The Effect of Timing on Jump Bidding in Ascending Auctions

Anthony M. Kwasnica*
Elena Katok†
Penn State University

April 24, 2006

The authors gratefully acknowledge the support from the New Faculty Research Grants, the Institute for the Study of Business Markets (ISBM), Smeal College of Business, Penn State University and the Laboratory for Economic Management and Auctions. Katok gratefully acknowledges the support of the National Science Foundation. The authors also thank Diana Wu for her assistance in completing the experiments and performing initial data analysis.

* Smeal College of Business, Penn State University, University Park, PA 16802; phone: 814 863-0542, fax: 814-865-6284, email: kwasnica@psu.edu
† Smeal College of Business, Penn State University, University Park, PA 16802; phone: 814 863-2180, fax: 814 863-7067, email: ekatok@psu.edu

The Effect of Timing on Jump Bidding in Ascending Auctions

Anthony M. Kwasnica and Elena Katok

We investigate the role of timing in ascending auctions under the premise that time is a valuable resource. Traditional models of the English auction ignore timing issues by assuming that the auction occurs instantaneously. However, when auctions are slow, as internet auctions used for procurement often are, there are significant opportunity or monitoring costs to bidders, and the choice of the size of the jump bid becomes a strategic decision. We study this choice in the experimental laboratory by systematically varying the opportunity costs associated with fast bidding. We find that when time is more valuable bidders respond by choosing larger jump bids. Surprisingly, the economic performance of the auction is not significantly affected. We develop a simple model of ascending auctions with impatient bidders that provides insights into the effect jump bids have on auction performance.

Keywords: Auctions, Experimental Economics

JEL Classifications: D44, C91

1. Introduction

The advent of the Internet has provided new opportunities for the use of auctions in general, and for the use of procurement auctions in particular. The use of *e-Sourcing*[1] for procurement has been increasing over the past decade, with total revenues projected to exceed $3 billion by 2005.[2] Auctions are typically used as part of e-Sourcing technologies, and have attracted considerable attention when General Electric claimed savings of over $600 million and net savings of over 8% in 2001 by using SourceBid, a reverse auction tool that is a part of GE's Global Exchange Network (Global Exchange Services 2003). Other examples of the use of electronic auctions for procurement include the U.S. General Services Administration (Sawhney 2003) that attributed savings of 12% to 48% to the use of reverse auctions, and FreeMarkets, now part of Ariba—the leading e-Sourcing provider— that saved approximately 20% for their customers on over $30 billion in purchases between 1995 and 2001.

[1] E-Sourcing refers to the use of internet-enabled applications and decision support tools that facilitate competitive and collaborative interactions among buyers and suppliers, through the use of online mechanisms including, specifically, reverse auctions. See Engelbrecht-Wiggans and Katok (forthcoming) for a discussion of the use of e-Sourcing mechanisms for procurement.

[2] According to a September 2002 report by the Aberdeen Group (Aberdeen Group 2002), e-Sourcing revenues increased from $820 million in 2001 to $1.14 billion in 2002, and are projected to increase to $3.13 billion in 2005.

The Internet allows geographically dispersed bidders to compete on price, potentially leading to lower costs for the buyers. Inernet auctions also permit the auction designer greater flexibility in deciding on the relative speed of the auction. Internet auctions typically last anywhere from a few hours (FreeMarkets) to over a week (eBay). There are a number of practical settings such as complex combinatorial auctions used to procure transportation services (see for example Ledyard et al. 2002) and department store sales (see for example Carare and Rothkopf 2005), in which fast auctions are not feasible. Standard auction theory does not consider the role of time in auctions; it assumes that all auctions occur instantaneously. While the standard theory may be sufficient when auctions are fast, as applications for slower, complex auctions become more prevalent, the issue of time, its associated costs, and the effect these costs have on bidding behavior, become more relevant.

High-value procurement auctions have two key features that make studying bidder behavior when time is valuable particularly pertinent: (1) they often have activity-based ending rules, so bidder behavior can affect the auction duration, and (2) executives involved in these high-valued auctions often have high opportunity costs associated with their time (e.g., they are highly paid and have many other responsibilities). Many on-line auctions used for procurement utilize some sort of "soft close" rule instead of a fixed ending time that is familiar from eBay. For example, the Federal Communications Commission (FCC) in its description of the commonly used SMR auction states the following about how an auction is ended: "In an SMR auction, there is no preset number of rounds. Bidding continues, round after round, until a round occurs in which all bidder activity ceases. That round becomes the closing round of the auction."[3] As a result of the above activity-based ending rule, the length of these auctions varied dramatically (the PCS DEF Block auction lasted 142 days). The discussion of the choice of auction ending rules has been an important topic in designing the FCC spectrum auctions, as well as other auctions such as those for transportation services (Ledyard et al. 2002). Even in simpler settings, many auctions use a soft close that allows bidder to respond if a bid is placed in the closing minutes.

Since the results of procurement auctions can significantly affect a supplier's profitability, these auctions also generally require the attention of executives within the company and, at times, the services of highly paid consultants. These consultants often charge on an hourly or daily basis, and executives have other important issues in the company to address. Therefore, if the supplier can end the auction sooner with similar results, the supplier is likely to experience lower costs. In addition, there may be added benefits to the early completion of an auction such as allowing more time to prepare to provide the terms of the supply contract.

Therefore, we investigate the role of bidder impatience on behavior in English auctions. The English auction is an open outcry, ascending auction; at any time bidders can bid amounts greater than the current high bid and possibly some minimum increment, and the winner is the bidder who placed the last high bid. Bidders in the English auction can take actions that affect auction duration and reduce the costs associated with slow auctions. They can do this by placing *jump bids* that are greater than the minimum increase required by the auctioneer. The empirical relevance of jump bidding has been widely noted in a number of settings including some of the largest, highest revenue auctions. Isaac et al. (2004) examine 41 spectrum auctions conducted by the FCC and find that jump bidding is a persistent and common feature of these auctions (sometimes over 40% of the bids are jump bids). Easley and Tenorio (2004) use data from 236 internet auctions and find that jump bidding is observed in over 1/3 of their sample, providing

[3] From http://wireless.fcc.gov/auctions/default.htm?job=about_auctions&page=2.

additional evidence that an environment very similar to the one we analyze and implement in the laboratory is applicable to internet auctions[4].

The jump bidding strategy, while beneficial in reducing the auction duration, may also negatively affect auction performance. The winning bidder may pass by the second highest willingness-to-pay, and this may result in foregone profits for the bidder, Alternatively, since placing bids extends the auction and increases costs, bidders will never bid precisely up to their valuation (Proposition 2). Thus, bidders may stop bidding prior to reaching the second highest willingness-to-pay, and this may result in reduced revenue for the auctioneer. While a number of experimental studies have suggested that jump bidding may be detrimental to auction performance (Banks et al. 2003, Porter et al. 2003), our study systematically varies the incentives for jump bidding in order to observe the extent to which jump bidding affects the overall performance of the institution. We find that while bidder behavior is affected by an increase in the opportunity cost of time, the aggregate performance of the auction (efficiency, bidder profits, and seller revenue) is robust to these costs. These results are particularly relevant for designers of high-valued procurement auctions.

We begin by briefly reviewing some related literature (section 2) We formulate some simple theory that helps us articulate research hypotheses and provide a baseline for laboratory tests (section 3). We then implement impatience in the laboratory with a treatment in which bidders can complete as many auctions as they can during a fixed period of time. We compare bidding behavior in this treatment (hence referred to as the "timed" treatment) with the behavior in sessions in which bidders completed a fixed and pre-determined number of auctions in a

[4] Easley and Tenorio (2004) data came from auctions that were conducted on two Internet auction sites, Onsale.com and uBid.com. Auctions on both sites had activity-based closing rules: "…this rule specified that, after the posted closing of the auction, bidding would stop when no bid has been received in the last 5 (Onsale) or 10 (uBid) minutes." (p. 1412). The closing rule for our laboratory auctions was the same: it specified that the bidding stops if there were no new bids for 30 seconds.

session (hence referred to as the "untimed" treatment). The description of the experimental design and the protocol is in section 4, and the results are in section 5. In section 6 we present conclusions and discuss practical implications of our work. Proofs are contained in the appendix.

2. Related Literature

In the present paper we extend Katok and Kwasnica (2005). In Katok and Kwasnica (2005) we focused specifically on two common auction formats: the Dutch or reverse clock auction, and the first-price sealed bid auction. While these auctions are strategically equivalent under the traditional assumptions of auction theory, they vary markedly in terms of the role of timing. In the Dutch auction, a decision to stop the clock at a higher price is also a decision to end the auction earlier. In the first-price sealed-bid auction, the bidders have no direct ability to control the time at which the object is sold. However, in both cases, the auction designer can make important design choices based upon the importance of timing; he can select different clock speeds (Dutch auction) or decide on different closing times for accepting bids (sealed-bid auctions).

In Katok and Kwasnica (2005) we develop a simple theory of Dutch auctions with impatient bidders, and test this theory in the laboratory by comparing four institutions: the sealed-bid first-price auction, and the Dutch auctions with three different clock speeds (slow, medium, and fast). We find that, contrary to standard theory but in line with our theory of impatient bidders, the auctioneer's revenue increases as the clock slows. In addition to providing a valuable insight for auction designers, our work also provides an explanation to an often-cited anomaly in the experimental auction literature: Cox et al. (1982) report that fast Dutch auctions in the laboratory yield lower revenue than sealed-bid first-price auctions, but Lucking-Reiley (1999) reports the opposite result for a slow Dutch auction conducted over the Internet. Our theory of impatient bidders organizes that data, as well as our own data, that compares the institutions in a more controlled way. Carare and Rothkopf (2005) describe a decision theoretic model of a slow Dutch auction that can also explain some of the differences.

Most previous studies that model costly bidding in ascending-bid auctions have focused on the value of jump bidding as a technique for bidders to signal their values. Avery (1998) develops a model for the affiliated value setting, and Daniel and Hirshleifer (1998) and Easley and Tenorio (2004) present a model for the private value setting. Those models assume that bidders incur a cost every time they *place a bid*, and show that there exist equilibria in which bidders place large jump bids early in order to communicate information and end bidding early. Our focus is on bidding behavior when *time itself*, rather than the actual placement of bids, is valuable, so bidders incur cost that increases with auction duration. In that, we examine a setting similar to what we originally studied in Katok and Kwasnica (2005), in which bidders experience significant opportunity or monitoring costs associated with the auctions. Isaac et al. (2004) also examined a model with bidder impatience, but they impose discounting and use a simulation-based approach in order to arrive at their theoretical results.

An early and influential work was that of Rothkopf and Harstad (1994). They examined the choice of bid increments in single-unit ascending auctions. They also presented a decision theoretic model where bid jumping is optimal late in the auction. Recently, Bapna et al. (2003) has examined the important issue of bid increment choice by the auctioneer in multi-unit auctions. In order to develop a tractable model, they make a number of modeling assumptions including focusing on a pedestrian bidding by the bidders. Rather than assuming a particular behavior by the bidders, our objective is to understand the strategic choices made by impatient bidders. Hopefully, a better understanding of jump bidding strategies by bidders will result in even better bid increment choices by a revenue maximizing auctioneer.

3. A simple model of English auctions with impatient bidders

We consider the English auction with two bidders. Both bidders are risk neutral and have independent privately-known values v_i v_i drawn with support on $[0,\bar{v}]$. We assume that bidders are impatient. As time passes bidders experience a cost $c(t)$ for participating in the auction. We assume that $c(t) \geq 0$ and increasing in t. A bidder's profit from participating in an auction that lasts for time t is given by

$$u_i(v_i,t) = \begin{cases} v_i - b - c(t) & \text{if win} \\ -c(t) & \text{otherwise} \end{cases},$$

where b is the price the winning bidder pays. The cost $c(t)$ can be thought of as the cost of monitoring the auction or the opportunity cost associated with the time spent bidding in the auction. A bidder must pay these costs win or lose, regardless of the actual number of bids placed.

In the laboratory, these costs are most likely the bidder's perceived value of ending the auction earlier in order to speed the completion of the experimental session or in order to complete more auction periods. In practice, they might be the salaries of designated bidders, or the cost associated with delayed contract completion. Note that these costs also distinguish our model from that of Daniel and Hirshliefer (1998) and Easley and Tenorio (2004); in both of those models bidders bear the costs only upon bidding. While these models are most appropriate in settings where other costs such as those associated with monitoring the auction or the opportunity costs associated with delayed completion of the transaction are minimal, in the realm of on-line procurement there are numerous settings in which the auction will require considerable attention by highly paid executives *throughout* the auction and that earlier consummation of the contract could result in substantial savings.

The English auction begins at time $t = 1$. Bidders can simultaneously enter bids or abstain from bidding. Whenever a new bid is placed, the high bid, b_t, is announced and the auction moves to the next round. There is a minimum bid increment m assumed to be constant for every round.[5] Therefore, a bid in round $t+1$ must be greater than or equal to the previous high bid plus m, or $b_{t+1} \geq b_t + m$. The auction ends at round t if both bidders abstain.[6]

A bidder's strategy is a decision to abstain or bid a certain amount greater than or equal to the current high bid plus the increment, given the history of bids placed. An equilibrium is then a set of strategies and consistent beliefs for each bidder such that each bidder is maximizing her expected utility given the strategies of the other bidders. In contrast to the Dutch and sealed bid auctions examined in Katok and Kwasnica (2005), where each player selects at most one action, the English auction is a dynamic game with many actions (bids) by each player. This complicates the analysis and makes complete characterization of the equilibrium set nearly impossible. While Isaac et al. (2004) use simulation to deal with this problem, we investigate what sorts of actions we can rule out as potential equilibria and then we turn to the laboratory in order to provide more detailed insights.

We first ask whether costs, as we have implemented them, will cause jump bidding. If there is no jump bidding, then bidders must be bidding the minimum increment m at all times until they reach their value. This behavior is known as *pedestrian* or straightforward bidding.

[5] In practice, the bid increment often changes during the course of the auction. The results presented here could be extended to such settings, but we maintain a fixed increment for simplicity. We discuss how our results might provide insights into the optimal design of increment levels in the conclusions.

[6] We are assuming that the auction has a 'soft close.' While many common consumer-to-consumer auction sites such as eBay use fixed closing time or 'hard close' rules, almost all large business-to-business auctions utilize some sort of soft close that depends upon bidding activity. While the way these rules are implemented may differ, the results of this research can provide insights into bidding behavior in many different auction implementations since bidders have the opportunity to speed up the auction by placing higher jump bids. Roth and Ockenfels (2002) discuss the different strategic incentives provided by hard and soft close rules.

The first proposition shows that for sufficiently high opportunity costs we can expect jump bidding in any equilibrium.

Proposition 1: For all m, there exists $c(t)$ such that pedestrian bidding is not an equilibrium.

Intuitively, when monitoring or opportunity costs accrue rapidly, a bidder would prefer to speed up the auction by increasing the bid by more than the minimum increment. For example, by increasing the bid by $2m$, a bidder knows that the auction will end at least one round sooner. The cost of this strategy is that she may pay a higher price in the event that she wins, but if the opportunity costs are high enough relative to the minimum bid increment she will prefer to offset the costs.

Unfortunately, it is difficult to say much more explicitly concerning what types of jump bidding equilibria we will see. There are certainly multiple equilibria and an exact characterization would involve complete description of a huge dynamic game. Since the game structure and costs are similar to those used in Daniel and Hirshliefer (1998), we know that there are jump bidding equilibria that involve signaling. In a signaling equilibrium, the bidders learn about the private value of the other bidder via the bids placed. While very complex signaling equilibria are possible, most reasonable strategies involve very few bids in the early rounds of the auction. In fact, following from Daniel and Hirshliefer, there exists a signaling equilibrium where all bidders bid the risk neutral Nash equilibrium bid in the first-price sealed bid auction in round one and abstain in subsequent rounds. While interesting, we do not expect such strategies to be the primary motivation for jump bidding. Therefore, we examine general characteristics of other types of equilibria of the English auction where time is valuable.

We begin by showing that performance of the auction can be affected by the presence of these costs. We show that bidders will never be willing to raise the bid level to their value. This may impact the performance of the auction by lowering revenue collected (since the bid fails to reach the second highest valuation) and reducing efficiency.

Proposition 2: In any equilibrium, for all *v*, *m* and *c*(*t*), there exists some standing high bid $b < v$ such that bidders will prefer to stop bidding.

Intuitively, the minimum increment immediately preceding each bidder's value $(v - m)$ is an upper bound on the bids they are willing to place in the auction; increasing the bid to one's value extends the auction by at least one round and results in no profit from the purchase of the object. However, the extent to which this behavior actually affects final auction performance is indeterminate. Auction performance can be affected in a number of ways. First, as we know from Proposition 1, bidders will be placing jump bids in equilibrium. This might cause them to jump over the second highest value leading to increased revenue for the seller and lower profits for the bidder. Second, as we know from Proposition 2, bidders will never get closer than one increment below their value. Thus, it is possible that the auction could end before bidding reaches the second-highest value, resulting in lower seller revenue and higher bidder profits. Finally, both these behaviors open the door for potential loses in economic efficiency (the highest valuing bidder does not win the object). Since these effects influence auction performance in opposite ways, we turn to the laboratory to understand jump bidding behavior when time is valuable.

4. Design of the Experiment

In all auctions two bidders compete for one unit of an artificial commodity, with the value of the commodity drawn from a discrete uniform distribution of 1 to 100. New values were drawn for each auction round. In every session there was a maximum of five independent markets (1-5) totaling 10 bidders participating at any given time. Each market had a different set of value draws, but the value draws were the same for all sessions.

The auction institution was the canonical English auction. Bidders were free at any time to place any bid that they liked. The only requirement was that the bid must be strictly greater than the current high bid. There was no minimum bid increment. We chose to avoid specific mention of a bid increment in fear that it might act as a natural focal point for bidders. Given the discrete nature of valuations, it is reasonable to assume that unit bids might have been assumed to be the minimum bid by many bidders.[7] We used a simple 'soft close' activity based rule to end the auction; if no new bids were placed for 30 seconds, the auction ended and the object was awarded to the high bidder at the amount of her last bid. Thus, any new bid always extended the auction at least 30 seconds and other bidders always had the opportunity to respond to new bids. Bidders were then given 40 seconds to record their earnings before the start of a new auction round. They were informed of their new value draw and bidding began again against the same bidder.[8]

The objective of this study was to systematically vary the costs associated with auction duration in order to observe how bidder behavior and auction performance responded to the change. We implemented the following two treatments:

1. *Untimed*. Bidders are told that they will complete exactly 20 auction periods.
2. *Timed*. Bidders are told that they can complete as many auction periods as possible in 60 minutes. At the end of 60 minutes, the bidders were paid according to the number of auctions actually completed.

[7] However, there are bidders who bid well below one unit at times.

[8] While the repeated interaction between the same bidders might invite repeated game strategizing, it was necessary to capture the benefits of faster bidding. If fast bidders had to wait for slower bidding groups to end their auction in order to be rematched, the incentive for fast bidding would have been mitigated. There is also little reason to believe

The expectation was that in the untimed treatment the costs associated with a longer auction are not significant since the bidders know that they will complete 20 auctions no matter what, and completing auctions faster only results in ending the experimental session slightly sooner. In the timed treatment, the speed of the auction is more salient; by completing the auctions faster, bidders are able to complete more auctions and increase their earnings. In our view, the strength of this design is that it induces the higher cost of time in the timed treatment naturally, which makes the environment more realistic. An alternative could have been to charge bidders some explicit fee $c(t)$, increasing in t. The number of auctions was chosen in the untimed treatment to closely approximate the number of auctions completed in the timed treatment in order control for possible learning or wealth differences across treatments.

A total of 23 independent markets (46 subjects) were observed under the timed treatment, and 21 (42 subjects) independent markets were observed under the untimed treatment. In total, 942 (533 timed, 409 untimed) separate auction rounds were observed.[9]

All sessions were conducted at Penn State's Laboratory for Economic Management & Auctions (LEMA) between March 2001 and October 2001. The software was developed using the zTree system (Fischbacher 1999). Participants were recruited through email announcements. Cash was the only incentive offered. Participants were paid their total individual earnings from the auctions plus a $7 show-up fee at the end of the session. Sessions lasted between 80 and 120 minutes and average earnings were $21.84 and $18.34 in the timed and untimed treatments respectively. All subjects participated only once.

that bidders could coordinate on a collusive strategy with one object for sale and no communication (Isaac and Walker 1984).

[9] The number of untimed auction rounds was less than 420 due to a computer malfunction in one session. The data is included in the analysis, with the exception of the reported average number of periods completed. The computer error was unexpected so it should not have affected behavior.

5. Results

In this section we discuss the results and how they compare to the model of bidding in section 2. We report the summary of the performance of auctions and the comparisons between the untimed and the timed treatments in Table 1. All comparisons are done using a t-test for samples with unequal variances, and using averages for each independent market as the unit of observation. The *p*-values reported are one-sided.

	Treatment		
Average (Standard Deviation)	Untimed	Timed	t-statistic (p-value)
Efficiency	0.89 (0.13)	0.90 (0.18)	0.79 (0.4364)
Bidder profit per auction	21.66 (8.50)	24.48 (9.65)	1.46 (0.1569)
Buyer revenue per auction	48.55 (7.72)	47.83 (7.98)	0.89 (0.3832)
Seconds per auction	187.50 (32.05)	147.87 (32.36)	4.61 (0.0001)
Number of auctions	20.00 (0.00)	23.13 (6.43)	2.64 (0.0146)
Seconds per bid	9.31 (2.77)	12.13 (3.77)	3.23 (0.0037)
Size of the jump bid	3.23 (1.40)	5.58 (2.55)	4.28 (0.0003)
Percentage of auctions ended early	0.28 (0.23)	0.40 (0.27)	1.95 (0.0635)
Distance between high bid and 2nd valuation	5.42 (5.26)	5.85 (6.28)	0.85 (0.4044)
Bids per auction	10.93 (3.48)	6.83 (2.91)	4.73 (0.0001)
Correlation between the first bid and value	0.28 (0.27)	0.43 (0.21)	2.37 (0.0263)
Number of observations	20	23	

Table 1. Summary of auction performance.

Result 1: The performance of the auction is not affected.

One of the primary concerns associated with jump bidding is that it allows for significant changes in the economic performance of the auction. For example, because bidders will always stop before their actual value, it is possible that the auction will not achieve allocative efficiency and seller revenue may decline. Therefore, perhaps the most intriguing result is that along a number of dimensions the performance of the auction does not suffer in the timed treatment.

First, consider allocative efficiency. An auction is said to be allocatively efficient if the bidder with the highest value was the winning bidder. In the untimed condition 89% of all auction periods are efficient, and in the timed condition the proportion of efficient periods is 90%. The difference is not statistically significant. Bidder profits and seller revenue are also similar under the two treatments. Per auction bidder profits average 21.66 per period under the untimed treatment as opposed to 24.48 under the timed condition. This difference is not statistically significant. Average seller revenue is 48.55 when the auction is untimed and 47.43 when it is timed (also not significantly different).

When combined with the findings of Katok and Kwasnica (2005), the first result demonstrates that the effect of timing is not independent of the institution. In English auctions bidder impatience does not affect the seller's revenues, but in Dutch auctions, as we report in Katok and Kwasnica (2005), bidder impatience increases the seller's revenue in a slow Dutch auction. Interestingly, bidder impatience does not affect efficiency in either mechanism.

Result 2: Auctions are completed faster in the timed treatment.

The time between the first and last bids placed in each auction period averaged 187.50 seconds in the untimed treatment but is significantly smaller at 147.87 seconds in the timed treatment.[10] This allows bidders in the timed treatment to complete significantly more auction periods than in the untimed treatment (23.13 vs. 20 in the timed condition).

Given the auction institution investigated, bidders actually had two methods they could use to speed up bidding. They could place bigger jump bids or respond more quickly to bids

[10] This is not the actual length of the auction. Due to the 30 second closing rule, all auctions lasted at least 30 seconds more. In addition, the data does not record the time elapsed between the opening of the auction period and

placed by the other bidders. For example, consider bidders who are placing jump bids of 10 every 10 seconds. They could accomplish the same task by placing bids of 1 greater than the high bid every 1 second. This faster strategy would have the advantage of avoiding jumping over the second highest value. However, there is probably a maximum rate at which bidders can reasonably respond to bids, and fast bidding might accentuate the bid preparation costs as in Daniel and Hirshleifer (1998). We expected that we might see both types of increases in the timed treatment. The opposite is the case; bidders tend to take somewhat longer between bids in the timed treatment. The number of seconds per bid is 9.31 in the untimed treatment, and is slightly larger, at 12.13 in the timed treatment. This difference is statistically significant. It may be that the added salience of the jump bid choice might have induced bidders to consider their bid somewhat longer. Despite the slower rate of bid placement, the bid level increases faster under the timed treatment.

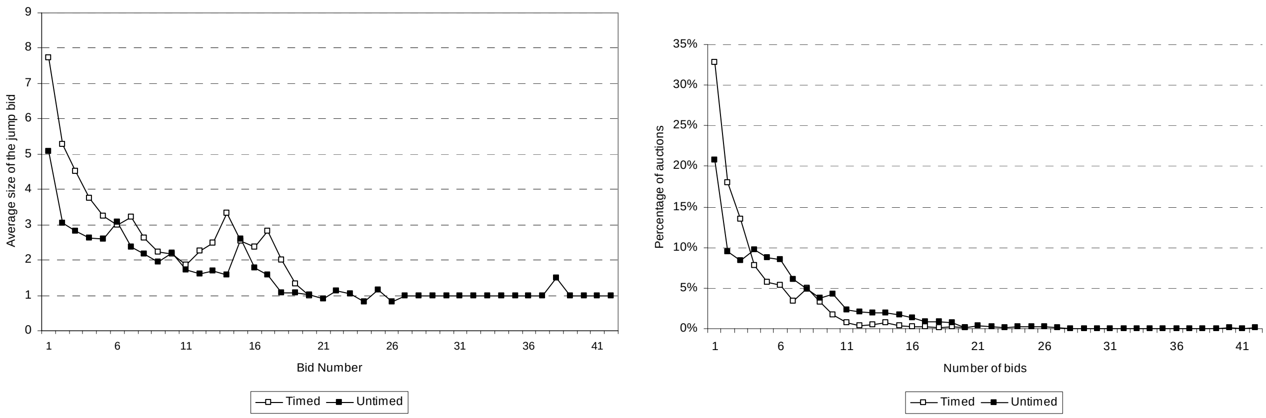
Result 3: Bidders place larger jump bids in the timed treatment.

The average size of the jump bid in the timed treatment is 5.58 compared to 3.23 in the untimed condition, and the difference is highly significant.

For the remainder of this paper, we focus on the size of the jump bid as the strategic choice variable. The next step is to investigate how the size of the jump bid is affected by other variables in the auction such as bidder values and the current high bid. Figure 1 shows how the size of the jump bid changes over time (a), and the percentage of auctions that had various numbers of bids placed (b). The "Bid Number" in Figure 1a refers to the order in which this bid was placed in the auction by a particular bidder. In other words, bid number 1 is the first bid placed by a bidder, bid number 2 the second, and so on.

The average first bid placed is higher in the timed treatment than in the untimed

the first bid placed. The first bid was generally placed shortly after the opening of the auction, and there is little treatment, and the average size of the jump bid decreases with each subsequent bid. This decrease appears to be somewhat faster in the timed treatment than in the untimed treatment. More bids are placed in the timed treatment than in the untimed treatment. The percentage of auctions that have 1, 2, and 3 bids placed is higher in the timed treatment, but the number of auctions with 4 or more bids placed is higher in the untimed treatment.

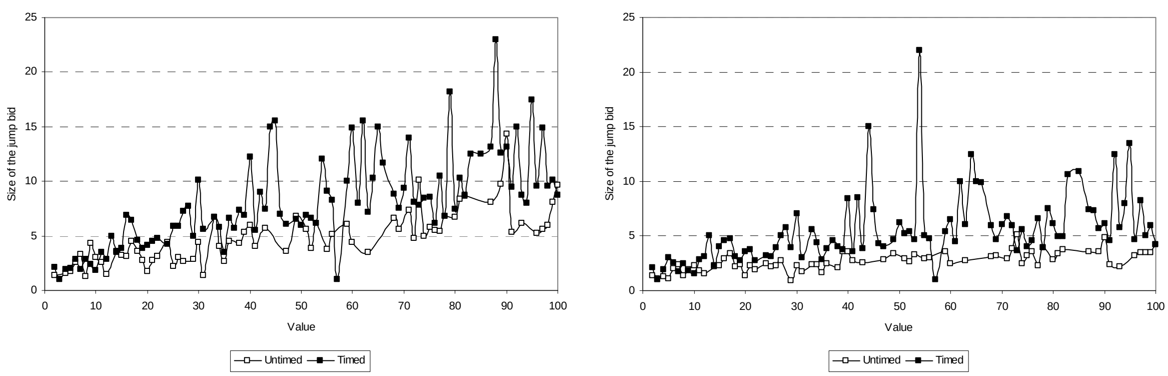


(a) Average size of the jump bid over time

(b) Percentage of auctions with various numbers of bids placed

Figure 1. The size of the jump bid over time, and the number of auctions with various numbers of bids placed.

Figure 2 shows the size of the first (a) and the average (b) jump bid as a function of the bidder's value.



(a) The average size of the first jump bid

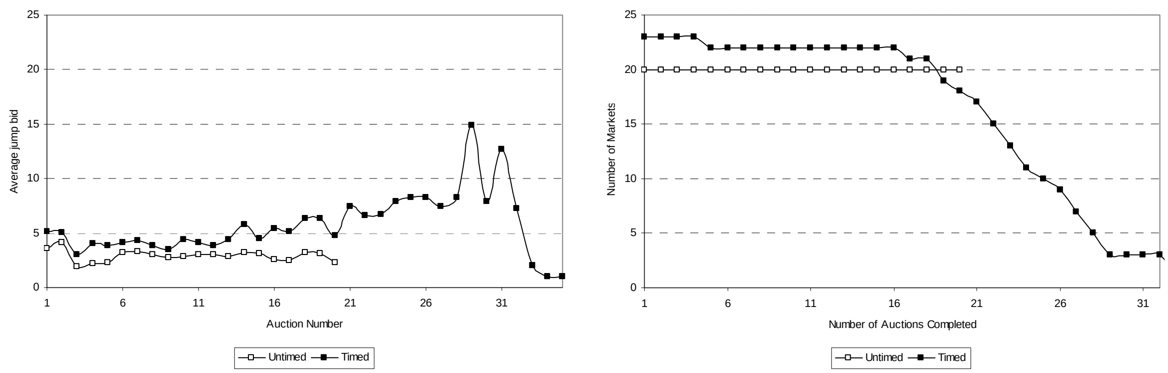
(b) The size of the average jump bid

Figure 2. The size of the first and the average jump bid as a function of the bidder's value

reason to expect significant variation due to the treatments.

Bidders with higher values start out bidding higher in both treatments, and they also appear to sustain the higher bidding level in both treatments, but the average size of the jump bids appears to be uniformly higher at medium and high values in the timed treatment.

Figure 3 shows the size of the average jump bid by period (a) and the total number of auctions that took place in a given period (b).



(a) Average jump bid per period (b) The number of auctions in a session

Figure 3. Activity per period

The average jump bid stays constant in the timed treatment, but appears to increase in later periods of the timed treatment. Of course we can see from Figure 3b that the number of auctions starts decreasing after period 20, and decreases quite sharply, so the larger average jump bids in later periods are due to a small number of groups that were actually able to conduct this many auctions. There is also endogeniety in the sense that groups who use bigger jump bids will be able to complete more auctions in the timed treatment.

In summary, average jump bids are higher in the timed treatment than in the untimed treatment, and the difference is due to several factors: (1) Bidders in timed treatment start out bidding higher, and although bidders in both treatments decrease the sizes of their jump bids over time, and bidders in the timed treatment decrease them faster (Figure 1a), nevertheless, since auctions end quicker in the timed treatment (Figure 1b) the average jump bids remains higher in that treatment. (2) Both, initial and average jump bids increase with value, but the jump bids for the same value are generally higher in the timed treatment (Figure 2). (3) The sizes of the jump bids do not change in later periods in untimed treatments but do increase in timed treatment (Figure 3a)[11].

Result 4: There is significant heterogeneity in bidder behavior.

Figure 5 shows the distributions of average jump bids by individuals in the timed and the untimed treatments. While smaller jump bids are more common under the untimed treatment, there are still differences across bidders.

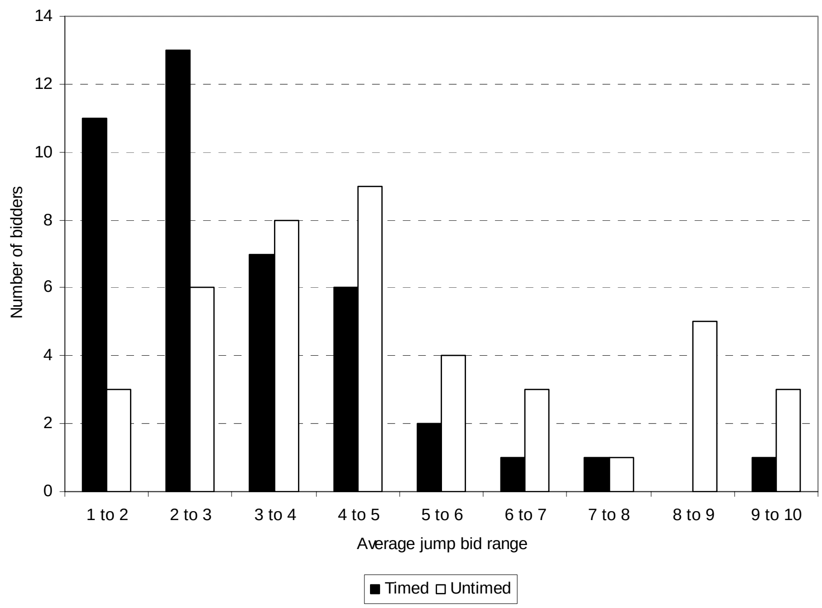


Figure 5. Distributions of average jump bids by bidder.

This heterogeneity can be observed in two more ways. First, in the OLS estimate, the R^2 increases from 0.16 to 0.34 when we add the fixed effects. Additionally, in individual regressions, the percentage of bidders for whom any given parameter is significant ranges from about 30% to about 76%. The R^2's in individual regressions range from 0 to 0.74, with median

[11] We can obtain results 1-3 more formally by using a regression model in which we regress the size of the jump bid on the treatment type (timed or untimed, the order of the bid, period, value, and the interaction effects between the treatment and the other variables. The size of the jump bid is higher in the timed treatment and decreases significantly as the auction continues. The size of the jump bid also appears to increase with bidder value. The effect of period and value is more pronounced in the timed treatment. We estimated the model using OLS with fixed effects for bidders; details are available from the authors.

at 0.25, so how the size of the jump bid relates to other variables for any given individual varies greatly. Interestingly, for individuals for whom the estimates are significant, virtually all of them have the same sign as the OLS estimates with fixed effects (except for the *PERIOD* estimates, which are not significant in the OLS with fixed effects), so although not all bidders respond to all the parameters in the same way, when they do respond, their response is consistent with our model.

Result 5: Bidders stop bidding before reaching their value.

Another prediction of the theory is that when bidders are impatient they will stop bidding below their value. In fact, as the cost of time increases we expect that bidders will stop short of their value sooner. There is some evidence of this behavior in the data. We first examine the proportion of experimental auctions that ended before the second highest valuation. When this happens, both bidders could have increased the level of bidding but decided not to. Under both treatments, a surprisingly large proportion of the auction periods end early. In the untimed treatment, 28% of all auction periods ended early. In the timed treatment, the percentage rises to 40%. The difference is weakly significant.

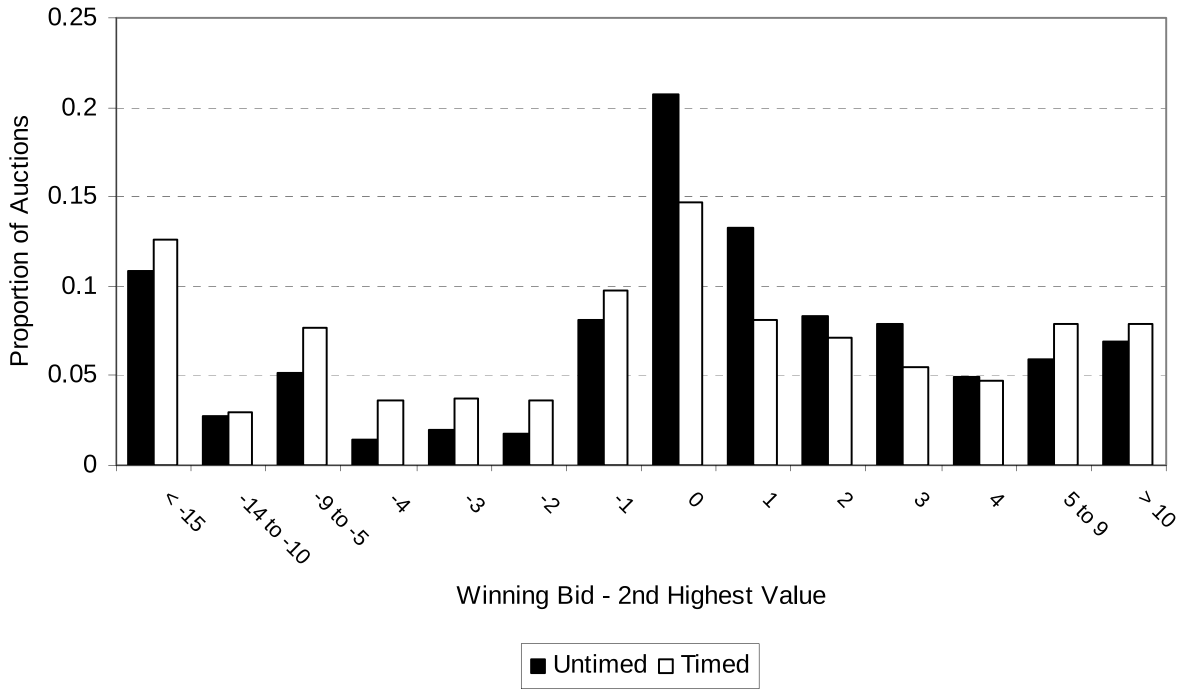


Figure 6. The distribution of the difference between the highest bid and the second highest valuation

These proportions also suggest that there is still a sizable portion of the auctions that meet or exceed the second highest valuation. This is not surprising since the eventual winner, in making strategic jump bid choices, can easily bid past the second highest value. The treatment condition does not seem to affect the average distance between the highest bid and the second highest valuation, which is 5.42 (untimed) and 5.85 (timed).

In Figure 6 we plot the distribution of the difference between the highest bid and the second highest valuation for the two treatments. The differences in the timed treatment are a bit more spread out than in the timed treatment.

Result 6: There is some evidence of signaling.

The only equilibrium we can easily identify is a signaling equilibrium similar to those already discussed by Daniel and Hirshleifer (1998) and Avery (1998). Signaling equilibria entail bidders placing value revealing high bids very early on in the auction process. As the discussion following Result 3 indicates, bid choices do appear related to a bidder's private value. Therefore, it is possible that the other bidder might update her information based upon the observed jump bid choice. There is little evidence that this is actually happening. If signaling is occurring, auctions should end after very few bids. However, under both treatment conditions the average number of bids is relatively high: 10.93 (untimed) and 6.83 (timed). While these averages are significantly different, the difference is not surprising since the size of the jump bid also increased in the timed treatment. Figure 7 shows the distribution of the number of bids placed by each market. Most groups average 5 or more bids per auction; in the timed treatment 74% of markets average at least 5 bids per auction and in the untimed treatment the proportion is 95%.

There are some groups, however, that do place very few bids. Six groups in the timed treatment and one group in the untimed treatments averaged less than 5 bids per round. This small number of bids may be suggestive of signaling or even tacit collusion. For example, one group (Market 5 on 4/12/01) consistently placed 1 or 2 bids per auction (average 1.85). Since Kwasnica and Sherstyuk (2005) have shown that bidders in ascending auctions for multiple objects can form tacit collusive agreements given enough time, it is worth investigating whether this behavior is more like collusion or signaling.[12]

[12] The distinction between signaling and collusion is small in this setting. One might address this as whether the bids are consistent with a one shot non-cooperative signaling equilibrium or must be supported by a repeated game influenced collusive arrangement.

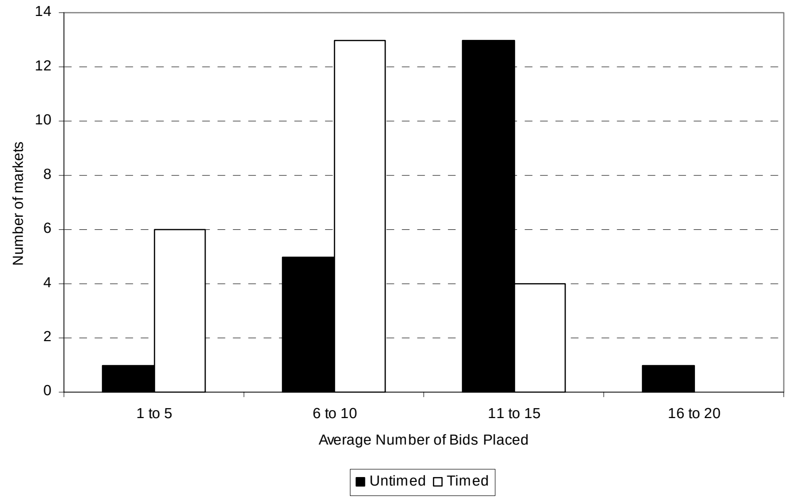


Figure 7: Distribution of average number of bids placed by market.

To provide a sense of the amount of signaling that might be happening, we compute the correlation between the first bid and the bidder's value in each market, and summarize this data in Figure 8.

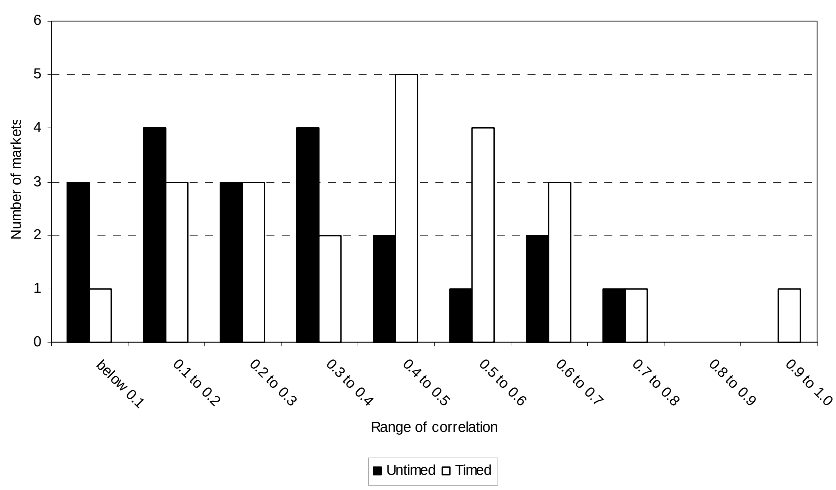


Figure 8. Average correlation between the first bid and the bidder's value

The average correlation is 0.28 in the untimed treatment and 0.43 in timed treatments. The difference is significant, suggesting that there may be more signaling in the timed treatment than in the untimed treatment. The average correlation in the seven (1 untimed and 6 timed) markets that averaged 5 or fewer bids per auction is 0.52, which is significantly higher than the correlation of 0.33 in the other markets (t = 2.10, p-value (one sided) = 0.0416). This is additional evidence that bidders in markets with fewer bids may be signaling, since in the simplest models of tacit collusion there is no correlation between bids and values.

6. Conclusions and Discussion

We present an experiment and a simple model of English auctions with impatient bidders. The results of the laboratory experiment are largely consistent with the predictions of the model. Bidders tend to increase the size of their jump bids as time becomes more costly and the size of the jump bid is a decreasing function the bid order (as well as the current high bid) and an increasing function of the bidder's valuation.

The data also reveals some more surprising results. Most importantly, making time more costly does not appear to directly impact the performance of the English auction. The auctions under the timed condition are just as efficient, yield the same revenue, and generate the same bidder profits as the untimed auctions. One of the primary motivations for the study of costly bidding is that it might impact the performance of the auction so we find this result intriguing. It is in contrast, for example, to the results we report in Katok and Kwasnica (2005) where we find that slow Dutch auctions can yield higher revenues than faster Dutch auctions and first-price sealed bid auctions.

Why might this be happening? We think there are at least two potential explanations. It may be that the experimental treatment may not have made time sufficiently costly. While it is clear that bidders did react to the treatment condition, perhaps the cost was not enough to create inefficient outcomes or differences in the division of surplus. Alternatively, given that bidders are following strategies in which the size of the jump bid decreases at high bid levels and close to their value, bidders are less likely to cross over the second highest value by very much. For all the cases in which they do jump beyond the second highest value, there are instances in which the bidding ends early (before the second highest value). It stands to reason that auctions with a greater number of bidders pose greater problems for efficiency since the expected distance between the first and second highest values will be smaller. Bidders might also have a greater incentive to signal high valuations by placing large jump bids early.

But the fact that in the laboratory bidders decrease their jump bids as the bid level increases, and that this prevents efficiency losses, offers a valuable insight to auction designers. A critical yet little studied element of auction design is that the auctioneer usually selects a minimum bid increment level. A better understanding of bidder behavior in these environments would provide insights that we would like to feed back into the revenue (or efficiency) maximizing decisions of the mechanism designer.

What increment should the auctioneer set given that he knows time is costly and bidding takes time? For example, eBay's rules about minimum bid increments prescribe that bid increments *increase* in proportion with the bid level, not decrease. Given that many people treat eBay as if it were an English auction (see for example Roth and Ockenfels (2002) and Ockenfels and Roth (2002,2003)), impatience may actually cause a decrease in efficiency on eBay (in contrast to our experiment), since at high bid levels the institution would prevent people from increasing their bids in smaller increments. The practical question of how to set the minimum bid increment most effectively in an eBay-like setting may well be an empirical one. Given that bidders are impatient, many do not understand proxy bidding and bid on eBay as if it were an English auction, while others use the hard closing rule strategically and snipe, a controlled laboratory setting may be appropriate to gain further insight into this question.

The FCC spectrum auctions also use an increasing minimum increment schedule. While the justification for the FCC design is to speed up the auction, it seems that bigger increments early on and small increments in the end might be more beneficial. In fact, as our experiments demonstrate, that is what occurs naturally when bidders are given the choice of increment level; these sort of decreasing increment levels is what one often observes when watching a skilled oral auctioneer at work.

Finally, the distinction between collusion and signaling should be examined more closely. While some of the literature on jump bidding has identified signaling equilibria, recent work by Brusco and Lopomo (2001) and Kwasnica and Sherstyuk (2005) has shown that signaling can be used for tacit collusion (e.g., coordinating on a strategy that is Pareto improving for the bidders). When bidding is costly, can collusive signaling equilibria be found?

References

Aberdeen Group, Making e-Sourcing Strategic: From Tactical Technology to Core Business Strategy, September 2002, Boston, MA http://www.marketresearch.com.

Avery, Christopher, "Strategic Jump Bidding in English Auctions," *Review of Economic Studies*, 1998, 65, pp. 185-201.

Bapna, R., Paulo Goes, and Alok Gupta, "Analysis and Design of Business-to-Consumer Online Auctions," *Management Science*, 2003, 49(1), pp. 85-101.

Banks, J., Olson, M., Porter, D., and Smith, V. "Theory, Experiment and the Federal Communications Commission Spectrum Auctions," *Journal of Economic Behavior and Organization*, 2003, 51(3), pp. 303-350.

Brusco, S. and Lopomo, G., "Collusion via Signaling in Simultaneous Ascending Bid Auctions with Heterogeneous Objects, with and without Complementarities," *Review of Economic Studies*, 2002, 69(2), pp. 407-436.

Carare, Octavian and Rothkopf, Michael, "Slow Dutch Auctions," *Management Scienc*e, March, 2005, 51(3).

Cox, James, Bruce Roberson, and Vernon L. Smith, "Theory and Behavior of single object auctions," *Research in Experimental Economics*, 1982, 1, pp. 61-99.

Cramton, Peter, "The FCC Spectrum Auctions: An Early Assessment," *Journal of Economics and Management Strategy*, 1997, 6, pp.431-495.

Daniel, Kent D., and David Hirshleifer, "A Theory of Costly Sequential Bidding," Mimeo. 1998.

Easley, Robery F. and Rafale Tenorio, “Jump Bidding Strategies in Internet Auctions,” *Management Science*, October 2004, 50(10), pp. 1407-1419.

Engelbrecht-Wiggans, R. and Elena Katok, “e-Sourcing in Procurement: Theory and Behavior in Reverse Auctions with Non-Competitive Contracts,” *Management Science*, forthcoming.

Fischbacher, U., “z-Tree - Zurich Toolbox for Readymade Economic Experiments - Experimenter's Manual,” Working Paper Nr. 21, Institute for Empirical Research in Economics, University of Zurich, 1999.

Global Exchange Services, “GE GSN, The World’s Largest Private Web Marketplace: case study,” General Electric, Gaithersburg, MD, 2003.

Isaac, R.M., T.C. Salmon and A. Zillante, “A Theory of Jump Bidding in Ascending Auctions.” Mimeo. 2004.

Isaac, R.M. and Walker, J.M., “Information and Conspiracy in Sealed Bid Auctions,” *Journal of Economic Behavior and Organization*, 1985, Vol. 6. pp. 139-159.

Katok, Elena and Anthony M. Kwasnica, “Time is Money: The effect of clock speed on seller’s revenue in Dutch auctions,” ISBM Working Paper 11-2002, can be accessed at: http://lema.smeal.psu.edu/katok/dutch_post.pdf, last revision 11/2005.

Kwasnica, Anthony M. and Katerina Sherstyuk, “Collusion and Equilibrium Selection in Auctions,” forthcoming in *The Economic Journal*, 2005.

Lucking-Reiley, David H. "Using Field Experiments to Test Equivalence Between Auction Formats: Magic on the Internet." *American Economic Review*, December 1999, 89(5), pp. 1063-1080.

Milgrom, Paul and Robert Weber, “A Theory of Auctions and Competitive Bidding,” *Econometrica*, 1982, 50, pp. 1089-1122.

Ockenfels, Axel and Alvin E. Roth, “The Timing of Bids in Internet Auctions: Market Design, Bidder Behavior, and Artificial Agents,” *AI Magazine*, 2002, Fall, pp. 79-88.

Ockenfels, Axel and Alvin E. Roth, “Late and Multiple Bidding in Second-Price Internet Auctions: Theory and Evidence,” *Games and Economics Behavior*, 2003.

Porter, D., Rassenti, S., Roopnarine, A., and Smith, V. “Combinatorial Auction Design,” Proceedings of the National Academy of Sciences of the United States of America, 2003, 100(9), pp. 11153-11157.

Roth, Alvin E. and Axel Ockenfels “Last-Minute Bidding and the Rules for Ending Second-Price Auctions: Evidence from eBay and Amazon Auctions on the Internet,” *American Economic Review*, 92 (4), September 2002, 1093-1103.

Rothkopf, Michael H. and Ronald M. Harstad “On the role of discrete bid levels in oral auctions,” European Journal of Operational Research, 74(3), May 1994, 572-581.

Sawhney, M., “Forward Thinking about Reverse Auctions,” *CIO Magazine*, article number 060103, June 1 2003.

Appendix

Proof of Proposition 1. Suppose not. Then for all $c(t)$ and *m* bidding $b_{t+1} = b_t + m$ up to v_i is an equilibrium for both bidders. Consider a bidder with a value v_i and suppose the current high bid is held by the other bidder (*j*) at $b_t = v_i - 3m.$ Then pedestrian bidding would prescribe that bidder *i* bid $b_{t+1} = v_i - 2m$ in the next round. Then, given that the other bidder is also bidding in such a manner, a number of things can happen. If $v_i - 3m \le v_j < v_i - m,$ bidder *i* will win with a bid of b_{t+1} since *j* will be unwilling to raise the bid. If, however, $v_j \ge v_i - m,$ the other bidder will outbid bidder *i* in the next round with a bid of $b_{t+2} = v_i - m.$ If so, then *i* will bid $b_{t+3} = v_i$ in the next round. In which case, bidder *i* will be outbid only if $v_j \ge v_i + m.$[13] The expected value from pedestrian bidding at this stage is thus given by:

$$E^P = (2m - c(t+1))\,p_1 + (-c(t+3))[p_2 + p_3] + (-c(t+4))\,p_4 \qquad (1)$$

where

$$\begin{aligned} p_1 &= F(v_j < v_i - m \mid v_j \ge v_i - 3m) \\ p_2 &= F(v_i - m \le v_j < v_i \mid v_j \ge v_i - 3m) \\ p_3 &= F(v_i \le v_j < v_i + m \mid v_j \ge v_i - 3m) \\ p_4 &= F(v_j \ge v_i + m \mid v_j \ge v_i - 3m). \end{aligned}$$

[13] This result holds even if we allow for pedestrian bidding where bidders stop short of their value as we show to be the case in all equilibria where time is valuable (Proposition 2).

Note that $p_1 + p_2 + p_3 + p_4 = 1.$ Now consider a jump bidding strategy of bidding $b_{t+1} = v_i - m.$ If this strategy is used, then bidder *i* will win in this round if $v_j \le v_i,$ and bidder *i* will be outbid (and not bid again) if $v_j > v_i.$ This strategy yields the following expected payoff:

$$E^J = (m - c(t+1))[p_1 + p_2] + (-c(t+2))[p_3 + p_4]. \qquad (2)$$

By supposition that pedestrian bidding is an equilibrium, it must be that $E^P \ge E^J,$ or

$$mp_1 + (-m + (c(t+1) - c(t+3)))\,p_2 + (c(t+2) - c(t+3))\,p_3 + (c(t+2) - c(t+4))\,p_4 \ge 0. \quad (3)$$

Note that since $c(t)$ is increasing mp_1 is the only positive term. Thus, it is easy to see how one could construct cost functions to yield a contradiction. Specifically, let cost be linear in *t*, or $c(t) = ct.$ Then we have the following inequality from (3):

$$\begin{aligned} mp_1 + (-m - 2c)\,p_2 + (-c)\,p_3 + (-2c)\,p_4 &\ge 0 \\ m(p_1 - p_2) - c(2p_2 + p_3 + 2p_4) &\ge 0 \\ c &\le \frac{m(p_1 - p_2)}{2p_2 + p_3 + 2p_4}. \end{aligned}$$

Thus, as long as $c > \dfrac{m(p_1 - p_2)}{2p_2 + p_3 + 2p_4},$ the jump bidding strategy will be preferred yielding a contradiction with pedestrian bidding being an equilibrium.

Proof of Proposition 2. Consider $b_t = v_i - m.$ In this case, not bidding (abstaining) yields the guaranteed payoff (loss) of $-c(t)$ whereas bidding $b_{t+1} = v_i$ (the minimum acceptable bid) yields a payoff of either $-c(t+1)$ if bidder *i* wins the auction, or $-c(t+2)$ if bidder *i* is subsequently outbid. Clearly, $-c(t) > -c(t+1)\,p + -c(t+2)(1-p)$ for all *p* and *t*, where $p > 0$ is the probability of the auction ending at $b_{t+1} = v_i.$ This shows that bidders will always stop bidding *at least* one increment before reaching their value.