding strategy $b(v)$, where v is a bidder's reservation value. Bidders' valuations are drawn independently from a distribution F(.).

4   BIDDING STRATEGY UNDER CERTAINY

We start by assuming that bidders know the number of new and seasoned bidders that will bid in each auction. As in all private value models, the bidder is assumed to know the distribution of reservation values of other bidders but the actual value is private information to each bidder. A seasoned bidder *A* will bid his

reservation value, since for him there are no future auctions. On the other hand, a new bidder, *B* has to consider how her first auction bid affects the likelihood of being able to participate in a second auction. Before formally deriving B's optimal strategy, a simple example provides some intuition for B's strategy.

Example 1: B bids in two auctions. In either auction, B competes with another bidder whose bid is drawn from a uniform distribution U(0,6). B's reservation value is 4. We consider the following alternatives:

Alternative 1: B bids her reservation value in both auctions. Recall that since this is a second price auction, B wins at its opponents bid x when x <= 4.

$$E(u)=1.78$$

Alternative 2: B bids less than her reservation value in the first period and reservation value in the second period. If she bids 2 in the first auction, her expected utility is:

$$E(u)=1.89$$

The increments in her bid will increase her expected utility initially. Once it reaches 2.67, her expected utility begins to drop. Simple calculations show that the optimal bid for bidder B in the first period is 2.67.

We define B's expected utility if she bids *x* given her reservation value of *v* as

$$E(u(x,v))=\int_0^x (v\text{-}z)d\,\Phi\,(z)+\int_0^v \ (1-\Phi\,(x))\ (v-z)$$

$$d\,\underline{\Phi}\,(x) \qquad\qquad (4-1)$$

The first integral is the bidder's expected payoff in her first auction, where $\Phi\,(z)=Pr\,(b\,(x^{(1)}))\langle z\&y^{(1)}\langle z$, and where *b(x)* is the other new bidders' bidding strategy, and $x^{(1)}$ is the largest reservation value among new bidders (excluding bidder B) in auction 1.Hence the largest bid of new bidders is $b\,(x^{(1)})$. Similarly, $y^{(1)}$ denotes the largest reservation value, and hence, also the highest bid among seasoned bidders in auction 1. Similarly, we define $\underline{x}^{(1)}$, $\underline{y}^{(1)}$ for the second auction as the highest bids among the new bidders and seasoned bidders (excluding B). Therefore $\Phi\,(x)=Pr\,(b\,(x^{(1)}))\langle x\&\&y^{(1)}\langle x$ is the probability of B winning her first auction. The second term in equation *(4-1)* is B's expected payoff in her second auction.

Solving the first order condition for an interior optimum with respect to *x*, we have the following optimal first period bid x*:

$$x*(v)=v\text{-}\int_0^v \ \underline{\Phi}\,(z)\,dz \qquad\qquad (4-2)$$

where $\int_0^v \ \Phi\,(z)\,dz$ is bidder B's expected payoff if she bids in her second auction.

From the above equation, we may derive the following properties of bidder B's optimal strategy.

Property 1:x * is B's dominant strategy in the sense that it is independent of the strategies of other bidders in the first auction.

$\Phi\,(x)$ includes all the information about the remaining bidders in the first auction. In B's optimal strategy, there is no $\Phi\,(x)$, meaning that her first period bid is independent of the strategies of all other bidders. The conclusion may seem surprising but it is easy to understand. If we let *v2* represent B's expected payoff from period 2 auction, B's "real" valuation of the first auction is *v1-v2*. Hence, according to the private-value model, B should bid her "real" valuation.

Property 2: *x* *<v This property explains why some experienced bidders would like to bid less than their reservation values in the first auction. Simply put, the option of being able to bid in a second auction is valuable. The smaller the value of this option, the greater is the probability of winning in the first auction. Thus the first period bid must trade-off the payoff from the first auction against the option value.

Property 3: * x increases when 2 *N* or 2 *M* increases. Here *N2* and *M2* denote the number of new bidders and seasoned bidders respectively. Intuitively, when the number of bidders increases, bidder B faces more competition in the second auction, which makes the second auction less valuable to her. Hence, B increases her bid in the first auction.

5   CONCLUSIONS

Online sequential auctions are different from non-Internet sequential auctions. In most theoretical models of sequential auctions, the number of auctions is fixed; bidders enter and leave the auctions at the same point (or winners leave and the rest remain). So, the *k*th auction of bidder A is also assumed to be the *k*th auction of bidder B. However, in online sequential auctions, no such symmetry can be assumed. Each bidder faces a continuous stream of auctions. Bidders enter those auctions at different times and may have participated in different number of auctions. Thus, the principal contribution of this paper is a model of online sequential auctions that captures important features of these auctions neglected in earlier models of sequential auctions. Next, we will mainly study on how uncertainty affects bidding strategies

6   REFERENCES

[1] Abrache, J., T. G. Crainic, M. Gendreau. Design issues for combinatorial auctions. *Proceedings of the Fourth International Conference on Electronic Commerce Researc*h, Dallas. 2002.

[2] Alan, S., H. Alan. Online reverse auctions and their role in buyer–supplier relationships. *Journal of Purchasing & Supply Management* 9 257–268. 2003.

[3] Ba, S.l., A. B. Whinston, H. Zhang . Building trust in online auction markets through an economic incentive mechanism. *Decision Support Syste*m 35 273-286. 2003.

[4] Bass, S. M., H. Kwakenaak. Rating and Ranking of Multiple Aspect Alternative Using Fuzzy Sets. *Automatica* 13 47-58. 1977.

[5] Ben-ameur, H., B. Chaib-draa. Multi-item Auctions for Automatic Negotiation. *CIRANO Working Papers* 68. 2002.

[6] Bichler, M. Bidding languages and winner determination in multi-attribute auctions. *IBM Research Report* RC 22478. 1998.

[7] Bichler, M. Winner Determination Algorithms for Electronic Auctions: A Framework Design . *Proceedings of the Third International Conference on E-Commerce and Web Technologies* 37-46. 1997.

[8] Bichler, M., M. Kaukal, A. Segev. Multi-attribute auctions for electronic procurement. In *Proceedings of the First IBM IAC Workshop on Internet Based Negotiation Technologies* 18-19. 1999.

[9] Bichler, M. An experimental analysis of multi-attribute auctions. *Decision Support System* **29**(3) 249 – 268. 2000.

[10] Bleeker, A., L. Meertens A Semantics for BAN Logic. *DIMACS Workshop on Design and Forma Verification of Security Protocols*. .1997.

[11] Branco, F. The design of multidimensional auctions. *RAND Journal of Economics* **28**(1) 63–81. 1997.

[12] Burmetister, B. A practical Approach to Multi-attribute Auctions. *DEXA Workshops* 670-674. 2002.

[13] Carr, R. I., J. W. Sandahl. General Bidding Model. *Journal of the Construction Division. ASCE* **108**(4) 639-651. 1982.

[14] Che, Y. K. Design Competition Through Multidimensional Auctions. *RAND Journal of Economics* **24**(4) 68-680. 1993.

[15] Chen, C.J., B.W. Lin. A resource-based view of IT outsourcing: knowledge sharing, communication, and coupling quality. *Asia Pacific Management Review* **6**(2) 149-173. 2001.

[16] Chen, S.Y. Theory and Application of Fuzzy System Decision Making. DLUT Press, Dalian China. 1994.

[17] David, E., S. Kraus. Protocols and Strategies of Automated Multi-Attribute auctions. *AAMAS 02' conference* No 2531. 2002.

[18] Dave, C. Explorations in evolutionary design of online auction market mechanisms. *Electronic Commerce Research and Applications* 2 162–175.2003.

[19] Dekrajangpetch, S. Interior-point Linear Programming Algorithm for Auction Methods. *IEEE Transactions on power systems* **15**(7) 572-578. 2001.

[20] Feng, W. J. Relative Efficiency in Multiobjective Optimization and Decision Making. *System Engineering and Electronic Technology*. **4**(3) 76-82. 1994.

[21] Friedman, L. A Competitive Bidding Strategy. Operations Research 4 106-112. 1956.

[22] Hunsberger, L., J. Barbara. A Combinatorial Auction for Collaborative Planning. *Proceedings of the Fourth International Conference on Multi-Agent Systems* 151-158. 2000.

[23] Jason, F. S., M. Margolis. A random nth-price auction. *Journal of economic behavior &organization* 46 409-421. 2001.

[24] Lee, H.G., T.H. Clark. Impact of the Electronic Marketplace on Transaction Cost and Market Structure. *International Journal of Electronic Commerce* **1**(1) 127-149. 1996.

[25] Lengweiler, Y. The multiple unit auction with variable supply. *Economic Theory Journal* **14** (2) 373–392. 1999.

[26] Li, Y. J., Y. Z. Cao. The new development of NSS. *Asia Pacific Management Review* **6**(2) 197-215. 2002.

[27] Lin, R., Y. Z. Zhang. Theoretic Analysis on Second Sealed Auction. *Zhejiang Social Science* **3**(3) 78-95. 1999.

[28] Liu, S. L., Research on multi-attribute decision making theory， method and application*s. Paper dissertation*. Beihang University, Beijing. 1997.

[29] Liu, S. L., S. Y. Wang. Decision Theoretic Approaches to Bidding and Auctions. *Studies in International Technology and Economy* **1**(2) 20-33. 1998.

[30] Maes, P., R.H Guttman, A. Moukas. Agents that Buy and Sell. *Communications of the ACM* 42 81-91. 1999.

[31] Maskin, E., J. Riley. Optimal auctions with risk-averse buyers. *Ecoometrica* **52**(6) 1473-1518. 1984.

[32] McAfee, R. P., J. McMillan. Auctions and Bidding. *Journal of Economic Literature* **25**(2) 699-738. 1987.

[33] Milgrom, P., R. J. Weber. A theory of auctions and competive bidding. *Ecoometrica* 50 1089-1122. 1982.

[34] Mishra, D., D. Veeranant. A multi-attribute Reverse Auction for Outsourcing. *Proceedings of the 13th International Workshop on Database and Expert Systems Application* 675-679. 2002.

[35] Morin, T. L., R. H. Clough. Competitive Bidding

models. Journal of the Construction *Division. ASCE* **95**(1) 85-107. 1959.

[36] Qi, Y.F. Multi-criteria Decision Making. Weapon Industry Press, Beijing. 1989.

[37] Richard, E. W. On a possible Benefit to Bid Takers from Using Multi-Stage Auctions. *Management Science* **34**(9) 1109-1120. 1998.

[38] Richter, C. W., G. B. Sheble. Genetic Algorithm Evolution of Utility Bidding Strategies for the Competitive Marketplace. *IEEE Transactions on Power Systems* **13**(1) 256-261. 1998.

[39] Sandholm, T. eMediator: A Next Generation Electronic Commerce Server. *AAAI Workshop on AI in Electronic Commerce* 46-55. 1999.

[40] Srividhya, S. Design and Verification of A Secure Electronic Auction Protocol. T*he 17th IEEE Symposium on Reliable Distributed Systems* 204-210. 1998.

[41] Teich, J., H. Wallenius, J. Wallenius. Multiple-issue auction and market algorithms for the world wide web. *Decision Support System* 26 49-66. 1999.

[42] Teich, J., H. Wallenius, J. Wallenius. A Multiple Unit Auction Algorithms: Some Theory and A Web Implementation In Electronic Markets. *International Journal of Electronic Commerce and Business Media* 9 1-7. 1999.

[43] Teich, J. An Internet-based Procedure for Reverse Auctions Combining Aspects of Negotiations and Auctions. *Proceedings of DEXA 2000.* 2000.

[44] Vickrey, W. Counterspeculation auctions and sealed tenders. *Journal of Finance* 16 8-37. 1961.

[45] Vincent, A.M., J. A. Skeel. Internet reverse auctions: Valuable tool in experienced hands. *Business Horizon* **45**(4) 70-76. 2002

[46] Vigoroso, M. Are Internet auction ready to gear up? *Purchasing* Feb11 Boston. 1999.

[47] Wade, R.L., R. B. Harris. A Bidding Strategy. *Journal of the Construction Division ASCE* **102**(1) 197-211. 1976.

[48] Wang, K., T.G. Eric. A study of online auction sites in Taiwan: product, auction rule, and trading type International. *Journal of Information Management* 127–142. 2002

[49] Wang, W. L. Shill Bidding in Multi-round Online Auction. *Proceeding of the 35th Hawaii International Conference on System Sciences*. 2002.

[50] Yue, C.Y. Decision Making Theory and Method. Science Press, Beijing. 2003.

[51] Yong, S. K., B. J. Yum. Identification of Navigational Paths of Users Routed through Proxy Servers for Web Usage Mining. *Asia Pacific Management Review* **7**(4) 499-512. 2002.

[52] Zhan, W. J., S. Y. Wang. Review on the Smith's mystery and development of double auctions. *Journal of Management Science in CHINA* **4**(6) 1-12. 2003.

[53] Zhang, W. J. Auction Theory and Information Discover. *Foreign Economics and Management* 3 99-110. 1996.