The Effect of Timing on Bid Increments in Ascending Auctions

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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 bid increment level becomes a strategic decision. We study the choice of bid increments in the experimental laboratory by systematically altering the opportunity costs associated with fast bidding. We find that when time is more valuable bidders respond by bidding larger increments. 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 bid increments have on auction performance.

**Keywords:** Auctions, Experimental Economics

**JEL Classifications:** D44, C91

1. **Introduction and related literature**

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 *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 (GEN).\(^3\) Other examples of the use of electronic auctions for procurement include the U.S. General Services Administration (Sawhney 2003) that attributed

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\(^1\) 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 (2005) 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.

\(^3\) According to a case study written by GE’s Global Exchange Services (Global Exchange Services 2003), GE’s Global Exchange Network is used by about 35,000 suppliers and handles over 10,000 e-invoicing enquiries per day. Approximately 37,000 reverse auctions, worth about $28.6 billion, have been conducted between 2000 and the 2\(^{nd}\) quarter of 2002, generating $680 million in savings in 2000-01 and additional $900 million in savings projected for 2002.
savings of 12% to 48% to the use of reverse auctions, and FreeMarkets—the leading on-line auction software provide—that saved approximately 20% for their customers on over $30 billion in purchases between 1995 and 2001.

The Internet allows geographically dispersed bidders to compete on price, potentially leading to lower costs for the buyers, and Internet auctions typically last anywhere from a few hours (FreeMarkets) to over a week (eBay). The Internet technology puts a limit on how fast an auction can run because issues such as network congestion must be considered. Besides the Internet, there are a number of other settings such as complex combinatorial auctions and department store sales (see for example Carare and Rothkopf 2005), in which fast auctions are also not feasible. But standard auction theory does not consider the role of time in auctions; it assumes that all auctions occur instantaneously. As applications for slower auctions become more prevalent, the issue of time, its associated costs, and the effect these costs have on bidding behavior, become more relevant, and our work aims to start filling this gap.

In Katok and Kwasnica (2004) 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 (2004) 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 important 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.

In the present paper we extend our work in Katok and Kwasnica (2004), and investigate the role of bidder impatience on bidder behavior in English auctions. The English auction is an open outcry, ascending auction; bidders are free at any time to 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. As in the Dutch auction, bidders in the English auction can take actions to reduce the costs associated with slow auctions. The most obvious strategy is to jump bid or to bid an amount greater than the minimum increase required by the auctioneer. The empirical relevance of jump bid 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 Federal Communication Commission (FCC) and find that jumping bidding is a persistent and common (sometimes upward of 40% of the bids) feature of these auctions. Jump bidding may
allow a bidder to reduce the costs of slow auctions by speeding up the auction, but this strategy may also affect auction performance. In the process of bidding, the bidder might inadvertently pass by the second highest bidder resulting in foregone profits for the bidder, or the bidder might stop bidding early causing reduced revenue for the auctioneer. While a number of experimental studies have suggested that jumping 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 whether this affects the overall performance of the institution. Most previous studies have focused on the value of jump bidding as a technique for bidders to signal their values. In an affiliated value setting (Avery 1998) and in a private value setting with costly bidding (Daniel and Hirshleifer 1998), previous studies have shown that there exist equilibria where bidders place large jump bids early in order to communicate information and end bidding early. Our focus is on bidding behavior when time is valuable. Therefore, we examine a situation similar to that originally developed in Katok and Kwasnica (2004) where bidders experience significant opportunity or monitoring costs associated with the auctions.\(^4\) We find that while bidder behavior is affected by an increase in the costs associated with slow auctions, the aggregate performance of the auction (efficiency, bidder profits, and seller revenue) is robust to these costs. These results are particularly relevant for the designer of procurement auctions since the vast majority of these auctions are conducted as English auctions and the employees tasked with monitoring and bidding in these auction often face high opportunity costs (e.g., they are highly paid and many other responsibilities).

We start by formulating some simple theory that helps us articulate research hypotheses and provide a baseline for laboratory tests (section 2). We then implement impatience in the

\(^4\) 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.
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 predetermined number of auctions in a session (hence referred to as the “untimed” treatment). The description of the experimental design and the protocol is in section 3, and the results are in section 4. In section 5 we present conclusions and discuss practical implications of our work. Proofs are contained in the appendix.

2. 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 \( v_i \) drawn from the common distribution \( F \) with support on \([0, \bar{v}]\). We assume that bidders are impatient. As time passes bidders bare a cost \( c(t) \) for participating in the auction. A bidder’s profit from participating in an auction that lasts for time \( t \) is given by

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

(1)

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. 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 effort of repeatedly returning to the auction website to see if the object is still available. We assume that \( c(t) \geq 0 \) and increasing in \( t \).
The English auction is characterized in the following manner. The auction begins at time $t = 1$. Bidders can simultaneously enter a bid or abstain from bidding. The high bid, $b_t$, is announced 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.

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 (2004), where each player selects at most one action, the English auction is a dynamic game with many actions (bids) by each player. This greatly complicates the analysis and makes complete characterization of the equilibrium set nearly impossible. While Isaac et al. (2004) turn to simulation to deal with this problem, we investigate what sorts of actions we can rule out as potential equilibria and then 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. The first proposition shows that for sufficiently high opportunity costs we can expect jump bidding in any equilibrium.

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\(^5\) In practice, the bid increment often changes during the course of the auction. The results presented here could easily 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.
**Proposition 1:** For all \( m \), there exists \( c(t) \) such that pedestrian bidding is not in 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 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 bid increment she will prefer to offset the costs.

Unfortunately, it is difficult to say much more explicitly about the 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 essentially identical 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 certainly 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 bid) 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.

It is easy to see that 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 since increasing the bid to one’s value extends the auction by at least one round with no profit from the object purchase. However, the extent that 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 it would without costly bidding resulting in lower seller revenue and higher bidder profits. Finally, both these behaviors open the door for potential loses in economic efficiency (the object is not won by the highest valuing bidder). While these effects are certainly possible, they seem to pull the auction in different directions and it is difficult to determine theoretically the exact extent to which the auction will be impacted. Therefore, we turn to the laboratory to understand bid increment behavior when time is valuable.

3. 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. 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. If no new bids were placed in 30 seconds, the auction ended and the object was awarded to the high bidder at the amount of her last bid. 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.

The objective of this study was to systematically vary the costs associated with bidding in order to observe how bidder behavior and auction performance responded to the change. This study focuses on 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 auctions as possible in 60 minutes. At the end of 60 minutes, the bidders were paid according to the number of auctions actually completed.

The expectation was that in the untimed treatment the costs associated with a longer auction are negligible since the bidders know that they will complete 20 auctions no matter what. In the

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6 However, there are bidders who bid well below one unit at times.

7 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 that bidders could coordinate on a collusive strategy with one object for sale and no communication (Isaac and Walker 1984). Indeed, the data demonstrates this.
timed treatment, the speed of the auction should now be salient. By completing the auctions faster, bidders are able to complete more auctions thereby increasing their earnings. This is not to say that a faster auction has no benefits in the untimed treatment. In fact, if a group completed 20 auctions faster in the untimed treatment, they would be paid their earnings and allowed to leave sooner. Assuming that bidders value their time outside of the lab and would rather get paid sooner rather than later, it is easy to see that experimental bidders might even perceive some opportunity costs in the untimed treatment. The hope, however, is that in the untimed treatment the speed of the auction is a much more obvious concern.

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.\(^8\)

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.

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\(^8\) 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, since the computer error was unexpected so it should not have affected behavior.
4. Results

In this section we discuss the results and how they compare to the model of bidding we presented earlier. We report the summary of the performance of auctions and the comparisons between the untimed and the timed treatments in Table 1.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Untimed</th>
<th>Timed</th>
<th>t-statistic (p-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of auctions</td>
<td>20.00</td>
<td>24.05</td>
<td>4.05 (0.0005)</td>
</tr>
<tr>
<td>Average Bid increment</td>
<td>2.88</td>
<td>5.47</td>
<td>4.47 (0.0002)</td>
</tr>
<tr>
<td>Seconds per Auction</td>
<td>101.00</td>
<td>59.50</td>
<td>7.47 (0.0001)</td>
</tr>
<tr>
<td>Seconds per bid</td>
<td>13.70</td>
<td>15.87</td>
<td>5.77 (0.0001)</td>
</tr>
<tr>
<td>Average Revenue</td>
<td>32.2</td>
<td>31.9</td>
<td>0.22 (0.4155)</td>
</tr>
<tr>
<td>Average Bidder profit</td>
<td>29.4</td>
<td>31.6</td>
<td>1.2 (0.1215)</td>
</tr>
<tr>
<td>Efficiency</td>
<td>90.40%</td>
<td>89.80%</td>
<td></td>
</tr>
</tbody>
</table>

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 potentially 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 90.4% of all auction periods are efficient, and in the timed condition the proportion of efficient periods is still 89.8%. A Chi-squared test for differences in these proportions finds no statistically significant
difference ($X^2 = 0.034$). Bidder profits and seller revenue are also similar under the two treatments. Bidder profits average 31.6 per period under the timed treatment as opposed to 29.4 under the untimed condition. This difference is not statistically significant. Average seller revenue is 32.2 when the auction is untimed and 31.9 when it is timed (also not significantly different).

When combined with the findings of Katok and Kwasnica (2004), the first result demonstrates that the effect of timing is not independent of the institution. In English auctions impatience does not affect the seller’s revenues, but in Dutch auctions, as we report in Katok and Kwasnica (2004), impatience increases the seller’s revenue. Interestingly, impatience does not affect efficiency in either mechanism.

In order to understand why we see no difference in overall auction performance between the two treatments, we turn to an examination of individual bidder behavior.

Result 2: The bid increment increases in the timed treatment.

When time is costly bidders should increase the bid increment at all current bid levels. The average increment in the timed treatment is 5.47 compared to 2.88 in the untimed condition, and the difference is highly significant. Not surprisingly, this leads to faster auctions. The time between the first and last bids placed in each auction period averaged 101.0 seconds in the untimed treatment but is significantly smaller at 59.5 seconds in the timed treatment. This allows bidders in the timed treatment to complete significantly more auction periods (24.0) than the 20 in the untimed condition.

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9 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 the first bid placed. The first bid was generally placed shortly after the opening of the auction, and there is little reason to expect significant variation due to the treatments.
Given the auction institution investigated, bidders actually had two methods they could use to speed up bidding. They could place bigger increments or respond more quickly to bids 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 bid. 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 second per bid is 13.7 in the untimed treatment, and is slightly larger, at 15.9 in the timed treatment. This difference is statistically significant. It may be that the added salience of the bid increment 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.

For the remainder of this paper, we focus on the bid increment as the strategic choice variable. The next step is to investigate how the bid increment is affected by other variables in the auction such as bidder values and the current high bid. Figure 1 shows how the bid increment changes over time (a), and the percentage of auctions that had various numbers of bids placed.

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10 This incentive could not be easily avoided with other implementations of the English auction. For example, in an iterative auction like the theory model, bidders could simply make their selection in that stage quicker causing a quicker movement to the next stage. The only sure solution to avoid this would be to guarantee that each iteration lasted a fixed period of time such as is the case in the FCC spectrum auctions. This, however, creates very slow auctions.
The average first bid placed is higher in the timed treatment than in the untimed treatment, and the bid increment 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.

Figure 2 shows the first (a) and the average (b) bid increment as a function of the bidder’s value.
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 bid increments appear to be uniformly higher at medium and high values in the timed treatment.

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

![Graphs showing average bid increment and number of auctions](image)

The bid increment stays constant in the timed treatment (as it should), 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 increments in later periods are due to a small number of groups that were actually able to conduct this many auctions. There is also some endogenerity in the sense that groups who use bigger increments will be able to complete more auctions in the timed treatment.

In summary, average bid increments are higher in the timed treatment than in the untimed treatment, and the difference is due to several factors: (1) Bidders in timed treatments start out bidding higher, and although bidders in both treatments decrease their bid increments 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 bid increment remains higher in that
treatment. Both, initial and average bid increments increase with value, but the bid increments for the same value are generally higher in the timed treatment (Figure 2). Bid increments do not change in later periods in untimed treatments but do increase in timed treatment (Figure 3a). The number of auctions groups are able to conduct decreases steadily after the 20th period.

We now present these results more formally using the following regression model:

\[
\begin{align*}
\log(X_{i,order}) = \beta_0 + \beta_1 \delta + \beta_2\log(X_{i,order}) + \beta_3\log(X_{i,order})^2 + \epsilon
\end{align*}
\]

where \(b_{it} - b_{it-1}\) is the bid increment for bidder \(i\), \(\delta\) is 1 if bidder \(i\) is in the timed treatment and 0 otherwise, \(X_{i,order}\) is the order of that bid\(^{11}\) (in other words, the order of bidder \(i\)'s first bid is 1, her second bid is 2, and so on), and we use \(\log(X_{i,order})\) in the model because it is apparent from Figure 1a that the relationship between the bid increment and the order of bid is non-linear, \(X_{i,period}\) is the period number in which the bid was placed, \(X_{i,value}\) is \(i\)'s value when she placed the bid. We use ordinary least squares (OLS) with fixed effects to estimate (1) and report the results in the second column of Table 2. As an additional robustness check we also estimate a separate model for each bidder \(i\):

\[
\begin{align*}
\log(X_{i,order}) = \beta_0 + \beta_1 \delta + \beta_2\log(X_{i,order}) + \beta_3\log(X_{i,order})^2 + \epsilon
\end{align*}
\]

\(^{11}\) We use the bid order instead of the current highest bid in the regression model in order to avoid potential multicollinearity between the current highest bid and the value, and improve exposition. The bid order carries similar information as the current highest bid (since the highest bid increases every time a new bid is placed). Regression results are almost identical if we use the current highest bid, but the relationship cannot be easily seen graphically as the relationship in Figure 1a.
We present the means of the individual coefficients and the corresponding standard errors in the third column of Table 2. In the last two columns of the table we report the percentage of subjects for whom the estimate of (2) was significant, and the percentage of subjects for whom the estimate was significant and the sign of the estimate was consistent with the sign of the corresponding estimate in the OLS with fixed effects model.

<table>
<thead>
<tr>
<th></th>
<th>OLS with fixed effects (model (1))</th>
<th>Individual OLS (model (2))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimate (standard error)</td>
<td>Estimate (standard error)</td>
</tr>
<tr>
<td>$\beta_i$ (intercept)</td>
<td>2.7423 (0.243) **</td>
<td>2.7761 (0.4172) **</td>
</tr>
<tr>
<td>$\delta_i$ (treatment)</td>
<td>0.9023 (0.3932) **</td>
<td>-2.3764 (0.3582) **</td>
</tr>
<tr>
<td>$\beta_{order}$</td>
<td>-1.2916 (0.0742) **</td>
<td>-2.3764 (0.3582) **</td>
</tr>
<tr>
<td>$\beta_{order}^T$</td>
<td>-1.1121 (0.1221) **</td>
<td>-1.1121 (0.1221) **</td>
</tr>
<tr>
<td>$\beta_{period}$</td>
<td>0.0141 (0.0111)</td>
<td>0.1244 (0.0773)</td>
</tr>
<tr>
<td>$\beta_{period}^T$</td>
<td>0.0457 (0.0153) **</td>
<td>0.0457 (0.0153) **</td>
</tr>
<tr>
<td>$\beta_{value}$</td>
<td>0.0324 (0.0024) **</td>
<td>0.0481 (0.0069) **</td>
</tr>
<tr>
<td>$\beta_{value}^T$</td>
<td>0.0212 (0.0036) **</td>
<td>0.0212 (0.0036) **</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.3387</td>
<td>0.2611</td>
</tr>
</tbody>
</table>

** p-value < 0.05; * p-value < 0.10
Table 2. Regression results

The results we report in Table 2 mostly confirm the patterns suggested by Figures 1-3. The bid increment is higher in the timed treatment and decreases significantly as the auction continues. The bid increment also appears to increase with bidder value. The effect of period and value is more pronounced in the timed treatment.
Result 3: There is significant heterogeneity in bidder behavior.

There is a substantial amount of heterogeneity. Figure 5 shows the distributions of average bid increments by individuals in the timed and the untimed treatments. While smaller increments are more common under the untimed treatment, there are still differences across bidders.

![Figure 5. Distributions of average bid increment by bidder.](image)

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 at 0.25, so how the bid increment 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 $\beta_{\text{period}}$ 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, they respond in the way consistent with our model.

**Result 4: 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. The data provides some evidence of this behavior. 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, 31.4% of all auction periods ended early. In the timed treatment, the percentage rises to 44.0%. Using a Chi-squared test, we can reject the hypothesis that these proportions are equal at any reasonable level of significance ($X^2 = 14.98$). 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 bid increment choices can easily bid past the second highest bid. Contingent upon stopping below one’s value, the treatment condition does not appear to matter. The average distance between the winning bid and the second highest value in these auctions was 14.3 (untimed) and 12.4 (timed), which is not a statistically significant difference ($t=1.02$). It is somewhat surprising that the timed treatment did not cause this distance to increase more.
Result 5: 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 and Avery. Signaling equilibria entail bidders placing value revealing high bids very early on in the auction process. As the discussion following Result 2 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 bid increment choice. There seems to be 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: 10.9 (untimed) and 6.5 (timed). While these averages are significantly different (t = 8.00), it should not be surprising since the bid increment also increased in the timed treatment. Figure 6 shows the distribution of the number of bids placed by 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 averaged less than 5 bids per round. This might be evidence 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 (2003) 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.\footnote{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.}
5. 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 their bid increment as time becomes more costly and the bid increment is a decreasing function the bid number (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 (2004) 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 where the bid increment decreases at high bid levels and close to their value, bidders are unlikely to cross over the second highest value by very much, and for all the cases where they accidentally jump beyond the second highest bid there are instances where 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 less. Also, bidders might have a greater incentive to bid large increments early on.

But the fact that in the lab bidders decrease their bid increments 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. By understanding bidder behavior in these environments, we would like to feed that back into the revenue (or efficiency) maximizing decisions of the mechanism designer. What increment should the auctioneer set given that they know 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 FCC spectrum auctions also use an increasing minimum increment schedule. While the justification for these designs 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 organically 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 must be examined more closely. While some of the literature on bid jumps has identified signaling equilibria, recent work by Brusco and Lopomo (2001) and Kwasnica and Sherstyuk (2002) 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


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 \(v_{i} - 3m \leq v_{j} < v_{i} - m\), bidder \(i\) will win with a bid of \(b_{t+1}\) since \(j\) will be unwilling to raise the bid. If, however, \(v_{j} \geq v_{i} - m\), 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 \(v_{j} \geq v_{i} + m\). The expected value from pedestrian bidding at this stage is thus given by:

\[
E^{p} = (2m - c(t + 1))p_{1} + (-c(t + 3))[p_{2} + p_{3}] + (-c(t + 4))p_{4} \tag{3}
\]

where

\[
p_{1} = F(v_{j} < v_{i} - m \mid v_{j} \geq v_{i} - 3m)
p_{2} = F(v_{i} - m \leq v_{j} < v_{i} \mid v_{j} \geq v_{i} - 3m)
p_{3} = F(v_{i} \leq v_{j} < v_{i} + m \mid v_{j} \geq v_{i} - 3m)
p_{4} = F(v_{j} \geq v_{i} + m \mid v_{j} \geq v_{i} - 3m).
\]

\[13\] 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 \( v_j \leq v_i \), and bidder \( i \) will be outbid (and not bid again) if \( v_j > v_i \). This strategy yields the following expected payoff:

\[
E^J = (m - c(t + 1))[p_1 + p_2] + (-c(t + 2))[p_3 + p_4]. \tag{4}
\]

By supposition that pedestrian bidding is an equilibrium, it must be that \( E^p \geq E^J \), or

\[
mp_1 + (-m + (c(t + 1) - c(t + 3)))p_2 + (c(t + 2) - c(t + 3))p_3 + (c(t + 2) - c(t + 4))p_4 \geq 0. \tag{5}
\]

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 (5):

\[
mp_1 + (-m - 2c)p_2 + (-c)p_3 + (-2c)p_4 \geq 0
\]

\[
m(p_1 - p_2) - c(2p_2 + p_3 + 2p_4) \geq 0
\]

\[
c \leq \frac{m(p_1 - p_2)}{2p_2 + p_3 + 2p_4}.
\]

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

**Proof of Proposition 2.** Consider \( b_i = v_i - m \). 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.