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A comparison of Candle Auctions and Hard Close Auctions with Common Values

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Abstract:

With this study, we contribute to the literature of auction design by presenting a new auction format: the *Candle auction*, a popular auction in the Middle Ages. Considering a common value framework, we theoretically and experimentally point out that the *Candle auction*, where bidding is allowed until a stochastic deadline, yields a better outcome to the seller than the *Hard Close auction*, the popular eBay online auction format.

Keywords: online auctions, market design, experimental economics, common value

JEL No: C73, C9, D44

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1. Motivation

Auction design has emerged as a popular topic in economic research. To the question "*which auction design leads to the best outcome"* no unique answer exists. The appropriate design depends mainly on the objective of the auction (revenue, allocation), the participants (buyers, sellers, auctioneer, third parties), and the object (private or common values, independent or interdependent). Several auction designs have been studied so far, basically starting with the seminal paper of Vickrey in 1962.

With this study, we contribute to the literature of auction design by presenting a theoretical and experimental analysis of *Candle auctions*. In the original version from the Middle Ages, bidders engage in an ascending auction until a burning candle dies out. Note, that the probability of the candle flame dying out was positive at any time. Historical evidence on this auction form includes chattels or leases in France, 14th/16th century, Ships in England, Books in Italy, and Goods from the East Indies, 17th century, chattels and real Estates of the church in France and Furs in England, 18th century (Cassady, 1967, Hobson, 1971, Patten, 1970, Sargent and Velde, 1995). We implement the idea of a stochastic deadline into the dynamic second price auction setting (Füllbrunn and Sadrieh, 2006, Houssain, 2008). Every bidding stage has a positive termination probability, i.e. the auction can end after every stage. Hence, neither bidder knows the number of bidding stages and the next bid can be the last bid.

In Hard Close auctions bidders have a pre-specified time period to submit bids. Using the proxy bidding system, the bidder with the highest bid receives the object and pays a price that equals the second highest bid.[1] In the dynamic second price auction setting, bidders know exactly the number of bidding stages. Particular attention in this auction format is paid to the deadline, because in the last point in time bidders can submit one final bid, leaving no possibility for the other bidders to response.[2] Empirical studies show that bidding activity is concentrated on the

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[1] In the proxy bidding system bidder i submits a maximum bid she is prepared to pay and a bidding agent overbids all other bidders as long as i's maximum bid is reached. Therefore, the current bids equals (is a pre-specified bid increment higher) the second highest maximum bid.

[2] We do not examine transmission problems in the very last point in time. For a discussion and experimental results on that issue, see Ariely et al. (2005).

end of the auction (Roth and Ockenfels 2002, Bajari and Hortaçsu 2003, Anwar et al. 2006, Hayne et al. 2003, Wilcox 2000) and many strategic reasons for late bidding have been discussed (Ockenfels and Roth 2006, Wintr 2004, Engelberg and Williams 2005, Rasmusen 2004, Hossain 2008, Füllbrunn 2007).[3]

Theoretical and empirical literature support late bidding behavior in common value environments as well. Assuming asymmetric bidders, Ockenfels and Roth (2006) provide a model where experts submit bids late in the auction in order to avoid revelation of more accurate information to the dealer. In an empirical study, Roth and Ockenfels (2002) show a higher frequency of late bidding in eBay auctions with *Antiques*, where "retail prices are usually not available and the value of an item is often ambiguous and sometimes require experts to appraise", than with C*omputers*, where "information about the retail price of most items is in general easily available". Assuming symmetric bidders, Bajari and Hortaçsu (2003) develop a model where information revelation during the Hard Close auction cannot be an equilibrium strategy. They predict that bids arrive only in the last stage. Hence, bidders choose bids only due to their private information. However, we found no experimental contribution that considers common values neither in Candle auctions nor in Hard Close auctions.

We hypothesize that the Candle auction is a device that reveals information in a common value environment and, thus, yields a better outcome to the seller. We provide theoretical and experimental evidence to support this thesis.

In the next section, we describe the game and discuss game theoretic issues. The design and the results of the experiment are considered in section 3, before we conclude in section 4.

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[3] Further mentioned reasons for late bidding or therefore, for multiple bidding are auction fever (Heyman et al. 2004), escalation of commitment and competitive arousal (Ku et al. 2005), the pseudo-endowment effect (Wolf et al. 2005).

2. The Game

We use the framework of *Sudden Termination Auctions* as firstly discussed in Füllbrunn and Sadrieh (2006). The auction consists of at most T bidding stages. In each bidding stage t, every bidder has the opportunity to submit her first bid or to raise her previous bid. The auction ends after any bidding stage t with the termination probability $q_t \epsilon \; [0, 1]$. In the Hard Close auction the termination probability equals zero in all stages $t < T$ and 1 in stage T. The Candle auction is defined by an increasing termination probability, i.e. $q_t < q_{\,t+1}$ for all $t < T$ and $q_T = 1$. The last conducted stage is called the final stage. A stage with some termination probability $q_t > 0$ is called a hazard stage.

According to the eBay pricing rule used in Ockenfels and Roth (2006), we study a dynamic second price auction, in which at any time t the current price is equal to the second highest bid submitted in the previous stage. The current holder(s) at time t is (are) the bidder(s) who has (have) submitted the highest bid. In each stage all bidders are informed on the current price and on their status as current holders. They are not informed on the bids of the other bidders.

When the auction ends, the current holder receives the item and pays the current price. Ties are broken by assigning the item with equal probabilities to one of the current holders. The payoff of the buyer - the bidder who receives the item - equals the difference between the common value and the price. All other bidders receive a zero payoff.

We consider the traditional common value model (Rothkopf, 1969; Wilson, 1969). The value of the object V is drawn from a uniform distribution on the interval $[V_l;\; V_h]$. During the auction the bidders do not know the common value. Each bidder $i \; (i = 1, \dots, n)$ receives a private signal s_i that is an unbiased estimation of the object valuation. Bidders are symmetric in that the distribution of the signals is identical for all bidders. The signals are identically and independently drawn from a uniform distribution that is centered on V with upper limit $V + \varepsilon$ and lower limit $V - \varepsilon$. We concentrate our analysis only on signals within the *region 2* interval

(Kagel and Levin 2002), i.e. $V_l + \varepsilon \leq s_i \leq V_h - \varepsilon$, because bidders with signals out of region 2 have additional information associated with the end-point values V_l or V_h, respectively.[4]

In both formats the final stage equals the Vickrey auction, i.e. the second price sealed bid auction. According to Matthews (1977), Milgrom and Weber (1982) and Levin and Kagel (1986) the equilibrium bid function (the *Vickrey bid*) with risk neutral bidders equals

$$b^V(s) = s - \frac{n-2}{n}\varepsilon.$$

The bidder with the highest signal receives the object and pays a price $p^V = b^V(s_{n-1})$, assuming signals $s_1 < s_2 < \cdots < s_n$ for bidder $1, \ldots, n$, respectively.

In the following, we demonstrate in a sketch of a proof that prices in Candle auctions are higher than in Hard Close auctions, because bidders in Candle auctions submit bids earlier in the auction process. In order to simplify the analysis, we consider two bidding stages ($T = 2$). The bidders submit a bid in the first stage. The second stage occurs with probability $1 - q$, where q equals zero in the Hard Close and is within 0 and 1 in the Candle auction. If the second stage occurs, the bidders observe all bids besides the highest. Afterwards, the bidders may submit a final bid.

Further on, we only consider two first stage bid possibilities. The bidders can submit either an informative bid (b^I) or an uninformative bid (b^U). The informative bid allows an exact inference on the bidders signal, i.e. $(b^I)^{-1}(b^I(s)) = s$. The function $b^I(s)$ is monotonically increasing with the signal and we assume $b^I(s_1) > 0$. Without information, the final stage is a Vickrey auction and the bidders will not exceed the Vickrey bid in the first stage, i.e. $b^I(s) \leq b^V(s)$. The uninformative bid provides no information on the bidders' signal. In order to avoid trouble with potential inferences from a specific bid, we assume $b^U(s)$ to be zero.

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[4] A consideration of signals in the whole valuation interval makes the analysis and the interpretation unnecessarily complicated for our purposes.

The Hard Close Auction

In the Hard Close auction two stages exist. At first, we consider second stage bids before we consider the entire bidding strategies.

Assuming solely uninformative bids in the first stage, the bidders have no additional information in the second stage. Thus, the second stage is basically a Vickrey auction with the respective outcome.

Assuming solely informative bids in the first stage, bidder $i \neq n$ infers all signals besides the highest in the second stage. Bidder n knows all signals. In the Vickrey auction the weakly dominant strategy is to submit a bid that equals the expected value of the object given all information. Therefore, the second stage bids equal[5]

$$b_n = \max\{b^I(s_n); E[V|s_1 = (b^I)^{-1}(b^I(s_1)), \dots, s_{n-1} = (b^I)^{-1}(b^I(s_{n-1})), s_{n-1}]\},$$

and

$$b_{i\neq n} = \max\{b^I(s_{n-1}); E[V|s_1 = (b^I)^{-1}(b^I(s_1)), \dots, s_{n-1} = (b^I)^{-1}(b^I(s_{n-1})), s_n > s_{n-1}]\}.$$

The according price is $p^I = b_{i\neq n}$. We refer to this situation as the *information outcome*.

Interjection: How do bidders in the second stage handle the observed information? At first assume all signals are common knowledge and you have to guess the common value. It is generally known, that the average of the signals is a good point estimator. However, a not even worse estimator is the median of the highest and the lowest signal. We ran several simulations with 10,000,000 observations each for a different number of n. The following table 1 displays one result. For every n the averages of the difference and of the distance are closer to the true value for the median estimator than for the average. In addition, the standard deviation is lower.[6] Concerning Greene (1999) the median estimator is more efficient than the average.[7]

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[5] Notice: if all bidders have the expected order statistics $b_n = b_{i\neq n}$ holds.

[6] Testing for $n = 4$ and $n = 10$ leaves no significant difference concerning the average of both estimators. However, the standard deviation for the median estimator is significantly lower in every case.

Table1: Estimation of the common value

n	V - average		V - median		abs(V - average)		abs(V - median)	
3	0,34	(600)	0,32	(569)	488	(350)	450	(349)
4	0,29	(520)	0,22	(465)	420	(306)	360	(294)
5	0,18	(465)	0,10	(393)	375	(275)	300	(254)
6	0,26	(424)	0,15	(340)	341	(252)	257	(223)
7	0,23	(393)	0,14	(300)	316	(234)	225	(198)
8	0,20	(367)	0,15	(268)	295	(219)	200	(179)
9	0,19	(346)	0,11	(243)	278	(207)	180	(163)
10	0,17	(329)	0,08	(221)	264	(196)	164	(149)
20	0,06	(232)	-0,02	(118)	186	(139)	86	(82)

Standard deviation in brackets, avg. = average of all signals, median = median of the highest and the lowest signal, V = common value, abs = distance

Using the median estimator the second stage bids equal

$$\hat{b}_n = \frac{s_1+s_n}{2}, \text{ and } \hat{b}_{i\neq n} = \frac{s_1+E[s_n|s_n>s_{n-1}]}{2}.$$

Using s_{n-1} as the lower boundary for $E[s_n|s_n > s_{n-1}]$, the expected sub game exceeds the Vickrey price:

$$\hat{b}_{i\neq n}(E[s_n|s_n > s_{n-1}] = s_{n-1}) = V - \frac{\varepsilon}{n+1} > V - \frac{2(n-1)\varepsilon}{n(n+1)} = E[p^V].$$

Hence, the bidder with the highest signal receives a higher expected payoff if bidders submit uninformative bids.

Can a symmetric strategy $B^I(s_i)$, with informative bids in the first stage, be an equilibrium strategy? It is sufficient to show that a defection of one bidder leads to a higher expected payoff to this bidder. Assume a unilateral defection in the first period of bidder n who submits $b^U(s_n)$, while bidder $i \neq n$ submits $b^I(s_i)$. In the second stage only $n-2$ bids are revealed and the according signals are common knowledge. For a sufficient high number of bidders, one missing signal disappears in the mass of the other signals. Therefore, we assume that the other bidders

[7] Concerning Greene (1999), an estimator of a parameter θ is unbiased if the mean of the sampling distribution is θ, i.e. $E[\hat{\theta}]=\theta$ (p.103, Def.4.2). Further on, an unbiased estimator $\hat{\theta}_1$ is more efficient than another unbiased estimator $\hat{\theta}_2$ if the sampling variance of $\hat{\theta}_1$ is less than that of $\hat{\theta}_2$ (p.103, Def.4.3).

neglect the missing signal. In the second stage the highest observed signal equals s_{n-2}.[8] Now three different bidder types separated by information levels exist: the bidder with the highest signal, who knows all signals but the second highest, the bidder with the second highest signal, who knows all signals but the highest, and all other bidders, who know all signals but the two highest. Due to an inferior information level of the other bidders, we only discuss the behavior of the two bidders with the highest signals.

The bidder with the second highest signal submits a bid assuming to have the highest signal, i.e. $\hat{b}_{n-1} = \frac{s_1+s_{n-1}}{2} < b_{i\neq n}$. Even if she assumes to have the second highest signal, her second stage bid will not exceed $b_{i\neq n}$. Bidder n knows that the signal of current holder exceeds s_{n-2}. However, she cannot see whether her signal is higher or lower. Assuming to have the highest signal her bid equals $\hat{b}_n = \frac{s_1+s_n}{2}$, and assuming to have the second highest signal her bid exceeds $\widehat{b}_n$. Independent of her real decision, her bid exceeds the bid of her direct competitor. Hence, the price equals $\widehat{b}_{n-1}$ and undercuts $b_{i\neq n}$.

Due to the uninformative bid, bidder n leaves bidder $n-1$ in the dark about a higher signal. Thus, the resulting price stochastically dominates a price without deviation and increases the payoff for bidder n. Summing up, a strategy $B^I(s_i)$ cannot be an equilibrium strategy.

Can a strategy $B^U(s_i)$ with uninformative bids in the first stage be an equilibrium strategy? Assume a unilateral defection in the first period, i.e. some bidder submits $b^I(s)$ in the first stage. Due to the fact that the highest bid is not revealed in the second stage, the Vickrey outcome evolves. Hence, for bidder i the strategy

$$B^U(s_i) = \left(b_1 = b^U,\ b_2 = \begin{cases} b^V(s_i), \text{ if } b_{j\neq i} = b^U \\ b^{BR}, \text{ elsewise} \end{cases} \right)$$

is an equilibrium strategy. In the first stage the bidders submit uninformative bids and in the second stage the bidders submit the Vickrey bid, unless a sufficient number of bidders submit informative bids in the first stage. In this case the bidders respond with a best response bid b^{BR}.

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[8] We are aware of the fact that the signal is not shown. However, we say the bidders *observe* a signal although they infer the signal from the observed bid.

Clearly the results hold when we consider T stages. The bidders submit uninformative bids until the final stage. In the final stage they submit the Vickrey bid.

In line with the argumentation of Bajari and Hortaçsu (2003) our theoretical consideration predicts *non-serious bids*, i.e. low or zero bids that are not correlated to the signal in the first $T-1$ stages, and Vickrey bids in stage T.

<u>The Candle Auction</u>

If we only consider symmetric bids in the first stage, the same results hold for the Candle auction given the second stage occurs. That is, if all bidders submit b^U, the Vickrey outcome evolves and if all bidders submit $b^I(s)$, the information outcome evolves. However, these outcomes occur only with probability $1-q$. With probability q the first stage is decisive.

Let $\tau = 1, 2$ be the realized numbers of stages. Further on let π^V and π^I be the expected payoffs, and p^V and p^I the expected prices for the Vickrey and the information outcome, respectively.

Can a strategy $B^U(s_i)$ as in the Hard Close auction be an equilibrium strategy? Assume, the bidders submit uninformative bids in the first stage. When $\tau = 1$, the auction turns into a lottery where each bidder receives V with probability $1/n$.[9] When $\tau = 2$, the bidder with the highest signal receives π^V. Hence, the expected payoff given all bidders submit an uninformative bid in the first stage for bidder i equals

$$E[\pi_i^U] = q\frac{V}{n} + \frac{1}{n}(1-q)\pi^V.$$

Now assume a deviation of bidder j, i.e. she alone submits an informative bid in the first stage. The according expected profit for bidder j equals

$$E\left[\pi_j\right] = qV + \frac{1}{n}(1-q)\pi^V > E\left[\pi_j^U\right].$$

When $\tau = 1$, she receives the entire surplus V, and when $\tau = 2$, she has no disadvantages even

[9] For simplification we allow a zero price.

if she has the highest signal. Hence, a deviation is worthwhile and the equilibrium strategy from the Hard Close auction does not hold.

Can a strategy $B^I(s_i)$ with informative bids in the first stage be an equilibrium strategy? Assume the bidders' informative bid equals $b^I(s) = b^V(s)$ in the first stage (Due to the fact that an individual informative bid function $b_i^I(s) > b^I(s)$ increases the probability of winning in the first stage, we do not think that the assumption of bidding the highest possible informative bid is farfetched). Hence, only the bidder with the highest signal wins independent of the number of stages. The expected payoff given all bidders submit an Vickrey bid in the first stage for any bidder equals

$$E[\pi_i^I] = \frac{1}{n}(q\pi^V + (1-q)\pi^I).$$

Now assume a deviation of bidder j, i.e. she submits an uninformative bid in the first stage. When $\tau = 1$, her payoff is zero. When $\tau = 2$ and bidder j has not the highest signal she cannot win in the second stage, given a sufficient number of bidders. This is due to the fact that she has almost the same information apart from the bidder with the highest signal. When $\tau = 2$ and bidder j has the highest signal, she wins in the second stage and receives a higher payoff $\bar{\pi}^I = V - \hat{b}_{n-1} > V - b_{i \neq n} = \pi^I$ (see page 7). In the following we assume $\bar{\pi}^I = \pi^I + \delta\varepsilon$ with $0 < \delta \leq \varepsilon/(n+1)$. Therefore, bidder j submits an uninformative bid only if

$$\frac{1}{n}(q\pi^V + (1-q)\pi^I) < \frac{1}{n}(1-q)(\pi^I + \delta\varepsilon), \text{ i.e. if } q < \frac{\delta\varepsilon}{\pi^V + \delta\varepsilon} \equiv q^*,$$

assuming that the bidder for $q = q^*$ decides on bidding the informative bid. Otherwise, she submits the informative bid in the first stage.

If the auctioneer or the seller is interested in higher prices, she chooses a termination probability that is not lower than q^*. This is due to the fact that the expected revenue given $q < q^*$ equals $qb^V(s_{n-2}) + (1-q)\hat{b}_{n-1}$ that is lower than $q^*b^V(s_{n-1}) + (1-q^*)b_{i \neq n}$. Therefore, we assume the seller to choose a termination probability $q \geq q^*$ that hinders the bidders to deviate from submitting informative bids.

Summing up, a termination probability below q^* leads to a worthwhile deviation and also a strategy $B^I(s_i)$ cannot be an equilibrium strategy. A termination probability above (or equal to) q^* hinders a unilateral deviation due to the fact that the expected second stage advantage from defection cannot outweigh the first stage loss. Hence, a strategy $B^I(s_i)$ with informative bids in the first stage is an equilibrium strategy if the termination probability is sufficiently high. The according strategy for bidder i is

$$B^I(s_i|q \geq q^*) = \left(b_1 = b^V,\ b_2 = \begin{cases} b_n, \text{ if } b_j = b^V \text{ and } i = n \\ b_{i \neq n}, \text{ if } b_j = b^V \text{ and } i \neq n \\ b^{BR}, \text{ elsewise} \end{cases} \right).$$

In the first stage the bidders submit informative bids and in the second stage the bidders submit the expected valuation given the revealed information, unless a sufficient number of bidders submit uninformative bids in the first stage. In this case the bidders respond with a best response bid b^{BR}.

In order to compare the results to the Hard Close auction it is necessary to determine the termination probability q. A revenue maximizing seller chooses $q = q^*$. The seller has to prevent defection, i.e. $q \geq q^*$. In this case her revenue is either p^V with probability q or p^I with probability $1 - q$. Due to $p^I > p^V$ the seller also has to maximize the probability to gain p^I. Hence, the termination probability should be the lowest given $q \geq q^*$.

Comparison between Hard Close and Candle Auction

Given the mentioned symmetric strategies and the seller's decision, the expected price in the Hard Close auction equals $p^{HC} = p^V$, and the expected price in the Candle auction equals $p^{CA} = q^* p^V + (1 - q^*) p^I$. The expected price in the Candle auction is higher than in the Hard Close auction. Hence, if the seller has to choose between the Hard Close auction and the Candle auction, the seller would choose the Candle auction due to higher revenue.

However, the assumption of an informative bid that equals the Vickrey bid in the first stage of the Candle auction seems to terminate this result. Relaxing this assumption, the Candle auction result depends on the first stage bid function $b^I(s)$. A first stage bid function below the Vickrey bid leads to a lower first stage price $b^I(s_{n-1}) \leq p^V$. The seller has to adjust the termination probability accordingly, e.g. $q^{**} > q^*$, to prevent defection from the informative bid in the first stage. The according expected price changes to $p^{CA}\left(b^I(s) < b^V(s)\right) = q^{**}b^I(s_{n-1}) + (1-q^{**})p^I$, and is lower than p^{CA}. Hence, there exists an informative bid function $\bar{b}^I(s)$ in which $p^{CA}\left(\bar{b}^I(s)\right) = p^{HC}$, i.e. the Candle auction yields higher expected revenues if $\bar{b}^I(s) < b^I(s) \leq b^V(s)$ and lower or equal expected revenues if $b^I(s) < \bar{b}^I(s)$.

3. The Experiment

I. Setup

We compare two treatments, i.e. the Hard Close auction treatment (HC) and the Candle auction Treatment (CA). The HC lasted 6 stages. Keeping the expected duration almost equal, the CA lasted at most 20 stages with a termination probability of $q_t = t/20$.[10] Thus, in the first stage the termination probability is 5%, in the second 10%, in the third 15%, and so on. The expected duration equals 5.29 stages.[11]

The experiment was programmed and conducted with the software z-Tree (Fischbacher, 2007) and took place in the Magdeburger Experimental Labor (MaXLab) with undergraduate students from the University of Magdeburg recruited via ORSEE (Greiner, 2004). The subjects had not participated in an auction experiment before. After the instructions were read aloud, the students were randomly assigned to the terminals.

Bids and values were expressed in an experimental currency unit (ECU), which at the end of a session was transferred from 1 ECU into 0.0056 Euro Cents. The participants received an endowment of 1800 ECU (=10 Euro) to absorb losses. Before each auction, the sealed common value was drawn from the interval [2,500; 22,500]. Thereupon, the signals were drawn from the interval [V - 1,800; V + 1,800].[12]

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[10] More termination probability profiles are imaginable (Füllbrunn and Sadrieh, 2006).

[11] On average 5.33 stages have been played.

[12] We use the same values as in Cox, Dinkin, and Swarthout (2001).

In each treatment, subjects were randomly and anonymously matched before each auction. The random draws were organized in such a way that 8 out of 16 subjects in each session represented an independent observation group. Since 64 subjects took part in 4 sessions we collected data from 8 independent observation groups in each treatment. A total of 16 auctions were played by each subject. To get familiar with the common value environment the first 4 auctions were trial periods without monetary incentives.

At any time, all subjects had knowledge about their ECU balance that was calculated by adding the payoff of each auction to the endowment. At the end of a session, the bidders ECU has been paid-out in Euros. The sessions lasted on average 1:40 hour in the Hard Close auction treatments and 2 hours in the Candle auction treatment. The average payoff is about 17 Euro in HC and 14.50 Euro in CA.

In total 256 auctions with 1024 observations were conducted in each treatment. However, not all observations can be used to provide accurate results. We only consider signals from the region 2 interval (compare p. 3), i.e. we discard auctions with signals lower than 4,300 ECU and higher than 20,700 ECU. The endowment proved to be too low for some bidders, who ended the experiment with a negative balance. The enforcement of payment transactions from subjects was not credible and, thus, we discard all auctions with bidders that ever had a negative credit balance.[13] Finally, we discard the trial periods. This leaves us with 600 observations in CA and 616 observations in HC.

In order to compare the treatments, we use the Vickrey auction outcome as a benchmark. With $n = 4$ and $\varepsilon = 1{,}800$, the risk neutral Nash equilibrium bid in a Vickrey auction equals $b^V(s) = s - 900$, the expected price $p^V(V) = V - 540$ and the winner payoff $\pi^V = 540$.

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[13] If the bidders face a negative balance and the enforcement of payments of the bidders is not credible, the bidders can change their strategy. The bidders always bid the highest possible bid in order to have a chance to win the auction.

II. Results

<u>Allocation and determination of prices</u>

The theoretical considerations predict the winner to have the highest signal. Figure 1 displays the fraction of winners by the signal rank, i.e. the highest, the 2nd and 3rd highest, and the lowest signal. A comparison between the first section (periods 1-4) and the last section (periods 9-12) yields no significant difference in any treatment; i.e. the fraction does not change in the course of the experiment. The fraction of high signal winners in CA is 56 percent and in HC 51 percent, with no significant differences across treatments. These results suggest a deviation of the theoretical prediction. However, the modus of the winners have the highest signal; and Rose and Kagel (2000) show that even in clock auctions only 63 percent of the high signal bidders receive the object.

Figure 1: Frequency of highest and 2nd highest bids by signal rank

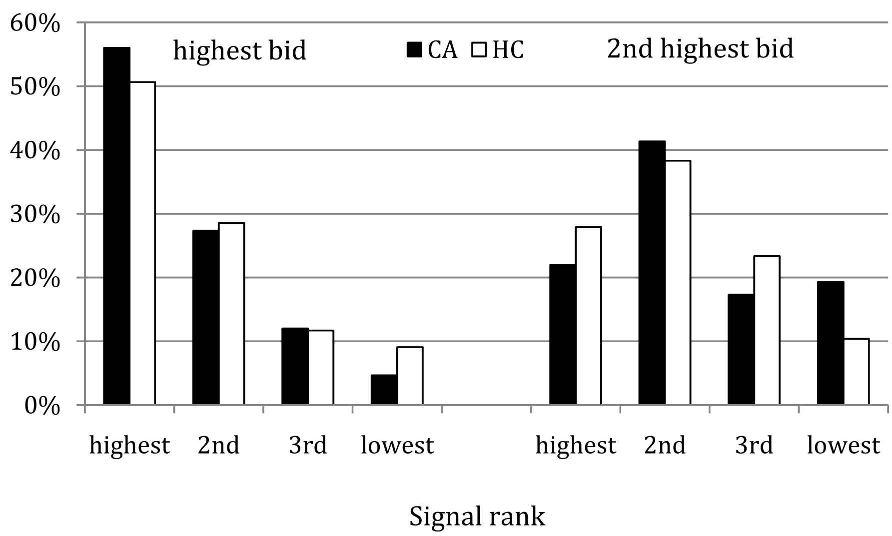
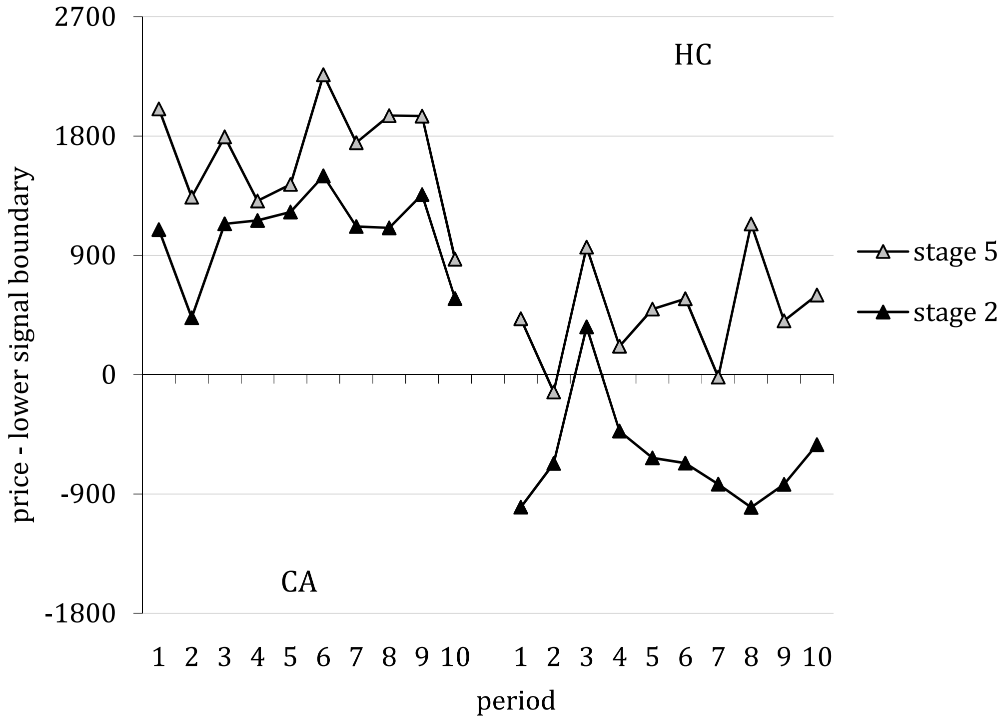


Figure 1 displays also the fraction of bidders with the 2nd highest bid by the signal rank. In the Vickrey auction the bidder with the 2nd highest signal determines the price due to the monotone increasing bid function. While the HC results should be in line with the Vickrey prediction, in CA any bidder, besides the bidder with the highest signal, may determine the price (given a sufficient level of information revelation). A comparison between the first section and the last section yields no significant difference in any treatment. In both treatments most of the prices have been determined by bidders that had not the 2^{nd} highest signal. However, the bidder with the 2^{nd} highest signal determined the prices more often than each other rank, i.e. the modus is in line with the Vickrey prediction. We found no significant differences across treatments.

<u>Current Prices</u>

Besides the signal, bidders are only able to use the price as a source of information. Do the prices reveal information? Figure 2 displays current standardized median prices, i.e. the observed price minus the lower signal range boundary in the second stage (the first observed price) and the final stage (the last observed price). A standardized price of 1,800 ECU equals the

Figure 2: Current Median Prices (standardized)



Standardized price = price – lower signal range boundary

common value and a standardized price of 0 ECU equals the lowest possible signal given the common value. A stage wise comparison of the standardized price between the first section and the last section yields significant difference in neither treatment.

The 2nd stage prices in CA significantly exceed the lower signal range boundary (Wilcoxon Sign Rank Test, two-tailed: p = 0.0357) while in HC the opposite is the case (Wilcoxon Sign Rank Test, two-tailed: p = 0.0357). Hence, the high price in CA gives some hints on serious bidding from the start, while in HC the price contains no information. The 2nd stage prices in CA are significantly higher than in HC (Mann Whitney U Test, two-tailed: p = 0.0023).

In CA the observed prices in the final stage nearly reach the common value, i.e. we cannot reject the hypothesis that the observed median price in the final stage undercuts the common value. In HC these observed prices merely exceed the lower signal boundary, i.e. we cannot reject the hypothesis that the observed median price in the final stage undercuts the lower signal boundary. If the bidders know that observed prices equal the lower signal boundary, they may rank their signal position. The final stage prices in CA are significantly higher than in HC (UTest, two-tailed: p = 0.0023). Note, in HC the final stage is the 6th stage while in CA this can be any stage from the 1st to the 20th stage.

When the bidders conceal information until the final stage, i.e. they submit uninformative bids; the equilibrium bid in the final stage is the Vickrey bid. But if current prices reach a certain amount, bidders are not able to submit the Vickrey bid. In CA 70 percent of the Vickrey bids could not be submitted due to high prices. 97 percent of the bidders with the lowest signals were not able to submit Vickrey bids. This faction for bidders with the highest signal is even 26 percent. In HC the frequency is lower. About 38 percent of the Vickrey bids could not be submitted.

Summing up, current prices in CA are higher than in HC. However, also in HC the last observed prices exceed the lower signal range boundary. In CA current prices prevent bidders from submitting Vickrey bids. Hence, we can conclude that prices have an impact on the final bid.

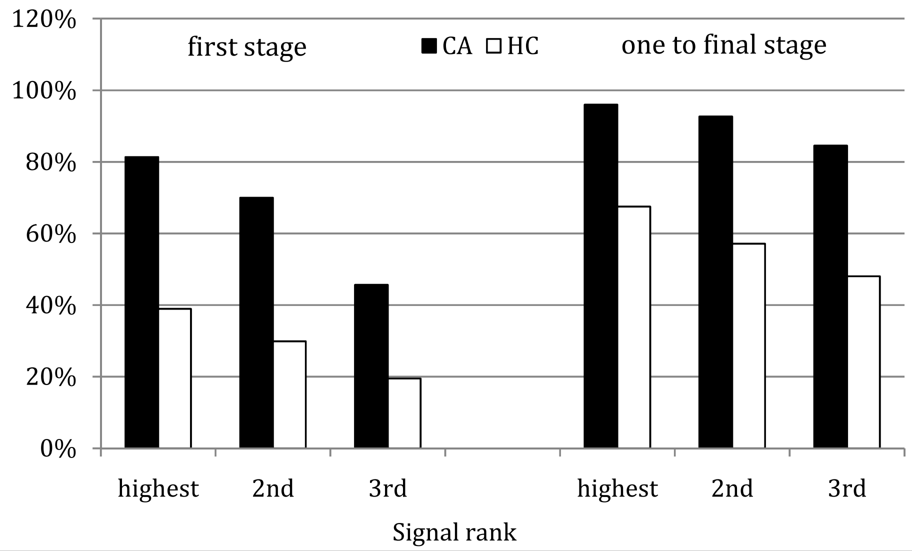
Informative Bids

Whether bidders submit informative bids depends on the definition of *informative*. In this section we call a bid of a bidder j informative, if the bid decreases the number of possible realizations of the common values for bidder i. This is the case if the possible range of the common value according to the signal of bidder i, $V \epsilon [s_i - \varepsilon;\ s_i + \varepsilon]$, is smaller due to additional information. From section 2 we know that without additional information the bid should not exceed the Vickrey bid, i.e. $b(s) \leq b^V(s)$. Now assume a bid b_j with $(b^V)^{-1}(b_j) \equiv \tilde{s}_j \leq s_j$. If bidder i observes this bid and $\tilde{s}_j > s_i$ holds, her common value range decreases to $[\ \tilde{s}_j - \varepsilon;\ s_i + \varepsilon]$. Hence, bidder i adjusts her estimation and supposes a higher common value than before.

In order to compare the treatments with subject to informative bids, we consider the realized signals and define a bid as an informative bid, if the bidder with the lowest signal can decrease her common value range, assuming she observes the bid. Technically spoken, a bid is an informative bid if $(b^V)^{-1}(b_j) \equiv \tilde{s}_j > s_1$ (for $j > 1$).

Figure 3 displays the frequency of informative bids by the signal rank in the first and the one final stage. Already in the first stage most of the bidders in CA submit informative bids. While in

Figure 3: Frequency of informative bids by signal rank



A bid is counted as informative if, assuming the bid is a Vickrey bid, the inverse of the bid exceeds the lowest signal, i.e. if $(b^V)^{-1}(b_j) \equiv \tilde{s}_j > s_1$ (for $j > 1$). Only periods 7-12.

CA almost 60 percent of the bids are informative bids. With 23 percent in HC this frequency is significantly lower (Mann Whitney U Test, two-tailed: 0.0063). The bids in the one to the final stage haven't been necessarily submitted without further information. Thus, the assumption that the bids have to be lower or equal to the Vickrey bids does not hold for all auctions. Nevertheless, the frequency of informative bids is significantly higher in CA than in HC (Mann Whitney U Test, two-tailed: 0.0063). However, one interesting point is that in HC more than 53 percent of the bidders submit informative bids before the last stage, which contradicts the prediction. Due to the fact that higher bids have been placed before, and that bidders may react on higher bids, the results give only a tendency towards the information revelation hypothesis.

Bidding Behavior

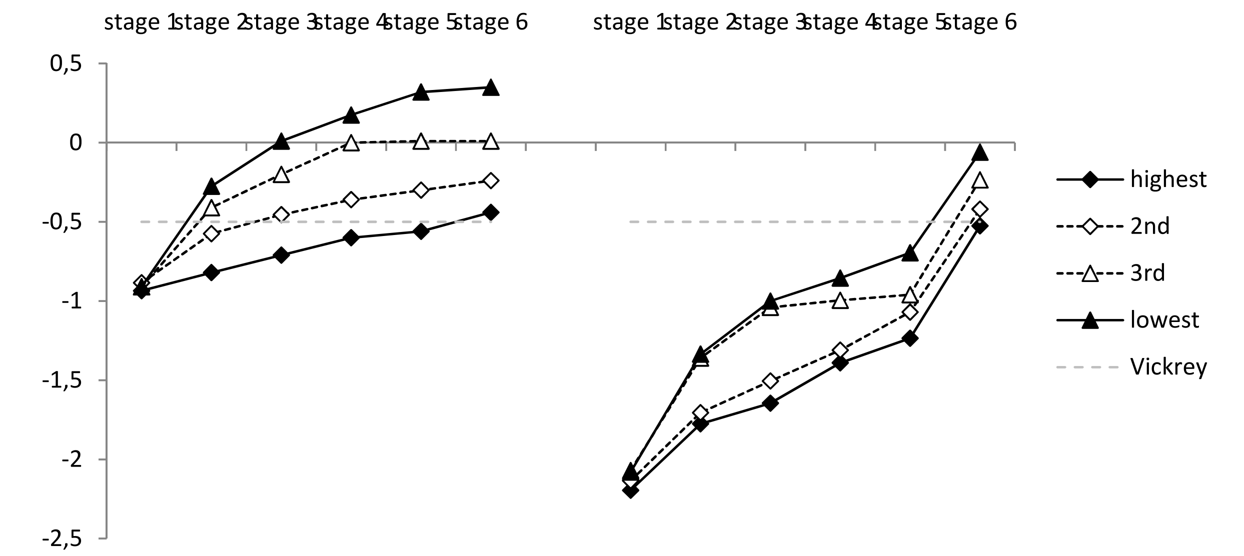
Without further information the bidders submit bids according to a monotonic function of their signal. In order to test whether the bidders use the same bid function, we define a bid shading parameter α that classifies the bid function due to $b(s) = s + 1{,}800\alpha$. This function is related to the Vickrey bid $b^V(s) = s + 1{,}800\alpha^V$ where α^V equals -0.5. Thus, the bidders undercut Vickrey bids when $\alpha < -0.5$ and submit bids that equal their signal for $\alpha = 0$.

In order to test whether the bidders gather information, we compare the bid shading parameter across signal ranks. Without assuming a special bidding function, symmetric bidders have the same α if their signal is the only information source. Hence, if the α differs across signal ranks the bidders have additional information. If so, we expect lower bids in comparison to the signals for higher signal rank bidders, i.e. α is low, and higher bids for lower signal rank bidders, i.e. α is high. Overall, the hypothesis is $\alpha_{1st} = \alpha_{2nd} = \alpha_{3rd} = \alpha_{4th}$. We test this hypothesis using the Friedman Test and the Wilcoxon Sign Rank Test.

Figure 4 displays the median of the bid shading parameter α over stages by signal rank. Comparing the observations of the first and the last section show no significant differences in α, separated by the signal rank and stage. Therefore, we pool all data.

In the first stage, differences across signal ranks have been found in neither treatment. This supports the hypothesis that bidders submit bids that depend only on their signals. Further evidence is found by comparing the distribution across signal ranks. Considering only the highest and lowest rank the Kolmogorov-Smirnov Test does not reject the hypothesis of equal distributions of α in either treatment. However, the bidding behavior in HC differs from the CA in that the parameter is significantly higher in CA than in HC (Mann Whitney U Test, two-tailed, p=0.0001). The median in CA equals -0.92.[14] The median in HC equals -2.12, which gives reason to believe that the bidders in the HC do not submit serious bids in the first stage.[15]

Figure 4: Bid shading parameter α by signal rank



$\propto = (b-s)/1800$, Median, all periods

As the figure displays the bids disperse in the second stage, i.e. bidders with a low signal have a high α and bidders with a high signal have a low α. We found significant differences across signal ranks (Friedman test: p=0.0065, and pair wise Wilcoxon Sign Rank Test, two-tailed: p<0.05). Considering only the highest and lowest rank, the Kolmogorov-Smirnov Test rejects the hypothesis of equal distributions of α in CA. The results give reason to believe that α is ordered dependent on signal ranks. Further on, many bidders exceed their Vickrey bid. This is the case in 70 percent of the bids from bidders with the lowest signal and even 30 percent of the bids from the bidders with the highest signal. Overall, the α of the lowest signal bidders significantly exceeds -0.5. Although, the figure shows different bids in HC, we found no

[14] Notice, with α=-1 the bid equals the lowest possible realization of the common value given the signal.

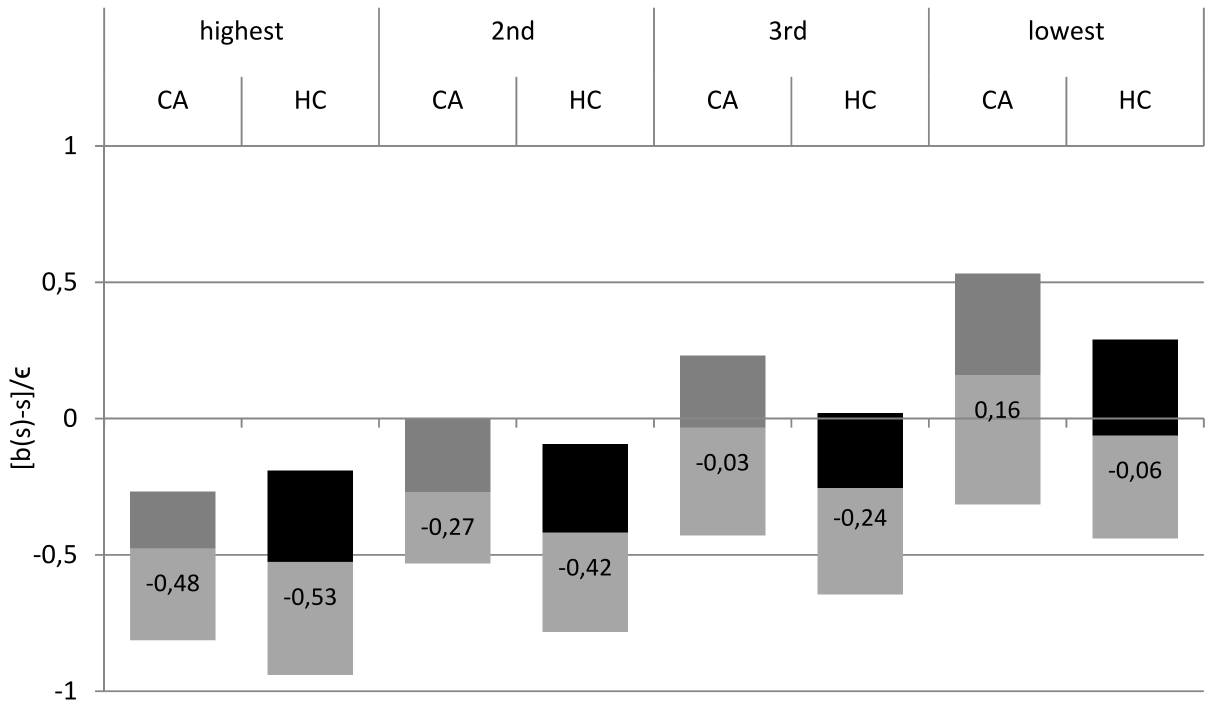
[15] The standard deviation of 2.85 in HC proofs the non serious bids in HC. In CA the standard deviation is with 1.85 lower than in HC.

significant differences across signal ranks.

After the second stage the α significantly differs across signal ranks in any treatment. In CA α (significantly) exceeds -0.5 for all signal ranks apart from the highest. Hence, early in the auction process the bidders submit serious bids. Finally, nearly 70 percent of all bidders exceed their Vickrey bid, while in HC we have almost 60 percent. The average stage, where these bidders exceed their Vickrey bid the first time, is significantly lower in CA 2.6 (2.02) for bidders with the highest (lowest) signal than in HC (4.41 (4.11)). Again, the bidders in CA submit serious bids earlier in the auction process in comparison to HC.

In the final stage, the bidders in HC make a substantial leap in their bids in that they increase their α above -0.5 (see figure 4). Figure 5 shows the quartiles of α (with emphasized median) in the final bidding stage.

Figure 5: Quartiles of Bid shading parameter α



$\propto = (b - s)/1800$, all periods, medians are emphasized

The figure suggests an order of bids according to the signal rank in both treatments, i.e. bidders with high signals submitted comparatively lower bids than bidders with lower signals. The Friedman Test rejects the hypothesis of equal distributions across ranks (Friedman test: CA p=0.0052, HC p=0.0052). Moreover, the pair wise Wilcoxon Sign Rank Test provides almost significant differences.

Concerning the Vickrey outcome, figure 5 shows a positive deviation for bidders who have not the highest signal. In CA the lowest three ranks significantly exceed – 0.5, and so do the lowest two ranks in HC (Wilcoxon test, two tailed: p<0.0173). Thus, if the bidders with the second highest signal determine the price, the data suggest prices above the Vickrey price in CA.

We also found evidence for signal bidders, i.e. bidders who submit bids that equal their signals. We cannot reject the hypothesis of $\alpha = 0$ for bidders with the lowest and the second lowest signal in CA and the lowest signal in HC. However, these bids are merely relevant for the outcome of the auction.

Comparing the treatments gives reason to believe that bidders in CA submit higher bids than the bidders in HC. Especially bidders with the second highest signal, who theoretically determine the price, submit a higher α in CA than in HC. Using the Kolmogorov-Smirnov Test (p=0.0013), we found a different distribution of α in CA than in HC. The distribution of α_{2nd} in CA is almost left from HC. However, the Mann Whitney U-test failed to provide evidence within ranks.

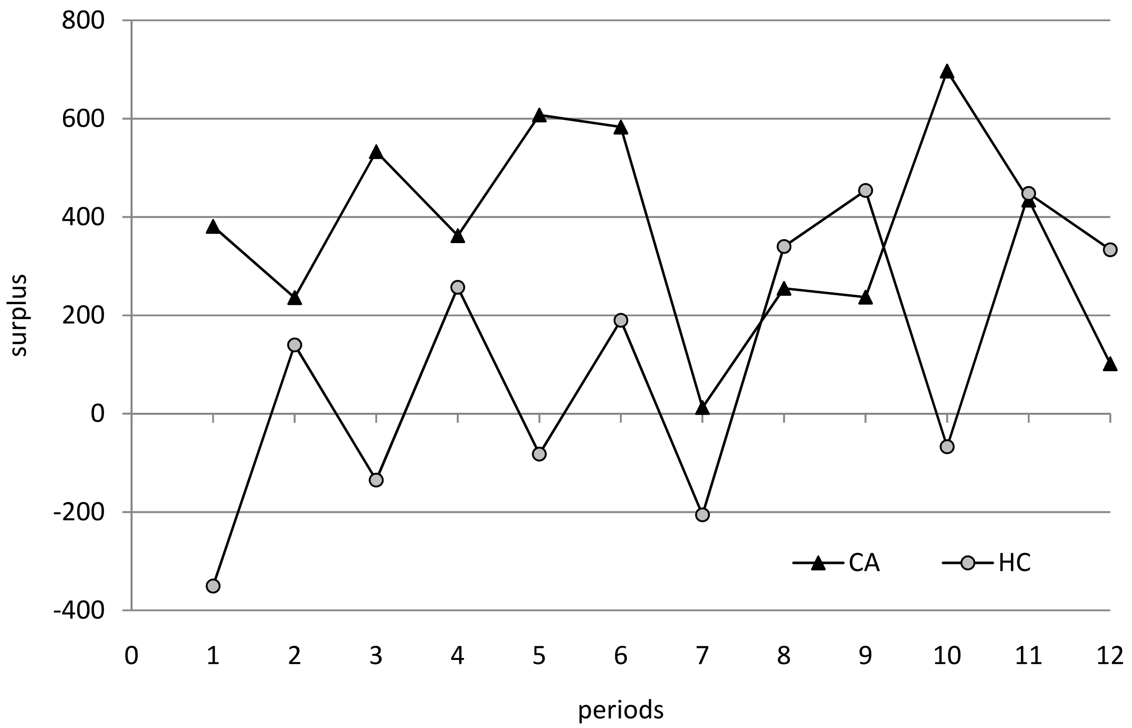
Sniping in Hard Close auctions is frequently observed in private value auctions. As shown above, also the theory of common value auctions predicts late bidding in Hard Close settings. If we consider bids in the auction process, we found no differences between stages until the last stage. In the 6th stage, however, the median increase of α equals 0.31. Further, in 80 percent of the cases, bidders submit their final bid in the final stage. Also, 84 percent of the winners submit their final bid in the final stage. Hence, bidders engage in late bidding behavior in HC, i.e. the bidders snipe.

<u>Surplus</u>

The seller chooses the auction format which yields the highest revenue. The realization of the common value, however, may have a deep impact on the comparison between treatments. Therefore, we consider the surplus, i.e. the difference between the Vickrey price and the final price. Figure 6 displays the surplus of the treatments in the course of time. A surplus of zero equals the Vickrey price.

Comparing the observations of the first and the last section show no significant differences in either treatment. Thus, pooling the data over all periods yields a median surplus of 388 in CA and 135 in HC. While the surplus in CA is significantly higher than the Vickrey price (Mann Whitney U Test, two-tailed, p=0.0117), we found no differences in HC. Using the Kolmogorov-Smirnov Test (p=0.0260), we found a different distribution of the surplus in CA than in HC. The surplus in CA is almost left from HC and the 2nd order stochastic dominance argument shows that the expected surplus in CA is at least as high as in HC. Further, the one-tailed Mann Whitney U Test rejects the hypothesis of a higher surplus in HC than in CA (Mann Whitney U Test, two-tailed, p=0.0294).

Figure 6: Surplus



Median surplus = Vickrey price – final price

Winner's Curse

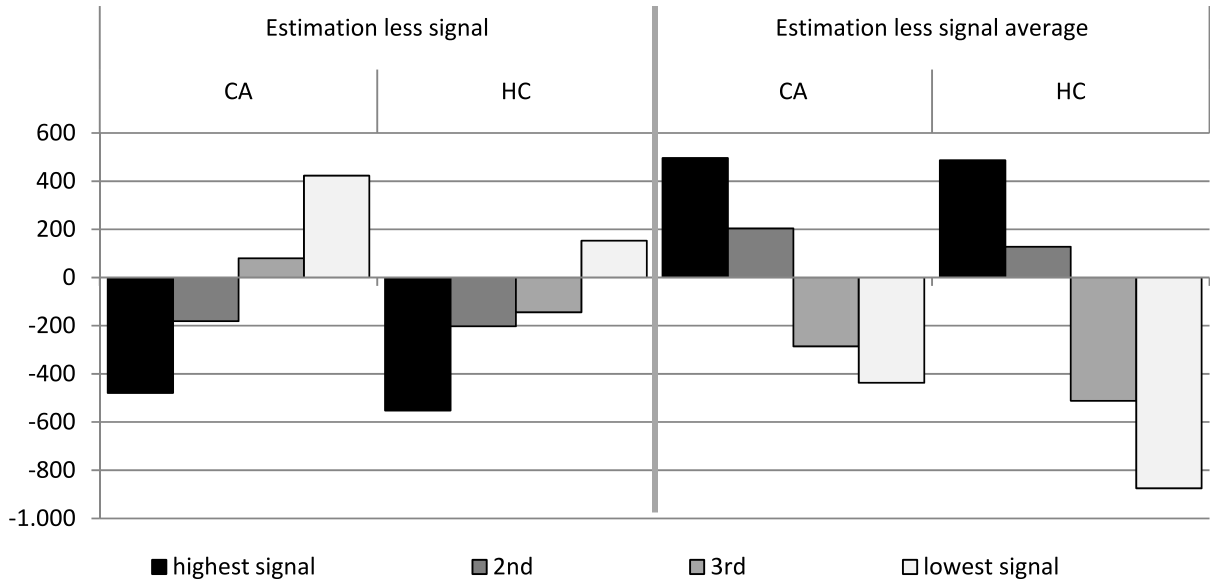
In equilibrium the winner is the bidder with the highest signal. If she does not take this into consideration, her winning bid can result in lower or even negative profits than in equilibrium. The systematic failure to account for this adverse selection problem is referred to as the *winner's curse* and is experimentally and empirically observed (Kagel and Levin 2002). Due to the fact that in second price auctions the bid of other bidders determines the price, the impact of the winner's curse is much weaker than in first price auctions. If we consider the payoff, we found that the frequency of winners with a negative payoff is 39 percent in CA and 35 percent in HC. We found no significant difference across treatments. If we compare the payoff to the Vickrey benchmark, we found that the frequency of bidders with a payoff below the Vickrey payoff is 71 percent in CA and 56 percent in HC. The frequency in CA is significantly higher than in HC (Fisher's Exact Test, two-tailed, $p = 0.039$). Overall, we found a higher propensity for a winner's curse in CA.

Estimation of Values

To find out whether the bidders realize that information is revealed, we ask the bidders to estimate the common value after the last bid. Without any further information the bidders' estimation bases only on private signals, i.e. the estimation equals the unconditional private signal. The data do not support this hypothesis as figure 7 displays. Bidders with high signals expect a lower value in comparison to their signal, while bidders with low signals expect a higher value. This is in line with the position of the signals, i.e. if bidders know their position they shade the estimation according to their position relative to the common value. For example, if a bidder knows to have the highest signal, it is also known that the common value is below the highest signal. In both treatments the results suggest that the bidders have an idea of their signal position and estimate accordingly.

When all signals are revealed the bidders' estimation should be the same. Due to the fact that an accurate estimation of the common value is not possible we refer to the average of the signals as a best estimator.[16] Bidders with high signals expect a higher value in comparison to their signal average, while bidders with low signals expect a lower value. This result indicates that bidders do not gather full information. Bidders with high signals overestimate the value while bidders with low signals underestimate the value.

Figure 7: Estimation of the common value – median differences



Left: Median of Estimation less signal, Right: Median Estimation of signal averages

Summing up, the bidders know, to some extent, their position but also over-/underestimate the valuation according to their position. However, the results can only be regarded as a trend due to the fact that there is no incentive of choosing the right estimation.

4. Conclusion

With this study, we contribute to the literature of auction design by presenting a theoretical and experimental analysis of Candle auctions in a common value framework. We compare this auction format to the commonly known Hard Close auction. In Candle auctions, where the bidders face the threat that the next bid is the last bid, the bidders submit serious bids earlier in

[16] Using a common value environment based on the average of signals as in Krishna and Morgan (1997) would allow an accurate estimation of the common value.

the auction process than in Hard Close auctions, where bidding is allowed until a known deadline. Early bids in Candle auctions allow the bidders to gather further information and submit higher bids. Hence, prices in Candle auctions are at least as high as in Hard Close auctions. We conclude that the seller is better off by choosing the Candle auction rather than by choosing the Hard Close auction.

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Appendix

Instructions (Translation)

Please read the following instructions carefully. Questions will be answered at the terminal. As from now, please stop communication among yourselves. In this experiment you take part in an auction. Therefore, you submit bids in a computer terminal. Your payoff depends on your success, i.e. it depends on your decisions and those of the other participants. For an easy handling you do not submit bids in Euro but in points. 180 points correspond to 1 Euro. At the beginning, you get a credit of 1800 points.

The auction

What does the auction looks like? You are a bidder in the auction. In this auction one object is offered. The bidder with the highest bid receives this object. The price for the object equals the second highest bid. In any auction four bidders participate: you and three other participants. However, this auction group will be reshuffled after each auction.

What is the bidding procedure? An auction consists of several bidding stages. In each stage, you can submit one bid that may not exceed 22,500 points. This bid is not common knowledge. When you want to retain your previous bid, leave the submission field blank. When you want to raise your previous bid, the new bid must exceed the current price. The current price is the second highest bid from the previous stage. After the first stage the current price can be found on the right side of the screen. On the left you will be informed if you are the highest bidder or not.

How long does an auction take? After the 6th stage, the auction ends.

Who receives the object? The bidder who finally submits the highest bid receives the object and pays the price. If there are two or more bidders who submit the highest bid, a random mechanism decides on which of the highest bidders receives the object. In this case, the price equals the highest bid.

The payoff

The value of the object lie in the range 2,500 and 22,500 points. This value will be randomly assigned to you by the computer, whereby every value in the interval is of same probability. He is from the computer before the auction drawn at random, with each value in the same interval is probable. No bidder knows this value.

Each bidder receives a signal, which corresponds to an estimation of the value. This signal is at most 1,800 points below and at most 1,800 points above the drawn value and will be randomly assigned to you by the computer, whereby every value in the interval [value - 1,800, value + 1,800] is of same probability. This signal is known only to you and not to the other bidders.

Example: The value equals 18,000 points. The signals will be drawn from the interval with the lower limit 16,200 and the upper limit 19,800. A possible signal constellation in this auction can be 17,384, 17,562, 16,205 and 19,175.

In summary, one object is sold via an auction. Its value is not known and equal for every bidder. You receive a signal, which is an estimate of that value. Each of your group members also receives a signal. All bidders only know their own signal, and neither the valuation of the object nor the signal of other bidders. If you receive a relatively high signal, the value is relatively high, and the other bidders have also relatively high signals. If you receive a relatively low signal, the value of the object is relatively low, and the other bidders have also relatively low signals.

How is the payoff calculated? If a bidder receives the object, its payoff equals value – price, i.e. you receive the valuation in points and pay the price. This difference will be added to the credit of the highest bidder. All other bidders receive no points.

Examples: (1) The value equals 18,176 points. The price is 17,894. Thus, the payment of the highest bidder equals 18,176 - 17,894 = 282 points. (2) The value equals 5,874 points. The price is 6,345. Thus, the payment of the highest bidder equals 5,874 - 6,345 = - 471 points, i.e. if the price exceeds the value a loss results. (3) The value equals 8,785 points. The price is 8,785. Thus, the payment of the highest bidder equals 8,785 - 8,785 = 0 points.

Estimate: After the last stage you will be ask for your estimation of the valuation. Enter here, what you believe is the value.

Does the auction take place only once? There are a total of 16 auctions. The first 4 auctions are auction samples, i.e. these auctions will not affect your payments and are for practice purposes. In the next 12 auctions, your payoff is added and subtracted to your credit, respectively. At the end your current credit multiplied by 0.0056 will be disbursed.

What happens then? You take a seat at the terminal you were assigned by lots. If you have any questions, please raise your hands. After having finished all auctions, you will get your payoff. Please leave the instructions after the experiment at your place/terminal.

Good luck!