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Abstract

We study a remarkable auction used in several fish markets around the world, notably in Honolulu and Sydney, whereby high-quality fish are sold fast through a hybrid auction that combines the Dutch and the English formats in one auction. Speedy sales are of essence for these perishable goods. Our theoretical model incorporating "time costs" demonstrates that such Honolulu-Sydney auction is preferred by the auctioneer over the Dutch auction when there are few bidders or when bidders have high time costs. Our laboratory experiments confirm that with a small number of bidders, Honolulu-Sydney auctions are significantly faster than Dutch auctions. Bidders overbid in Dutch, benefiting the auctioneer, but bidding approaches risk-neutral predictions as time costs increase. Bidders fare better in the Honolulu-Sydney format compared to Dutch across all treatments. We further observe bidder attempts to tacitly lower prices in Honolulu-Sydney auctions, substantiating existing concerns about pricing in some fish markets.

JEL classification code: C7, C92, D02, D44, L0

Key words: auction theory, time costs, laboratory experiments

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1 Introduction

Many fish and flower auctions around the world are characterized by large volumes of highly perishable and highly variable in quality goods that are auctioned off sequentially, by individual units or lots. Speed of auctions is of essence given the perishable nature and large volumes being traded in a short amount of time; however, competitive bidding on each item is also an essential requirement for price discovery, given the large variability in quality and other characteristics of each item.[1]

We explore a seemingly peculiar and largely under-studied dynamic auction format employed in several perishable goods markets around the world, such as in Honolulu and Sydney fish markets. In this auction, the auctioneer sets a starting price that is neither as low as in an English auction nor as high as in a Dutch, but at a middle ground, allowing bidders to bid at the onset (either by raising their hands during a verbal Honolulu auction or by clicking a button during an automated Sydney clock auction). If at least one bidder bids, the auction proceeds as an English (ascending price) auction. If there is no initial interest, the price begins to drop, as in a Dutch (descending price) auction. However, once a bidder bids, other bidders are allowed to counter-bid, potentially reverting the auction to an English auction. Although this auction format has been documented (Feldman, 2006) and is apparently employed in a number of fish markets in France and Denmark (Guillotreau and Jiménez-Toribio, 2006; Laksá and Marszalec, 2020) as well as in Honolulu and Sydney,[2] little is understood about the reasons for its emergence and its advantages over more traditional descending-only Dutch auction that is also commonly used for perishable goods. To the best of our knowledge, no previous theoretical or experimental investigations have been conducted.

Our goal is to understand the reason for the existence and the patterns of observed be-

[1] According to Hawaii-Seafood.org (2015) description of Honolulu fish auction, "Hundreds of fish are displayed on pallets on the auction floor. The United Fishing Agency auctioneer moves down the rows of fish surrounded by buyers who openly bid against each other for value, the best prices and quality fish. The majority of fish are sold individually. This competition continues until all the fish are sold. Up to 100,000 pounds of fish can be auctioned in a day... The... system allows for the efficient sale of the range of fish species, size and quality to suit each special market niche." See also Peterson (1973) for an early detailed record.

[2] Feldman (2006) provides the following description (p. 326, footnote 39): "At the Honolulu Fish Exchange... a modified form of the Dutch auction is used, with the auctioneer starting at a high price and then dropping it until a buyer places the first bid. The auctioneer then calls out a higher price with the hope of getting other buyers to start bidding..." Guillotreau and Jiménez-Toribio (2006) document a similar format used in fish sales in two French ports, and Laksá and Marszalec (2020) provide an identical description of the auction in the Faroe Fish market in Denmark. Finally, at the Ayazaga flower auction in Turkey, the starting price is determined by the auctioneer, and then may go up or down depending on buyers' bids (however, this flower auction does not allow for the price to go up again, once the price starts going down). See Appendix A for more details.

havior exhibited in this distinctive auction format. In both the Honolulu and Sydney fish markets, bidders do not usually wait until the price reaches extremely low or close to zero values during the Dutch stage; on the contrary, bidding typically starts with little delay, and each fish is auctioned off within seconds. This behavior does not align with standard explanations based on risk-neutral, risk-averse, loss-averse, or regret-avoiding bidder preferences, as none of these preferences give an apparent reason to end the Dutch stage prematurely when bidders always have the option to bid later at a lower price.[3]

Extensive consultations and discussions with the experts, administrators and bidders participating in both the Honolulu and Sydney auctions led us to deduce that this auction process is specifically designed to expedite the proceedings, preventing lengthy periods of price increases or decreases. For auctioneers, speed is of essence given the perishable nature of the good and the need to sell thousands of individual fishes or boxes within a 4-5 hour time frame. Similarly, wholesalers and restaurant owners who are repeat buyers encounter time constraints when they aim to purchase significant amounts of highly perishable products.[4]

Motivated by the above, we propose a model that incorporates time costs, where both the auctioneer and bidders are impatient and strictly prefer a fast auction to a slow one, and test this model in a controlled laboratory environment. Taking time costs into account, impatient bidders must balance the advantages of waiting for a lower price with the costs related to the auction's length. As a result, they may opt to bid earlier if they find waiting to be more detrimental. Our findings indicate that both bidders' and auctioneers' time costs can explain the various auction stages observed in the Honolulu-Sydney auction format.

We also examine the Dutch auction alongside the Honolulu-Sydney auction in our theoretical model and in the experiments, as Dutch auctions are also commonly used in perishable goods markets, such as fish, flowers, fresh produce, and meat (Cassady, 1967). In the Sydney Fish Market, for instance, there are two clocks running Dutch auctions, typically for less valuable seafood. The third clock, on the other hand, employs the Honolulu-Sydney auction format and sells high-quality seafood such as sashimi-grade tuna or live lobsters.

It is important to underline that, in our model with time costs, the well-known Revenue Equivalence result (Myerson, 1981; Riley and Samuelson, 1981) does not apply, meaning that different auction formats yielding the same allocation might produce varying utilities for the auctioneer. Comparing the Honolulu-Sydney to Dutch auctions, we find that utility

[3] Under the standard assumptions, it is a weakly dominant strategy for all bidders to wait until the price drops to zero in the Dutch stage, and then bid in the English (ascending) auction stage. Given this, the auctioneer may prefer the outcome-equivalent but less complex ascending bid English auction.

[4] Cassady (1967, p.60) notes that speed is of essence in many auction markets. In personal communication, an auction expert and experimental economics pioneer Charlie Plott also shared with us his belief that many auction procedures, such as the Honolulu-Sydney auction format, stem from the necessity to quickly conclude the auction.

comparisons are uncertain and depend on the time cost parameters of both the auctioneer and bidders. The blend of nominal revenue, which represents the object's sale price, and time cost effects, which reflect the auctioneer's welfare loss due to the auction's duration, establish the utility comparison between different auction formats.

In a Honolulu-Sydney auction, the auctioneer selects the optimal starting price, whereas the Dutch auction's starting price is typically set at the highest possible value. This "starting price effect" could potentially favor the Honolulu auction as it might result in a shorter auction duration compared to the Dutch, especially when there are few bidders. More specifically, when there are few bidders, the expected selling price would be significantly lower than the highest possible value (which is the Dutch auction's starting price), and this puts the Dutch auction at a disadvantage in terms of time costs. This effect decreases as the number of bidders grows.[5]

Our experimental results provide strong evidence of the speed advantage Honolulu-Sydney auctions compared to Dutch with a small number of bidders; as predicted, this advantage decreases with more bidders. However, we also find that Honolulu-Sydney auctions have lower prices than Dutch, as the former are more susceptible to suppressed price competition with a small number of bidders, while the latter exhibit consistent overbidding. As a result, Honolulu-Sydney auction benefits relative to Dutch are somewhat lower than predicted for the auctioneer, but higher than predicted for the bidders.

The paper proceeds as follows. In Section 2, we briefly discuss the relevant literature. The theoretical model of Honolulu-Sydney and Dutch auctions with time costs is presented in Section 3. Experimental design is discussed in Section 4. Section 5 presents experimental results and participant feedback on both auction formats. We conclude in Section 6.

2 Brief review of the literature

Much of the extant auction literature focuses on the ascending English and the descending Dutch auctions and their sealed-bid analogs in various types of environments (see, for example, Klemperer (1999), Klemperer (2004) and Milgrom (2004) for excellent overviews). We contribute to this literature by studying an original auction format that has already been in use around the world for several decades.

To the best of our knowledge, Katok and Roth (2004) is the only existing analytical study that discusses "alternative" Dutch auctions where the price may go down and then

[5]Using a reserve price would also speed up the sales; yet it could make the auction inefficient. In the context of a perishable goods, selling it now is really important because it cannot be sold later. Our consultation with executives at both the Sydney and Honolulu Fish Markets revealed that reserve prices rarely influence actual sales. Therefore, we do not consider reserve prices in this paper.

back up. However, they consider auctions of multiple homogeneous goods with divisible lots, and attribute the unusual price dynamics to the presence of synergies between parts of the lot. In Honolulu-Sydney auctions, each fish is sold separately, is indivisible, and units differ in quality, suggesting heterogeneous goods and separable values across units.[6]

Speed of auctions has been recognized as an important consideration for auction design in many contexts, notably the Federal Communication Commission spectrum auctions (Banks et al., 2003; Kwasnica et al., 2005); however, it has not been formally incorporated into the auctioneer objective function. For multi-unit auctions with single-unit demand bidders, Andersson and Erlanson (2013) propose a hybrid Vickrey-English-Dutch auction and show numerically that it has a speed advantage over Vickrey-English and Vickrey-Dutch formats. Yet they do not discuss a real-world application of this auction mechanism.

Katok and Kwasnica (2008) study the effect of Dutch auction clock speed on bidding behavior in Dutch auctions. They suggest a theoretical model that explains more overbidding in slower auctions by bidders' intrinsic cost of time, and support their explanation with experimental data. In comparison, in our experiments, we keep the speed of the clock constant, induce time costs through bidder payoffs, and compare bidder behavior in Honolulu and Dutch auctions with high and low bidder costs of time. Although we observe that some bidders delay their bids more than is optimal given the induced cost of time, overall, our data provide strong evidence of behavior consistent with positive time costs.

There is vast experimental literature documenting overbidding in first-price sealed bid and Dutch auctions (Cox et al., 1982), often attributing it to bidder risk aversion (Cox et al., 1988) or regret aversion (Filiz-Ozbay and Ozbay, 2007). In line with the previous studies, we observe overbidding in our Dutch experimental auctions. We further use post-auction questionnaires to compare bidder sentiments of satisfaction, regret and sensitivity to time costs between Dutch and Honolulu auctions.[7]

3 Model and Theoretical Results

We consider a single-item auction with n bidders in which both the auctioneer and the bidders are impatient. Bidders' private values are independently and identically distributed according to a twice differentiable cumulative distribution function F and a corresponding

[6] "The oral method of the Dutch auction ... is used mainly for the sale of nonstandardized items where quality differences require flexibility..." (Cassady, 1967, p.63). Graddy (2006) further writes that "Fish is more perishable,... and individual fish are more heterogeneous than most agricultural products."

[7] We are grateful to Yan Chen for suggesting that the Honolulu-Sydney format allows to alleviate the loser's regret for not bidding early enough to win in the Dutch auction, as it provides a "second chance to bid." We investigate this conjecture by comparing bidder post-auction affective states under the Honolulu-Sydney and Dutch auction formats.

density function f over $[0,1]$.

If the auction ends when bidder i with value v wins at price p after t units of time has passed, the auctioneer's utility is

$$U_A = p \cdot c_A(t)$$

and the winning bidder's utility is

$$U_B = (v - p) \cdot c_B(t),$$

where the time-adjustment function of the auctioneer $c_A(t)$ and that of a bidder $c_B(t)$ are strictly decreasing functions in time t.[8] More specifically, we have $c_A(\cdot), c_B(\cdot) : [0,2] \to [0,1]$[9] and $c'_A(\cdot)$, $c'_B(\cdot) < 0$. The bidders who don't win the item have zero utility.

3.1 Honolulu-Sydney Auction

The Honolulu-Sydney auction proceeds as follows. It begins with an initial price announced by the auctioneer. If no one bids at the initial price, the price starts going down until someone bids (i.e., operates as a Dutch auction). When a bidder bids, if at least one other bidder also bids at the current price, the price starts going up due to the excess demand for the item. The price continues to rise until only one bidder remains (i.e., operates as an English auction). If there is an interest at the starting price, the auction instantly becomes an English auction without any price drop, provided that at least one more bidder shows interest at the starting price. Hence, the Honolulu-Sydney auction can work in a pure Dutch, Dutch-then-English, or a pure English format depending on bidding behavior.

In this setting with impatient bidders, the time cost bidders incur from participating in the auction creates a non-trivial cost-benefit trade-off. On the one hand, an early bid helps save the cost of waiting at the expense of potentially paying a high price. In particular, early bidding is beneficial and helps avoid unnecessary wait times if a bidder anticipates excess demand around the opening price (otherwise, the price will first drop and rise again to the initial price level leading to unnecessary waiting costs). Consequently, each bidder is incentivized to start bidding before the price drops all the way to zero in the opening. On the other hand, considering that the auction may end up working as a pure Dutch auction (e.g., the first bid is above the valuation of the remaining bidders and discourages other bidders

[8] Note that the time-adjustment functions enter the utility functions in multiplicative form. An alternative formulation would have additive time-adjustment functions. We adopt multiplicative formulation mainly because of its analytical tractability, but also because additive formulation may result in bidders obtaining negative utilities even when the price paid is lower than the bidder's value.

[9] Note that the maximum amount of time the Honolulu-Sydney auction can take is 2, and the Dutch auction can take is 1.

from starting an English stage), waiting before bidding first may help reduce the final price provided that no other bidder shows interest.

Next, we formalize this auction and the involved trade-offs. Consider the auction starting at a price s. The price will decrease until a bidder bids for the first time. Considering symmetric bidding strategies, let us represent this bid price as a function of bidder value given the starting price by $p(v,s) \in [0,s]$ and assume $p(v,s)$ to be strictly increasing in v whenever $0 < p(v,s) < s$ (allowing for "pooling at the starting price and at 0"). After one bidder bids at p, in the ascending auction stage, due to the "$(v-p) \cdot c_B(t)$" formulation of utilities and $c_B(t)$ being non-negative, all bidders with value greater than p will remain in the auction until the price reaches their values. Consider a bidder with value v who bids when the price decreases to p. Her expected utility is given by:

$$EU_B^H(p;v,s) = G(p)(v-p)c_B(s-p) + \int_p^v (v-x)c_B(s+x-2p)dG(x)$$

where $G(x)$ denotes the probability distribution of the highest of $n-1$ random variables independently distributed according to F, i.e., $G(x) = F(x)^{n-1}$. This is because, (i) with probability $G(p)$, no other bidder will increase the price after p, and $s-p$ time has passed since then, and (ii) for a given price $x > p$, with probability $G(x)$, the highest competing bidder has a value less than x and $s+x-2p$ amount of time would pass if the price first drops from s to p and then increases to x.

For each bidder value v, given the starting price s, let us denote the solution to the bidder maximization problem

$$\max_{p\in[0,s]} EU_B^H(p;v,s)$$

by $p(v,s)$. It is easy to see that $p(v,s) < v$, since $p(v,s) \geq v$ clearly results in an expected utility of zero or less.

We consider a symmetric perfect Bayesian equilibrium of the Honolulu-Sydney auction where, when the starting price is s, each bidder with value v bids at the price $p(v,s)$ and in the English stage, each bidder will remain in the auction until the price reaches her value.

The auctioneer's expected utility when choosing the starting price s is given by:

$$EU_A^H(s) = \int_0^1 \left(\int_0^{p(v,s)} p(v,s)c_A(s-p(v,s))h(v,x)dx \right. \\ \left. + \int_{p(v,s)}^v xc_A(s+x-2p(v,s))h(v,x)dx \right) dv$$

where $h(v,x)$ is the joint density of the highest (denoted by v) and the second highest (denoted by x) of n random variables identically and independently distributed according to F.[10] This formulation follows because (i) if x is smaller than $p(v,s)$, then the selling price will be $p(v,s)$ and $s-p(v,s)$ time would pass until the auction ends, and (ii) if x is greater than $p(v,s)$, then the selling price will be x and $s+x-2p(v,s)$ time would pass until the auction ends.

In the Honolulu-Sydney auction, the auctioneer would choose the starting price s to maximize $EU_A^H(s)$.

Note that the equilibrium that we consider for the Honolulu-Sydney auction is efficient. This is because, (i) we assume that the bid functions in the Dutch stage are weakly increasing in values, and (ii) in the English (ascending) stage, each bidders remains in the auction until the price reaches her value. We note this in the following remark.

Remark 1. *In equilibrium, Honolulu-Sydney auction results in an efficient allocation, in that the item is allocated to the highest-value bidder.*

In order to get more insights into the equilibrium in Honolulu-Sydney auctions, let us consider an example.

Example 1. *Consider 2 bidders,* $F(v)=v$*, and* $c_B(t)=c_A(t)=1-\frac{t}{2}$.

Below we solve for the optimal bids for an arbitrary starting price s for this simple setup. The utility of a bidder who has value v and bids at a price $p\in[0,s]$ *is given by:*

$$\begin{aligned} EU_B^H(p;v,s) &= p(v-p)\left(1-\frac{s-p}{2}\right)+\int_p^v (v-x)\left(1-\frac{s+x-2p}{2}\right)dx \\ &= \frac{1}{12}(v-p)\left(6p+6v-3ps+5pv-3sv+2p^2-v^2\right) \end{aligned}$$

We have

$$\frac{\partial}{\partial p}EU_B^H(p;v,s)=6ps-12p-6pv-6p^2+6v^2.$$

First, note that

$$\frac{\partial^2}{\partial p^2}EU_B^H(p;v,s)=6s-12-6v-12p$$

which is negative for all p, s, and v. Hence, $EU_B^H(p;v,s)$ *is a concave function of p and would be maximized (at an interior solution) when* $\frac{\partial}{\partial p}EU_B^H(p;v,s)=0$.

By solving the first-order condition $\frac{\partial}{\partial p}EU_B^H(p;v,s)=0$*, we get the unique candidate for the maximizer as*

$$\frac{1}{2}\left(\sqrt{s^2-2sv-4s+5v^2+4v+4}-v+s-2\right)$$

[10] We have $h(v,x)=n(n-1)f(v)f(x)F(v)^{n-2}$.

Note that this function is increasing with s and v. Moreover,

$$p(v,s) \leq s$$

if and only if

$$s \leq \frac{v^2}{v+2}.$$

The highest value $\frac{v^2}{v+2}$ *can take is* $\frac{1}{3}$. *Therefore, when* $s \geq \frac{1}{3}$, *there is always an interior solution. On the other hand, when* $s \leq \frac{1}{3}$, *we may have* $p(v,s) > s$ *for* $v > \frac{1}{2}s + \frac{1}{2}\sqrt{s(s+8)}$. *Hence, in general, we have*

$$p(v,s) = \min\{s, \frac{1}{2}\left(\sqrt{s^2 - 2sv - 4s + 5v^2 + 4v + 4} - v + s - 2\right)\}. \tag{1}$$

Now, let us calculate the expected utility of the auctioneer with arbitrary s:

$$\begin{aligned} EU_A^H(s) = 2\int_0^1 \Bigg(& \int_0^{p(v,s)} p(v,s)\left(1 - \frac{s - p(v,s)}{2}\right)dx \\ & + \int_{p(v,s)}^{v} x\left(1 - \frac{s + x - 2p(v,s)}{2}\right)dx\Bigg)dv \end{aligned}$$

where $p(v,s)$ *is given by Equation 1. Suppressing the dependence of p on v and s and with a little algebra, we can write*

$$\begin{aligned} EU_A^H(s) &= 2\int_0^1 \left(p^2\left(1 - \frac{s-p}{2}\right) + \frac{(v-p)}{12}\left(6p + 6v - 3ps + 4pv - 3sv + 4p^2 - 2v^2\right)\right)dv \\ &= 2\int_0^1 \left(\frac{1}{2}pv^2 - \frac{1}{4}p^2 s - \frac{1}{4}sv^2 + \frac{1}{2}p^2 + \frac{1}{6}p^3 + \frac{1}{2}v^2 - \frac{1}{6}v^3\right)dv \end{aligned}$$

Although an analytical solution is difficult to obtain due to the specification of $p(v,s)$, *we can numerically calculate the optimal starting price as* $s \approx 0.28$.

Our first result is the following:

Proposition 1. *In a Bayesian Nash equilibrium of the Honolulu-Sydney auction, we can observe all three price dynamics:(i) pure Dutch (descending only), (ii) pure English (ascending-only), and (iii) Dutch and then English (descending then ascending) auction price dynamics.*

Proof. *Consider Example 1. In this example, the starting price will be approximately 0.28. Let* v_1 *denote bidder 1's value, and* v_2 *denote bidder 2's value. If* $v_1 \geq 0.9$ *and* $v_2 \geq 0.28$, *then we will observe pure English auction dynamics. If $v_1 < 0.9$ and $v_2 < p(v_1, 0.28)$, then we will observe pure Dutch auction dynamics. If $v_1 < 0.9$ and $v_1 > v_2 > p(v_1, 0.28)$, then we will observe first-Dutch-then-English auction price dynamics.* ■

This result implies that all three observed price dynamics: price only going down, price only going up, and price going down, then up, are theoretically possible.

3.2 Dutch Auctions

To compare our predictions for the Honolulu-Sydney auction with its main competitor, we now turn to the analysis of the Dutch auction with impatient bidders.

The equilibrium analysis of the Dutch auction is more straightforward. We examine a standard Dutch auction where the price continuously declines from 1 until a bidder shows interest, i.e., bids on the item, at which point the object is awarded at that price. We concentrate on a symmetric equilibrium in which all bidders bid according to a strictly increasing and differentiable function $\beta(\cdot) \to [0, 1]$. In this equilibrium, a bidder with a value of v bidding as though their value is v' will attain the expected utility of:

$$EU_B^D = (v - \beta(v'))c_B(1 - \beta(v'))G(v')$$

A necessary condition for β to be a symmetric equilibrium strategy is that the first-order derivative of the expression above with respect to v', evaluated at $v' = v$, must be zero. Consequently, we derive the following differential equation for β:

$$-\beta'(v)G(v)\left[c_B(1 - \beta(v)) + (v - \beta(v))c_B'(1 - \beta(v)\right] + (v - \beta(v))c_B(1 - \beta(v))g(v) = 0$$

The auctioneer's expected utility in the Dutch auction is given by

$$EU_A^D = \int_0^1 \beta(x)c_A(1 - \beta(x))dF^n(x).$$

It is worth noting that the Dutch equilibrium we consider here is efficient, given that we assume bid functions are strictly increasing in values.

Remark 2. *In equilibrium, the Dutch auction results in an efficient allocation, in that the item is allocated to the highest-value bidder.*

As it is analytically challenging to work with general time-adjustment functions, we will consider linear time-adjustment functions in the following subsection.

3.3 The Case of Linear Costs

The previous analyses are too complex to allow for closed-form solutions; they are also not suitable for numerical solutions with the generality of the time-adjustment function. In this section, we focus on a specific type of time-adjustment function for both the bidders and the auctioneer. Assume that for each bidder, the payoff shrinks linearly with time by a factor $a - bt$, where t represents the total duration of the auction and $b \leq a/2$ is the bidder unit time cost. Likewise, suppose that for the auctioneer, the payoff shrinks linearly with time by the factor $a - ct$, with t denoting the total auction duration and $c \leq a/2$ being the auctioneer unit time cost.[11]

We will begin by examining the Honolulu-Sydney auction.

3.3.1 Honolulu-Sydney Auction

The auctioneer starts the auction at price $s \in [0, 1]$. Consider a bidder with value v who bids at the time when the price decreases to p, his/her expected utility can now be written as

$$EU_B^H(p; v, s) = G(p)(v - p)(a - bs + bp) + \int_p^v (v - x)(a - bs - bx + 2bp)\, dG(x)$$

For each v, let us denote the solution to the maximization problem

$$\max_{p \in [0,s]} EU_B^H(p; v, s)$$

by $p(v, s)$. We can easily argue that $p(v, s) \leq v$ and also by definition $p(v, s) \in [0, s]$.

The first-order condition for the maximization problem is to have the partial derivative of $EU_B^H(p; v, s)$ with respect to p is equal to 0 at $p = p(v, s)$. We have:

$$\begin{aligned} \frac{\partial}{\partial p} EU_B^H(p; v, s) &= g(p)(v - p)(a - bs + bp) \\ &\quad - G(p)(a - bs + bp) \\ &\quad + G(p)(v - p)\, b \\ &\quad - (v - p)(a - bs - bp + 2bp)\, g(p) \\ &\quad + 2b \int_p^v (v - x)\, dG(x) \end{aligned}$$

Since the first and fourth lines cancel each other and by integration by parts in the fifth line,

[11] These constraints are not essential but they guarantee that the cost of time component of the utility remains positive for all possible durations up to the highest $t \leq 2$.

we can rewrite this as

$$\begin{aligned}\frac{\partial}{\partial p}EU_B^H(p;v,s) &= G(p)(vb-2bp-a+bs)+2b\left(\int_p^v G(x)\,dx-(v-p)G(p)\right)\\ &= 2b\int_p^v G(x)\,dx-G(p)(a-bs+bv)\end{aligned}$$

Given that $a>2b$, we can first argue that the second-order derivative is always negative. This is because

$$\frac{\partial}{\partial p}\left(\frac{\partial}{\partial p}EU_B^H(p;v,s)\right)=-2bG(p)-g(p)(a-bs+bv)$$

and $G(p)$, $g(p)$, $a-bs+bv$ are all positive.

Moreover, let us denote the first-order derivative $\frac{\partial}{\partial p}EU_B^H(p;v,s)$ by

$$K(p;v,s)\equiv 2b\int_p^v G(x)\,dx-G(p)(a-bs+bv) \tag{2}$$

Then $K(p;v,s)$ is strictly decreasing in p (since second order derivative is negative) and there is a unique solution to $K(p;v,s)=0$ in $p\in[0,v]$. This is because: (i) at $p=0$, $K(p;v,s)=2b\int_0^v G(x)\,dx>0$, and (ii) at $p=v$, $K(p;v,s)=-G(v)(a-bs+bv)<0$.

Let us denote this unique solution p that equates $K(p;v,s)$ to 0 by $k(v,s)$. If $k(v,s)\le s$, then it would be the price that a bidder with value v would bid. Otherwise, the bidder would bid s. Therefore, we can write the equilibrium bid of a bidder with value v as

$$p(v,s)=\min\{s,k(v,s)\},$$

which can be solved numerically.

Given that we can obtain a numerical solution for equilibrium bid functions, we can write the expected utility of the auctioneer as follows:

$$\begin{aligned}EU_A^H(s)=&\int_0^1\int_0^{p(v,s)}p(v,s)(a-c(s-p(v,s)))h(v,x)dxdv\\ &+\int_0^1\int_{p(v,s)}^v x(a-c(s+x-2p(v,s)))h(v,x)dxdv,\end{aligned}$$

The starting price s that maximizes the above equation will be chosen by the auctioneer and this optimal s again can be computed numerically.

Given the optimal starting price, the expected duration of the auction and the expected selling price (the auction revenue) are as follows (where the maximizer is used to perform the calculations):

$$ED^H = \int_0^1 \left(\int_0^{p(v,s)} (s - p(v,s))h(v,x)dx + \int_{p(v,s)}^v (s + x - 2p(v,s))h(v,x)dx \right) dv$$

$$ER_A^H = \int_0^1 \left(\int_0^{p(v,s)} p(v,s)h(v,x)dx + \int_{p(v,s)}^v xh(v,x)dx \right) dv$$

Lastly, interim and ex-ante expected utilities of the bidders are given by

$$EU_B^H(v) = G(p)(v - p(v,s)) (a - bs + bp(v,s)) + \int_{p(v,s)}^v (v - x) (a - bs - bx + 2bp(v,s)) \, dG(x)$$

and

$$EU_B^H = \int_0^1 EU_B^H(v)dF(v)$$

3.3.2 Dutch Auction

With regards to the Dutch auction, with linear time-adjustment functions, we can rewrite the necessary condition for the equilibrium bid function β as follows:

$$g(v)(v - \beta(v))(a - b(1 - \beta(v))) = \beta'(v) G(v)(a + 2b\beta(v) - b - bv)$$

This is an ordinary differential equation for β with boundary condition $\beta(0) = 0$.

Given that we have a solution for equilibrium bids, we can write the expected utility of the auctioneer as follows:

$$EU_A^D = \int_0^1 \beta(x)(a - c(1 - \beta(x)))dF^n(x).$$

The expected duration of the auction and the expected selling price are as follows:

$$ED^D = \int_0^1 (a - c(1 - \beta(x)))dF^n(x)$$

$$ER_A^D = \int_0^1 \beta(x)dF^n(x)$$

Lastly, interim and ex-ante expected utilities of the bidders are given by

$$EU_B^D(v) = (v - \beta(v))(a - b(1 - \beta(v))G(v)$$

and

$$EU_B^D = \int_0^1 EU_B^D(v)dF(v)$$

3.4 Comparison of the Two Auction Formats

With the ability to numerically solve for the equilibria for both Dutch and Honolulu-Sydney auctions, we can evaluate their performance based on various criteria, such as the auctioneer's expected utility, auction duration, and bidders' ex-ante expected utility in equilibrium.

First, let's examine an extreme scenario with patient bidders and an impatient auctioneer, $b = 0$ and $c > 0$. In this case, it is not difficult to see that the optimal starting price in the Honolulu-Sydney auction would be 0.[12] Consequently, the Honolulu-Sydney auction transforms into an English auction, and in both the Dutch and Honolulu-Sydney auctions, the behavior of the bidders becomes identical to that of the standard risk-neutral case. Under these circumstances, we can determine the exact conditions that make either Honolulu-Sydney or Dutch auctions more favorable.

In this scenario, we have

$$\begin{aligned} EU_A^H &= \int_0^1 x\,(1 - cx)\, dG\,(x) \\ EU_A^D &= \int_0^1 \beta^N\,(x)\left(1 - c\left(1 - \beta^N\,(x)\right)\right) dF^n\,(x) \end{aligned}$$

where β^N represents the standard risk-neutral equilibrium in Dutch auctions and is given by

$$\beta^N(x) = \frac{1}{G(x)} \int_0^x y dG(y)$$

Owing to the revenue equivalence result[13], we know that

$$\int_0^1 x dG\,(x) = \int_0^1 \beta^N\,(x)\, dF^n\,(x)$$

[12]When bidders have no time costs, they will not bid at a positive price, since they have nothing to gain by it. Then, since the auctioneer has a strictly positive time cost, she will start the auction at the price of 0.

[13]The revenue equivalence holds for this case since bidders have no time costs.

Let us denote this value (which is the expected selling price in the standard auctions with no time cost) by R.

Then, we can write

$$EU_A^H = R - c\int_0^1 x^2 dG(x)$$
$$EU_A^D = R - c\int_0^1 \beta^N(x)\left(1-\beta^N(x)\right) dF^n(x)$$

Thus, we can state that:

$$EU_A^H > EU_A^D$$

if and only if

$$\int_0^1 x^2 dG(x) < \int_0^1 \beta^N(x)\left(1-\beta^N(x)\right) dF^n(x),$$

or:

$$\int_0^1 x^2 dG(x) + \int_0^1 \left(\beta^N(x)\right)^2 dF^n(x) < R = \int_0^1 x dG(x).$$

It becomes apparent that as the number of bidders, n, increases, the left side of the inequality will exceed the right side, as both terms on the left and the single term on the right approach 1. Therefore, with a larger number of bidders, the Dutch auction becomes more appealing to the auctioneer. We summarize these observations as follows:

Proposition 2. *When $b = 0$ and $c > 0$, for any given value distribution, there exists n^* such that when $n < n^*$ the auctioneer prefers the Honolulu-Sydney auction over the Dutch auction, and when $n \geq n^*$ the auctioneer prefers the Dutch auction over the Honolulu-Sydney auction.*

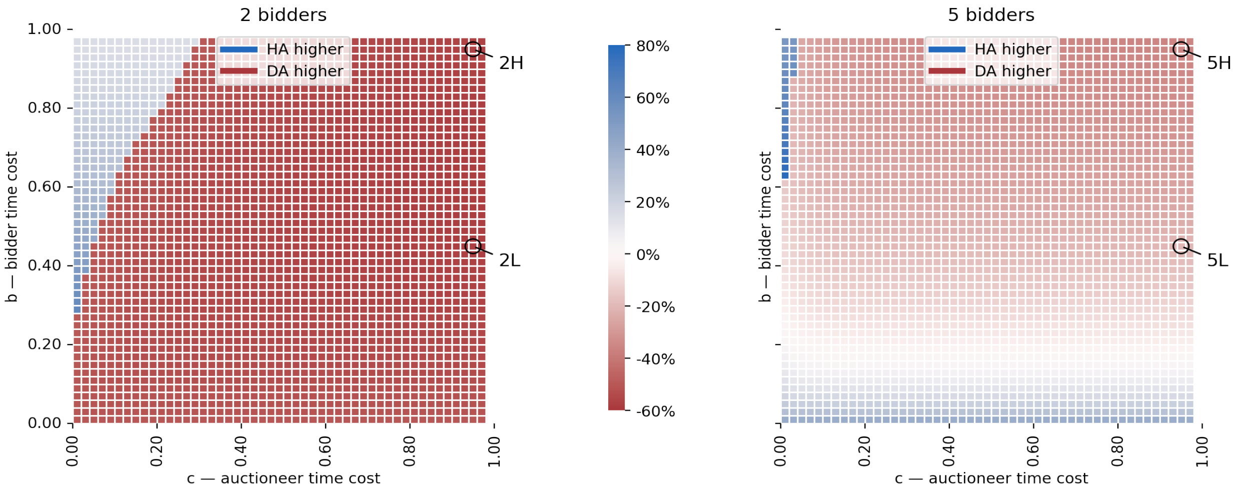
In fact, when F is uniform, some algebraic manipulation allows us to conclude that the Dutch auction yields a higher expected utility than the Honolulu-Sydney when there are at least three bidders.

Corollary 1. *When $b = 0$, $c > 0$, and values are uniformly distributed, the Dutch auction yields a higher expected utility than the Honolulu-Sydney auction if and only if $n \geq 3$.*

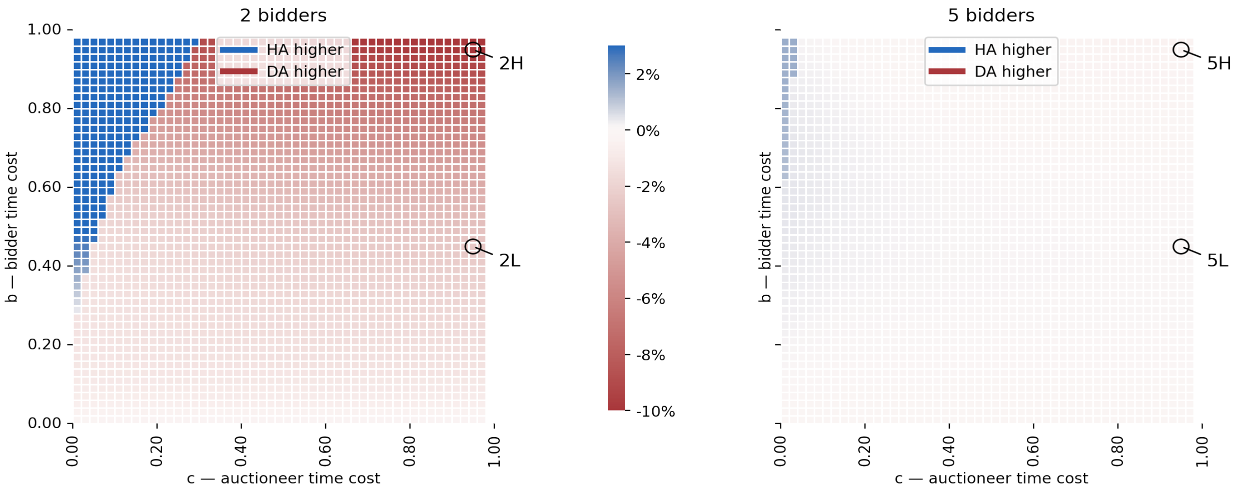
By the continuity of the auctioneer's utility function, this result extends to b low enough. Our numerical calculations presented below illustrate this point.

3.5 Numerical results

Our numerical algorithm enables us to compute the equilibrium bids, expected utilities, and expected selling prices and durations for both Dutch and Honolulu-Sydney auctions. In our



(a) Auction duration



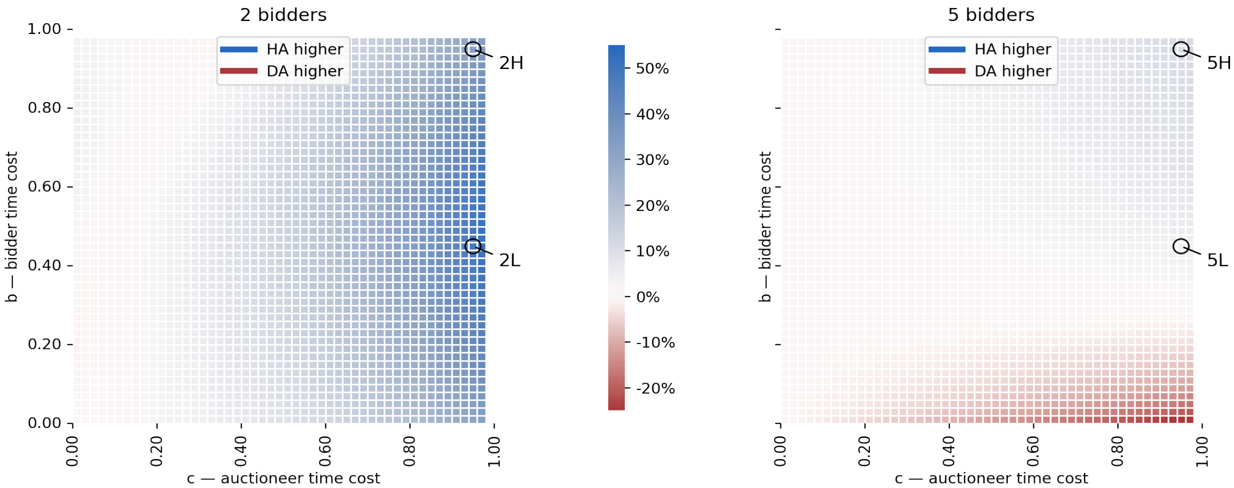
(b) Selling prices

Figure 1: Predicted duration and price differences of Honolulu and Dutch auctions

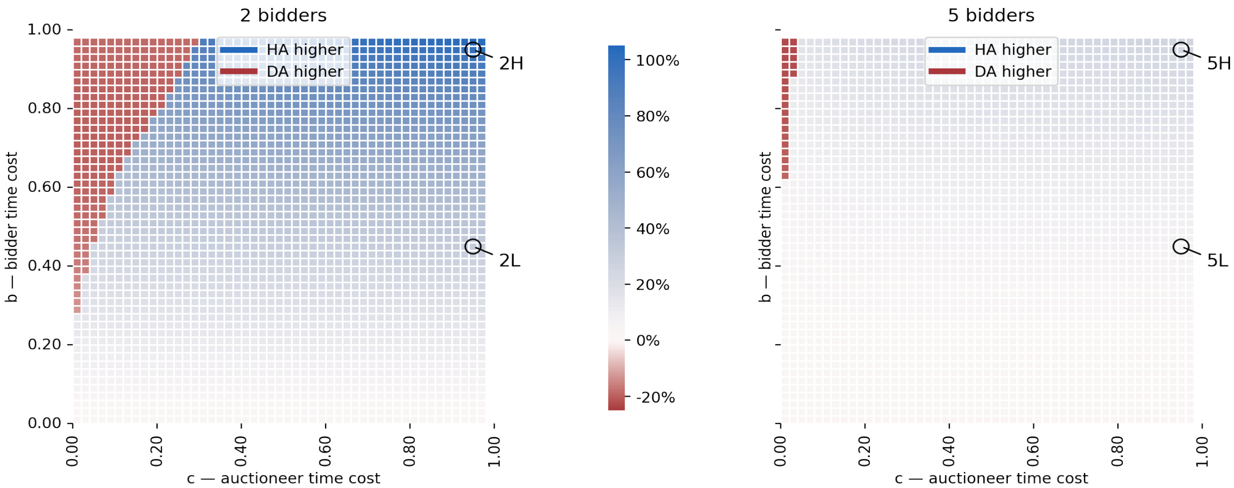
calculations, we assume F to be uniform and allow for variations in the number of bidders (n), the bidders' time cost parameter (b), and the auctioneer's time cost parameter (c).[14] The calculations confirm that, as observed in our extreme example, the Honolulu-Sydney auction's relative performance advantage (in terms of auctioneer utility) against the Dutch auction is less pronounced as the number of bidders grows. This observation aligns with real-world scenarios: Honolulu-Sydney auctions are employed for "premium seafood," which typically involves a smaller number of bidders compared to more conventional fish auctions, where Dutch auctions are commonly utilized.

The numerical estimations allow us to derive the following predictions regarding the

[14] We normalize a to be 1 in our numerical code.



(a) Utility for the auctioneer



(b) Utility for the bidder

Figure 2: Predicted auctioneer and bidder utility differences of Honolulu and Dutch auctions

relative performance of Dutch and Honolulu-Sydney auctions in terms of duration, selling price, and auctioneer and bidder utilities, depending on the number of bidders and the bidder and auctioneer's cost of time, as illustrated in Figure 1 and Figure 2. [15]

Prediction 1 (Relative performance of Honolulu-Sydney and Dutch auctions)**.** *Assume the distribution of bidder values is uniform, and the time-adjustment function is linear. Then, under a wide range of parameter values,*

1. *(Auction duration) Honolulu-Sydney auctions are faster than Dutch auctions, i.e., their average duration is shorter. The relative advantage of Honolulu-Sydney auctions over Dutch in terms of duration decreases with the number of bidders.*

[15] Appendix B and Figures B.2-B.5 therein provide more details.

2. *(Selling prices) The difference in average selling prices between Honolulu and Dutch auctions is small; it does not exceed 5-10 percent.*

3. *(Auctioneer utility) Assume the auctioneer cost of time is relatively high. Then Honolulu-Sydney auctions are always preferred to Dutch in the two-bidder case. For auctions with more than two bidders, Honolulu-Sydney auctions are preferred to Dutch when bidder cost of time is high, and Dutch auctions are preferred to Honolulu-Sydney when bidder cost of time is low.*

4. *(Buyer utility) Buyers prefer Honolulu-Sydney auction to Dutch under a wide range of parameter values. For auctions with a small number of bidders, the advantage of Honolulu-Sydney auctions over Dutch in terms of buyer utility increases with bidder cost of time. The relative advantage of Honolulu-Sydney auctions over Dutch decreases with the number of bidders.*

4 Experiment Objectives and Design

The laboratory experiments are designed to evaluate and compare the performance of Honolulu-Sydney (referred to as "Honolulu" hereafter for brevity) and Dutch auctions in view of the above theoretical analysis. We address the following questions. First, do Honolulu auctions manifest the predicted price adjustment flexibility, with prices going up, or down, or down then up, depending on the demand, and do they result in efficient allocations, as predicted? Further, are Honolulu auctions considerably faster than Dutch with a small number of bidders? Do the relative advantages of Honolulu and Dutch auctions in terms of speed, auctioneer utility, and bidder payoffs change depending on the number of bidders and bidder cost of time? Finally, we explore if bidder behavior is sensitive to the induced time costs, and look into heterogeneity of individual behavior.

4.1 Auction Design

Values, Auction Duration and Payoffs Our intent is to reproduce, in a laboratory setting, the auction institutions and environments similar to those in the existing fish markets, with speedy sales and noticeable costs of delay for participants.

All experimental participants are assigned the roles of bidders; the auctioneer role is carried out by the computer. At the beginning of an auction period, each participant is randomly assigned a private item value drawn from the uniform integer distribution on $[0, 50]$ experimental points, and is randomly matched with $(n-1)$ other participants to compete for a unit of a fictitious good. The participants are explicitly instructed that their earnings from the purchase will depend on the difference between their value for the good and the price they pay, and on how long the auction lasts; see experimental instructions included in the Experimental Materials. The payoff of a bidder with value v who makes a purchase at price p after t units of time is calculated as:

$$U_B = (v - p)\, c_B(t), \tag{3}$$

where the "time-adjustment factor" $c(t)$, as it is referred to in the experimental instructions, depends on the common to all bidders time cost parameter b:[16]

$$c_B(t) = \begin{cases} (1 - bt) & \text{if } v \geq p; \\ (1 + bt) & \text{if } v < p. \end{cases} \tag{4}$$

For both Dutch and Honolulu auctions, a virtual clock is used to determine the auction duration. The virtual clock ticks every second. For each tick of the virtual clock, the price changes (decreases or increases, depending on the auction format and its stage) by one point,[17] and the available buyer payoff shrinks according to the time-adjustment factor $c_B(t)$. At each point when the auction is open, each participant is given real-time information on the current price of the item, the auction time elapsed, and their unadjusted $(v - p)$ and time-adjusted $(v - p) \cdot c_B(t)$ payoffs if they were to buy the item at this price and time. Examples of a participant auction screen are given in the Experimental Materials. The bidder who buys the item in the auction receives their time-adjusted payoff at the time and price of sale; all other bidders receive zero payoffs in this auction.

The auctioneer payoff from a sale at price p and time t, used to assess the auction performance, is calculated as

$$U_A = p \cdot c_A(t),$$

where $c_A(t) = (1 - ct)$, and c is the auctioneer's cost of time parameter.

[16]Consistent with the model in Section 3, buyer positive payoffs (earnings) shrink in proportion of auction duration; yet the negative payoffs (losses) increase in proportion to auction duration. We replaced the time-adjustment function $(1 - bt)$ by $(1 + bt)$ for the negative payoff range to avoid undesirable effects of bidder losses possibly shrinking with longer auction duration if a bidder stays active in the ascending stage of the auction when the price surpasses their value. Since such behavior never occurs in equilibrium, the model predictions are not affected by this modification.

[17]Therefore, the price changes by 2% of the maximum item value every second, which is a fairly fast clock according to Katok and Kwasnica (2008). Their fast, medium and slow clocks are equivalent to 5%, 0.5% and 0.17% change per second, respectively.

Auction institutions The Dutch auction is implemented in the standard way: the auction opens at the price of 50, and the price decreases by one point with every tick of the virtual clock. The first subject to click the "Bid" button buys the item and receives a payoff equal to her displayed adjusted payoff at the time of her bid.

Under the Honolulu format, the auction opens at the auctioneer's optimal starting price set by the experimenter. Then either a bidder bids at the opening price, or the Dutch stage begins with the price decreasing by one point with every tick of the virtual clock until a bidder bids, becoming a "provisional buyer." Other bidders are then given 10 seconds to challenge this buyer by indicating their willingness to continue bidding. During this "Contest" stage, the virtual clock is stopped, and the price and time do not change. If no one challenges, then the auction ends and the provisional buyer is assigned the object at the price and time of their bid. If anyone challengers by clicking "Bid," the auction proceeds into the ascending price (English) stage, with the virtual clock ticking and the price rising by one point every second, until all but one bidder leave the auction. The remaining bidder is assigned the item at the last dropout price and time, and receives their corresponding time-adjusted payoff, while all others receive zero.

We compare the performance of Dutch and Honolulu auctions using a within-subject design, with a sequence of auctions under one institution followed by a sequence of auctions under the other institution. The sessions are conducted under either *DH* (Dutch-then-Honolulu), or *HD* (Honolulu-then-Dutch) sequence, and are counter-balanced for order.

Treatments To explore the effect of the number of bidders and the bidder cost of time on the auction performances, we implement a 2×2 between-subject design, with the number of bidders per auction $n \in \{2, 5\}$, and the bidder cost of time parameter $b \in \{H = 0.95, L = 0.45\}$, corresponding to the experimental buyer payoff shrinking by 1.9% and 0.9% with every tick of the virtual clock in the H (high cost) and L (low cost) environments, respectively. The auctioneer cost of time parameter is fixed at $c = 0.95$, corresponding to a 1.9% auctioneer payoff reduction per tick.[18] The combinations of parameter values n, b and c determine the optimal (for the auctioneer) starting prices s in Honolulu auctions, which are numerically estimated (see Section 3) and used in the corresponding treatments. The treatments are labeled $2H, 2L, 5H, 5L$, respectively, and summarized in Table 1.

Parameter values are chosen to provide a considerable variation in the relative performances of Honolulu and Dutch auctions across treatments. The time cost parameters are set high enough to have a noticeable effect on participant payoffs. We further accounted

[18]Parameter values b and c are given for the unit value scale of the theoretical model of Section 3 and then rescaled to the experimental value range of $[0, 50]$.

Table 1: Experimental design and session summary

Treatment	# of bidders	Bidder cost of time*	Starting price	# of auctions per institution	Sequence	# of sessions	# of participants
					Dutch-Honolulu	2	20
2H	2	0.019	21	18	Honolulu-Dutch	2	20
					Total	4	40
					Dutch-Honolulu	3	26
2L	2	0.009	12	18	Honolulu-Dutch	1	12
					Total	4	38
					Dutch-Honolulu	2	20
5H	5	0.019	32	25-28**	Honolulu-Dutch	2	25
					Total	4	45
					Dutch-Honolulu	2	20
5L	5	0.009	27	28	Honolulu-Dutch	1	15
					Total	3	35
All treatments						15	158

* Bidder cost of time parameters b and the starting prices are re-scaled for the experimental value and price range of $[0, 50]$.
** One 5H session had only 18 auctions per institution.

for the likely overbidding relative to the risk-neutral prediction in the Dutch auctions (Cox et al., 1982; Katok and Kwasnica, 2008) by choosing parameter values that would, in theory, favor Honolulu auctions over Dutch in all treatments, as we expected the Dutch auction to benefit the auctioneer more than predicted due to higher than predicted prices and shorter than predicted durations.[19] Figures 1 - 2 illustrate the theoretically predicted differences between the formats in expected auction durations, selling prices, and auctioneer and buyer payoffs under the four different treatments, with treatments parameter locations indicated by circles on each panel; see also Table 3 below. Consistent with Prediction 1, Honolulu auctions are expected to be shorter than Dutch and more preferred by the auctioneer and the bidders under all treatments, but the advantages of Honolulu over Dutch in terms of duration and auctioneer utility are predicted to become less pronounced in five-bidder auctions than in two-bidder auctions.

4.2 Experimental procedures

The auction experiment is programmed using oTree (Chen et al., 2016), with student participants recruited using ORSEE recruitment system (Greiner, 2015). Eight to 12 participants are recruited for each two-bidder auction session, and 10 to 15 participants for each five-

[19] In calibrating the experimental parameters, we conducted four pilot sessions with 40 participants to inform the experimental design. The pilot sessions had the value range of $[0, 100]$, a slower clock of one price tick per 1.3 seconds, and lower cost of time parameters; these auctions proved to be extremely slow and did not reflect the fast nature of the auctions we seek to model. We also observed that the cost of time was negligible under the original design. Consequently, we re-scaled the value range to $[0, 50]$ interval, increased the clock speed to one price tick per second, and increased the cost of time parameters.

bidder auction session. Before proceeding with the auctions, the experimenter reads aloud the experimental instructions and answers any questions, while the participants follow the instructions and complete tests for understanding on the computer screen. Each session includes two practice and 18-28 paid Honolulu auction rounds followed by an identical number of Dutch auction rounds (HD sequence) or vice versa (DH sequence). The session participants are randomly re-matched into groups of two (in 2-bidder treatments) or five (in 5-bidder treatments) for each round. Each auction institution is followed by a brief questionnaire soliciting participant feedback on the institution and participant affective states.[20] At the conclusion of a session, the participants are paid in private their cumulative earnings from the auctions, plus a show-up fee. The total duration of each session is between one and a half and two hours, including instructions.

We conducted a total of 15 independent sessions, with 158 unique student participants at the experimental laboratories of the University of Hawaii and the University of Technology Sydney, with 3-4 sessions per treatment. The sessions are summarized in Table 1. The average payments (including the participation fees of \$5 USD or \$10 AUD) were \$28.95 USD and \$52.57 AUD, respectively. Experimental instructions, screenshots and the post-auction survey are included in the Experimental Materials supplement.

5 Experimental Results

5.1 Auction performance

Price dynamics As predicted, we observe all three price dynamics under Honolulu auctions in the experiment: descending price only (Dutch), ascending price only (English), and descending followed by ascending prices (Dutch-then-English) (Table 2).

Yet the Dutch-then-English price dynamics are significantly more frequent, and the English-only dynamics are less frequent than predicted under all treatments, as supported by the Wilcoxon signed-rank tests comparing the actual percentage of these price dynamics to predicted ($p < 0.01$ and $p < 0.05$ for 2-bidder and 5-bidder auctions respectively, and $p < 0.01$ for all treatments pooled; see Table D.1 in the Appendix D.) This suggests that the participants often allowed prices to drop before bidding even if they would be better off bidding at the opening price. We explore this behavioral pattern in more detail in Section 5.2 below.

[20] Qualitative questions measuring regret and affective states are based on Camille et al. (2004). Each experimental session also included short pre- and post-auction surveys that assessed participants cognitive ability, risk, time and competitiveness preferences, and basic demographics. See Cacho (2023) for details.

Table 2: Price dynamics in Honolulu auctions

		Dutch then English		Dutch only		English only*	
Treatment	Statistics	Predicted	Actual	Predicted	Actual	Predicted	Actual
2H	Count	137	222	156	113	67	25
	Percentage	38.1%	61.7%	43.3%	31.4%	18.6%	6.9%
2L	Count	163	250	65	77	114	15
	Percentage	47.7%	73.1%	19.0%	22.5%	33.3%	4.4%
5H	Count	94	135	41	27	75	48
	Percentage	44.8%	64.3%	19.5%	12.9%	35.7%	22.9%
5L	Count	35	115	35	25	126	56
	Percentage	17.9%	58.7%	17.9%	12.8%	64.3%	28.6%

* To account for possible participant delays in executing their bids, bids within two points (two price ticks) from the starting price are considered as immediate bids, with the corresponding auction dynamics classified as English (ascending price) only.

Result 1. *As predicted, experimental Honolulu auctions are characterized by price adjustment flexibility, displaying all three price dynamics: descending only (Dutch), ascending only (English) and descending-then-ascending (Dutch-then-English). Compared to the theoretical predictions, the Dutch-then-English pattern is significantly more frequent, while the English-only pattern is less frequent.*

We next compare the main performance characteristics of Honolulu and Dutch auctions by treatment, as summarized in Table 3 and Figures 3 and 4. Results of hypotheses testing on the comparative performances of the two institutions, benchmarked against the theoretical predictions as given in Remarks 1, 2 and Prediction 1, are summarized in Table 4. All test results reported in Table 4 and in the remainder of the paper rely on session-clustered bootstrap estimations, unless noted otherwise. The estimation details can be found in Appendix C.

Table 3: Predicted and actual auction characteristics by treatment

	2H		2L		5H		5L	
	Predicted	Actual	Predicted	Actual	Predicted	Actual	Predicted	Actual
Value efficiency								
Dutch	100%	94.8%	100%	95.4%	100%	98.7%	100%	95.5%
Honolulu	100%	96.7%	100%	96.8%	100%	98.4%	100%	98.5%
Auction duration								
Dutch	28.4	29.9	32.1	29.5	15.7	14.3	16.4	13.0
Honolulu	12.5	20.6	14.2	19.6	10.3	18.4	9.0	15.5
H/D, %	44.0%	68.9%	44.2%	66.4%	65.6%	128.7%	54.9%	119.2%
Selling prices								
Dutch	21.6	20.6	17.9	21.1	34.3	36.3	33.6	37.6
Honolulu	19.8	17.0	18.1	15.6	33.9	33.4	33.3	32.2
H/D, %	91.7%	82.5%	101.1%	73.9%	98.8%	92.0%	99.1%	85.6%
Auctioneer payoffs								
Dutch	11.0	10.8	7.9	11.0	24.9	27.3	23.8	29.3
Honolulu	14.8	9.7	11.9	7.9	27.3	21.7	27.1	22.0
H/D, %	134.5%	90.0%	150.6%	71.8%	109.6%	79.5%	113.9%	75.1%
Bidder payoffs								
Dutch	5.9	4.5	11.1	8.1	5.1	3.3	6.7	1.5
Honolulu	11.7	9.7	14.0	14.2	6.1	4.3	8.1	7.8
H/D, %	198.3%	215.6%	126.1%	175.3%	119.6%	130.3%	120.9%	520.0%

Predictions are based on actual bidder values drawn. Value efficiency is in percent, auction duration in seconds, and prices and auctioneer and buyer utilities in experimental points. Buyer utility is conditional on buying. Bidder ex-ante utility can be obtained by dividing buyer utility by the number of bidders.

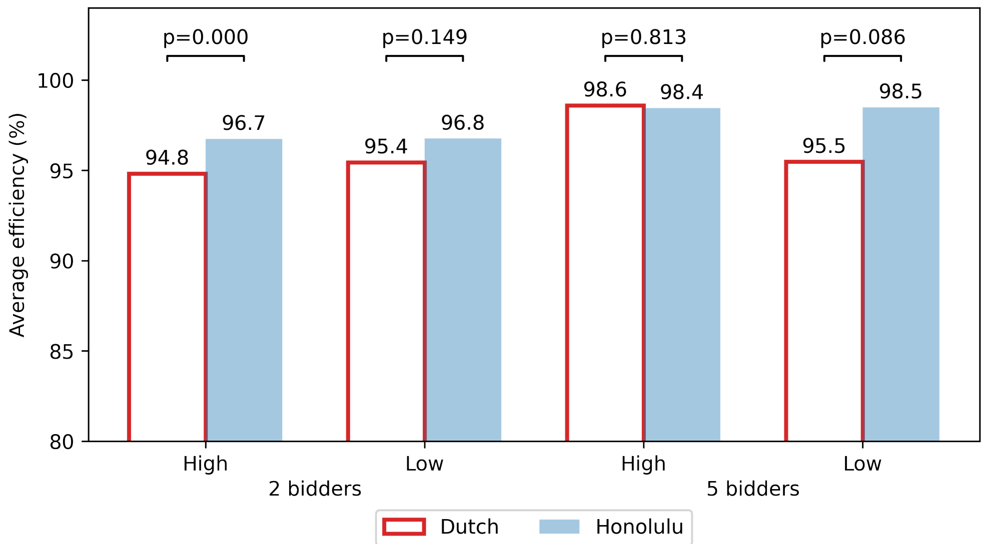


Figure 3: Auction efficiency by treatment

Value efficiency Value efficiency[21] is 95% or higher in all treatments under both auction formats. However, Honolulu auctions have about 1.5 percent higher efficiency than Dutch overall ($p < 0.001$ for the pooled data), and higher efficiency in three out of four treatments ($p < 0.1$, one-sided); see Figure 3 and Table 4. This higher efficiency is likely due to the majority of Honolulu auctions ending with the English stage, which is known to have the highest efficiency among all common auction formats.

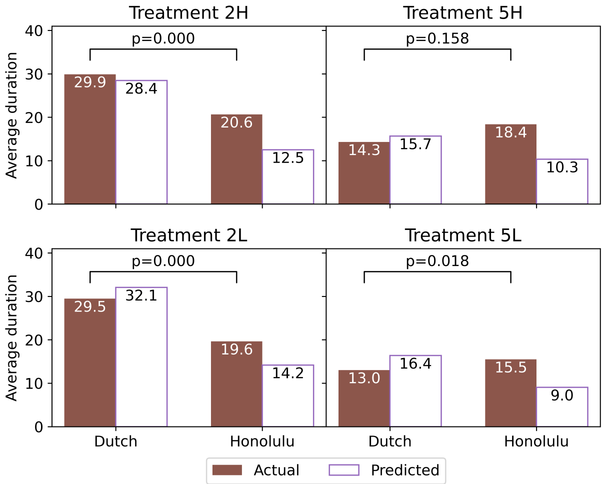
Table 4: Hypotheses tests of theoretical predictions

Characteristic	Prediction-based hypotheses*	cost/ bidders	Observed coeff.	Bootstr. std. err.	p-value	Prediction supported?
Efficiency	$H = D$	pooled	1.54	.43	0.000	no
	$H^h = D^h$	2 bidders	1.93	.48	0.000	no
	$H^l = D^l$	2 bidders	1.32	.91	0.149	yes
	$H^h = D^h$	5 bidders	-.15	.65	0.813	yes
	$H^l = D^l$	5 bidders	3.02	1.76	0.086	no
Duration	$D^2 > H^2$	high cost	9.26	1.70	0.000	yes
	$D^2 > H^2$	low cost	9.85	.93	0.000	yes
	$D^5 > H^5$	high cost	-4.08	2.90	0.921	no
	$D^5 > H^5$	low cost	-2.50	1.05	0.991	no
	$H^5/D^5 > H^2/D^2$	high cost	.60	.21	0.003	yes
	$H^5/D^5 > H^2/D^2$	low cost	.53	.13	0.000	yes
Selling price	$H^2/D^2 = 0.917$	high cost	-.092	.025	0.000	no
	$H^2/D^2 = 1.011$	low cost	-.270	.041	0.000	no
	$H^5/D^5 = 0.988$	high cost	-.068	.007	0.000	no
	$H^5/D^5 = 0.991$	low cost	-.134	.043	0.002	no
Auctioneer utility	$H^2 > D^2$	high cost	-1.09	.79	0.918	no
	$H^2 > D^2$	low cost	-3.14	.51	1.000	no
	$H^5 > D^5$	high cost	-5.60	1.77	0.999	no
	$H^5 > D^5$	low cost	-7.30	2.05	1.000	no
Buyer utility	$H^2 > D^2$	high cost	5.15	.76	0.000	yes
	$H^2 > D^2$	low cost	6.10	.66	0.000	yes
	$H^5 > D^5$	high cost	1.05	.82	0.100	yes
	$H^5 > D^5$	low cost	6.30	1.92	0.001	yes
	$H^h/D^h > H^l/D^l$	2 bidders	.379	.313	0.113	no
	$H^2/D^2 > H^5/D^5$	high cost	.81	.42	0.026	yes
	$H^2/D^2 > H^5/D^5$	low cost	-3.44	18.78	0.573	no

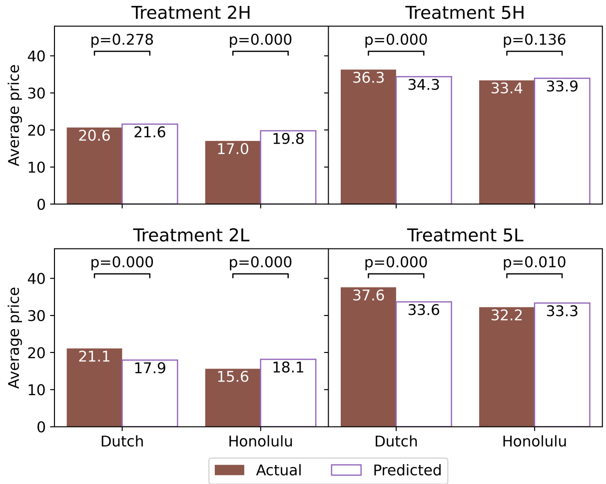
* H – Honolulu, D Dutch; h – high-cost, l – low-cost; 2 – 2-bidders, 5 – 5-bidders. Hypotheses for efficiency are based on Remarks 1- 2; for duration, auctioneer and buyer utilities – on Prediction 1; and for selling price ratios – on Table 3 predictions. Observed coefficients are for the difference between the LHS and the RHS expressions in the corresponding hypothesis; see Appendix C for the estimation details.

[21] The value efficiency is defined in the usual way, as the percent of the buyer item value to the highest value in the market.

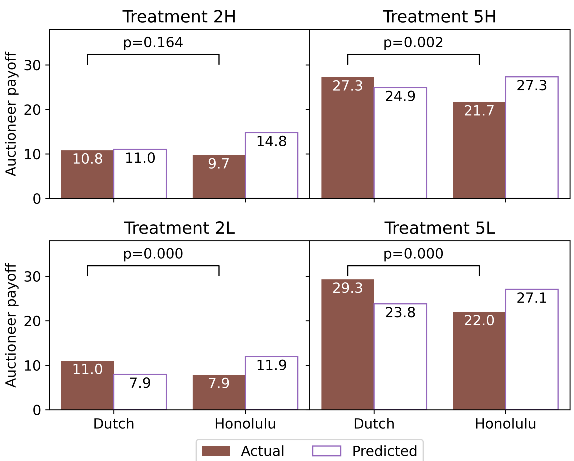
Result 2. *Efficiency is high under both auction formats and in all treatments, as predicted. Overall, Honolulu auctions are more efficient than Dutch.*



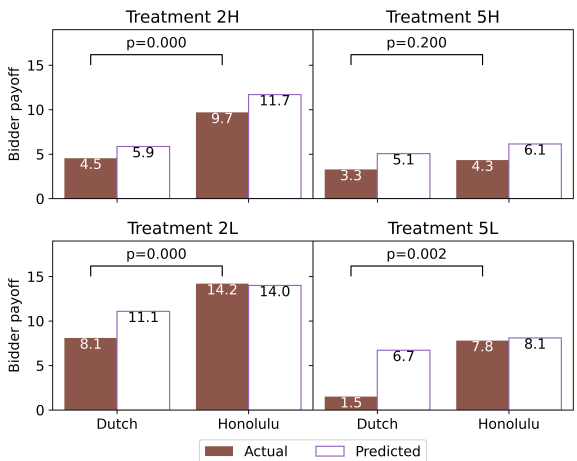
(a) Auction duration



(b) Selling prices



(c) Auctioneer payoffs



(d) Bidder payoffs

Figure 4: Auction performance by treatment

Auction duration As is evident from Figure 4a and Table 3, Honolulu auctions are significantly faster than Dutch in 2-bidder case ($p < 0.001$); we observe approximately one-third (32.1%) shorter duration in Honolulu auctions, although, on average, the difference is smaller than predicted. In contrast, Honolulu auctions are no faster but actually slower than Dutch in 5-bidder treatments, while they are predicted to be 39% faster. This is explained by longer-than-predicted Honolulu auctions combined with somewhat shorter-than-predicted Dutch auctions. The comparative statics prediction is therefore confirmed: the relative advantage of Honolulu auctions over Dutch decreases with the number of bidders, $H5/D5 > H2/D2$, for both high and low costs ($p < 0.01$, one-sided, in both cases; Table 4). Moreover, the observed auction durations are significantly shorter than those predicted under zero cost of time for all treatments and both auction formats (Figure E.1 in Appendix E).

Result 3. *Honolulu auctions are significantly faster than Dutch with two bidders. Yet Honolulu auctions take longer than predicted and are no faster than Dutch in five-bidder auctions. As predicted, the relative advantage of Honolulu auctions over Dutch, in terms of duration, decreases with the number of bidders.*

Selling prices From Figure 4b and Table 3, Dutch auctions have higher than predicted ($p < 0.01$) selling prices in all treatments other than 2H. This is not surprising as overbidding is commonly observed in Dutch auctions (Cox et al., 1982; Katok and Kwasnica, 2008). For Honolulu auctions, selling prices are lower than predicted ($p < 0.001$) with 2 bidders, suggesting suppressed price competition (to be explored in Section 5.2 below), and they are still lower (in 5L) or not significantly different from predicted (in 5H) with 5 bidders (Figure 4b). Consequently, the relative price differences between Dutch and Honolulu auctions exceeded those predicted for both 2-bidder and 5-bidder auctions ($p < 0.01$ in all cases, Table 4).

Result 4. *Dutch auctions have higher than predicted prices in most treatments, while Honolulu auction prices are no higher or lower than predicted. Consequently, Honolulu auctions have significantly lower prices than Dutch, with the price gap larger than predicted, in both two-bidder and five-bidder settings.*

Although the prices have a direct effect on the auctioneer's and bidders' utility, the standard revenue comparison is largely irrelevant because of the time costs. We next turn to a more relevant auctioneer utility comparison that incorporates both revenue and time cost considerations.

Auctioneer payoffs As illustrated in Figure 4c and Table 3, the auctioneer utility is not significantly different between Honolulu and Dutch auctions in 2H treatment ($p = 0.164$, two-sided). In other treatments, Dutch auctions benefit the auctioneer significantly more than Honolulu auctions, even when the opposite is predicted ($p > 0.9$ for the prediction-based hypothesis of $H > D$ for all treatments, Table 4). This is explained by auctioneer benefiting less than predicted from Honolulu auctions, while benefiting more than predicted from Dutch auctions. The shortfall of auctioneer utility in Honolulu auctions as compared to the predictions appears greater with two bidders, likely due to lower than predicted prices, as well as longer than predicted duration (Table 3); whereas the excess of auctioneer utility over predictions in Dutch auctions is likely due to higher than predicted prices.

Result 5. *Auctioneer payoffs under Dutch and Honolulu are not significantly different in 2-bidder, high-cost (2H) treatment. In other treatments, Dutch auctions benefit the auctioneer more than Honolulu auctions, even when the opposite is predicted.*

Bidder payoffs Figure 4d and Table 3 indicate that, as predicted, buyers are significantly better off under Honolulu auctions than under Dutch in all treatments ($p = 0.1$ for 5H and $p < 0.01$ for all other treatments, Table 4). For 2-bidder auctions, buyer average payoff under Honolulu is twice as high as under Dutch in 2H treatment, and 75 percent higher in 2L treatment, exceeding the predicted differences. The high cost of time leads to a significant reduction of buyer payoffs under both Dutch and Honolulu 2-bidder auctions; yet there is not enough evidence to conclude that Honolulu auctions become more beneficial relative to Dutch as the cost of time increases ($p = 0.113$ for the hypothesis $H^h/D^h > H^l/D^l$, Table 4). For 5-bidder auctions with high costs (5H treatment), the advantage of Honolulu relative to Dutch is significantly smaller than in 2-bidder 2H treatment, as predicted ($p = 0.026$); yet it is not smaller in 5L treatment compared to 2L ($p = 0.574$), likely due to significant over-bidding in the 5L Dutch auctions.

Result 6. *Bidders are significantly better off or no worse off in Honolulu auctions as compared to Dutch in all treatments. The benefit of Honolulu auctions compared to Dutch with 5 bidders persists more than predicted in some treatments.*

Overall, we obtain strong support for the theoretical predictions on the versatility of price dynamics and efficiency of Honolulu auctions (Proposition 1 and Remark 1), as well as this institution's speed advantages and higher buyer benefits relative to Dutch auctions(Prediction 1, parts 1 and 4). However, compared to the predictions regarding prices and auctioneer utilities (Prediction 1, parts 3 and 4), Honolulu auctions underperform relative to Dutch. To summarize:

Conclusion 1. *As predicted, Honolulu auctions are highly efficient, and are considerably faster than Dutch auctions with a small number of bidders. While the auctioneer's benefits from Honolulu auctions relative to Dutch are lower than predicted, the bidders' relative benefits often exceed the predictions.*

5.2 Bidder behavior

We next explore individual behavioral patterns that would explain the observed auction performances. Behavior varied widely across individuals, resulting in large differences of bidder payoffs.

To compare bidder payoffs across individuals with different value draws, we normalize actual payoffs under a given institution as a percentage theoretically predicted:[22]

$$\%Pay = \frac{Actual\ Total\ Payoff}{Predicted\ Total\ Payoff} \times 100\%.$$

We then categorize participants into Top and Bottom earners, depending on whether their percentage payoff falls above or below the median in their treatment.

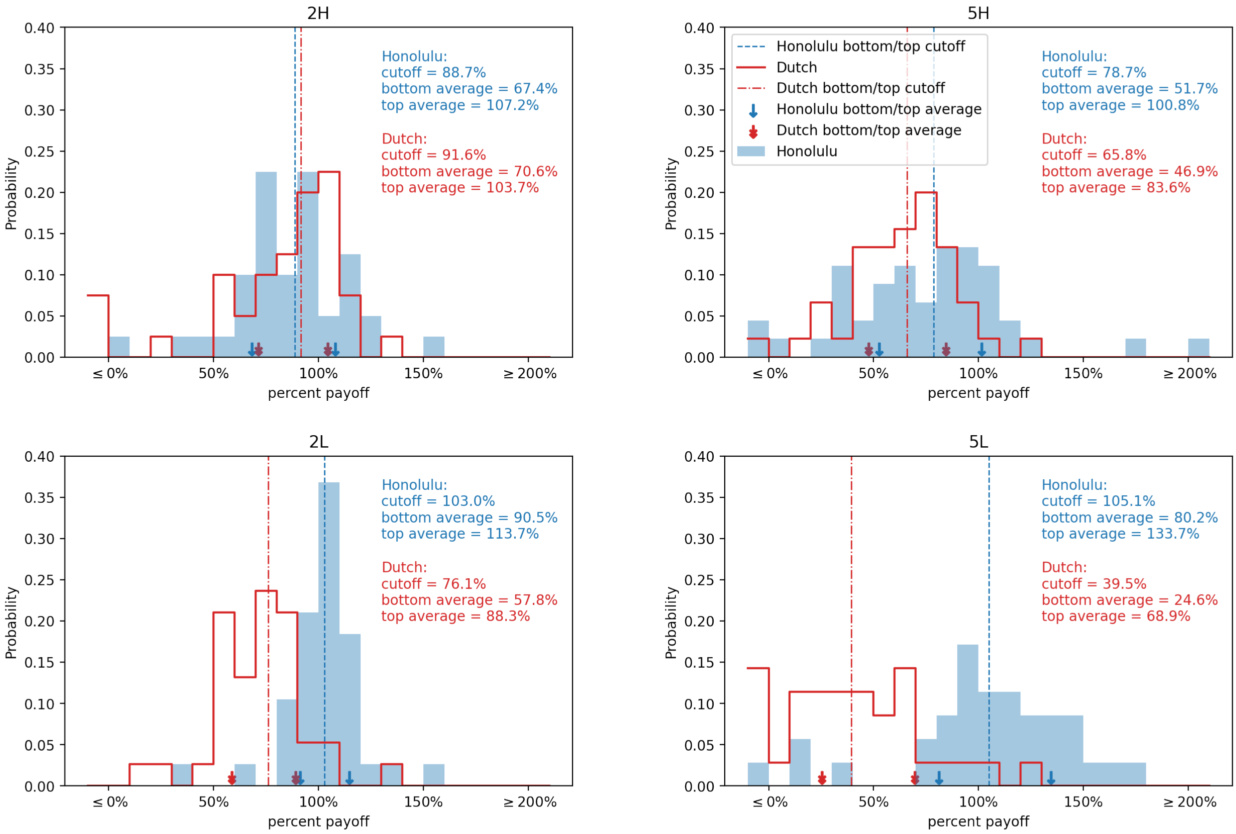


Figure 5: Distribution of percent payoffs, by treatment

Figure 5 display participant median percentage payoff (the cutoff value separating the Top and Bottom earners), and average percentage payoffs for Top and Bottom earners, by treatment. The differences between Top and Bottom earners percentage payoffs are

[22]The drawback of this measure are possibly extreme values for bidders who are predicted to earn zero or near zero, due to low value draws. We address this issue by censoring percentage payoff at -10% and 210%; the payoff percentages for only only eight bidders in Dutch auctions four bidders in Honolulu auctions (out of 158 total bidders) had to be censored. As an alternative, one could consider the average per period point deviations from the theoretical prediction by period; however, such measure would not be comparable across treatments. All qualitative findings are robust to the use of this alternative measure.

substantial under all treatments for both auction formats, with average Top earners often making higher earnings than predicted, while average Bottom earners making as low as 25 percent of the predicted payoffs in some treatments.

Below we compare the decisions of more successful, Top-earning bidders, with those of less successful, Bottom-earning bidders, to understand which bidding patterns are associated with earning success.

Dominated decisions A strictly dominated decision would involve bidding above value in the Dutch auction, leading to a sure loss. A weakly dominated decision in the Honolulu auction would involve (i) risking a loss by bidding above value in the Dutch and Contest stages of Honolulu auctions, or staying in bidding above value in the English stage; and (ii) "leaving money on the table" by dropping out of bidding in the Contest or English stages at a price below one's value. Table 5 lists the frequencies of dominated decisions in Dutch and Honolulu auctions (see also Table D.2 in Appendix D for dominated actions by auction stage). Almost all bids in Dutch auctions are undominated, as compared to 78 to 95 percent of (weakly) undominated decisions in Honolulu auctions. Further, the share of undominated decisions is no lower or higher for Top earners than for Bottom earners, under all stages of the auctions and under all treatments; the differences between Top and Bottom earners are highly significant for the pooled data, as well as for the most of the treatments and stages ($p < 0.05$, Wicoxon sign-rank test; see Table D.3 in Appendix D.)

Result 7. *The share of undominated decisions is significantly higher under Dutch than under Honolulu auctions. Top earners make dominated decisions less frequently than Bottom earners under both auction formats under most treatments.*

A higher share of dominated decisions may indicate a higher complexity of Honolulu auction compared to Dutch. Alternatively, leaving below value may be rationalizable in the framework of multi-period supergame, and may be explained by bidder attempts to suppress price competition. We explore these alternative explanations below when analyzing individual behavior in Honolulu auctions.

Bidding patterns in Dutch auctions While there is no analytical solution for the equilibrium bidding strategy in the Dutch auction if the bidder cost of time parameter is positive, i.e., $b > 0$ (Section 3), the equilibrium bidding strategy can be closely approximated by a linear function of bidder value:

$$DutchBid \approx \alpha_0 + \alpha_1 \times v, \tag{5}$$

Table 5: Frequencies of dominated decisions, by treatment

	2H		2L		5H		5L	
Decision	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
DUTCH AUCTION								
Bid above value	0	9	0	1	0	2	0	15
	0.0%	5.5%	0.0%	0.6%	0.0%	2.2%	0.0%	15.3%
Undominated bid	189	156	167	170	117	91	98	83
	100.0%	94.5%	100.0%	99.4%	100.0%	97.8%	100.0%	84.7%
HONOLULU AUCTION								
Leave below value -all	23	53	38	41	20	35	14	38
	6.4%	14.7%	11.1%	12.0%	4.1%	6.2%	2.9%	7.5%
- *foregone purchase*[2]	*23*	*53*	*38*	*41*	*13*	*21*	*7*	*24*
	6.4%	*14.7%*	*11.1%*	*12.0%*	*2.7%*	*3.7%*	*1.5%*	*4.8%*
Bid above value -all	5	25	3	13	7	45	10	25
	1.4%	6.9%	0.9%	3.8%	1.4%	8.0%	2.1%	5.0%
- *actual loss*[2]	*0*	*11*	*1*	*6*	*0*	*6*	*1*	*6*
	0.0%	*3.1%*	*0.3%*	*1.8%*	*0.0%*	*1.1%*	*0.2%*	*1.2%*
Undominated decision	332	282	301	288	461	482	452	441
	92.2%	78.3%	88.0%	84.2%	94.5%	85.8%	95.0%	87.5%

[1] The table lists the number of decisions in each category, and their percentage out of all decisions. Due to possible delays in bid transmission, decisions within 2 points of bidder value are considered to be "at value."
[2] Decisions in the corresponding category where the final auction price was below value (for foregone purchases), or the purchase was made at a price above value (for actual losses).

where v is bidder value, and α_0 and α_1 are the constant and the coefficient on value, respectively, which may both depend on the number n of bidders and bidder cost of time parameter b. By the continuity of the bidding function in the cost of time parameter, and given the analytical solution $DutchBid = \frac{(n-1)}{n} * v$ for the case of no time costs, $b = 0$, we expect the intercept to be close to zero, $\alpha_0 \approx 0$, and the coefficient on value to satisfy $\alpha_1 \in (0, 1)$, for all n and b. Figure 6 depicts all bids submitted in the Dutch auctions against bidder values. The theoretical prediction line is marked as "theory", with added regression lines of bids on values, displayed separately for Top and Bottom earners. Overall, the bidding behavior tracks the theoretical predictions rather well for both Top and Bottom earners; the slopes of the bidding functions on value are not significantly different from the theoretically predicted ($p > 0.05$) in all treatments, except for the Bottom earners in the 5L treatment. However, overbidding is common in all but the 2H treatment, and especially for the Bottom earners (see also Tables D.4- D.5 in Appendix D).

Figure 7 (left panel) further illustrates that, indeed, bidders overbid, on average, in all treatments in the Dutch auctions, except for the 2H treatment. Moreover, Top earners bid significantly lower and closer to the theoretical predictions than Bottom earners ($p < 0.1$ for

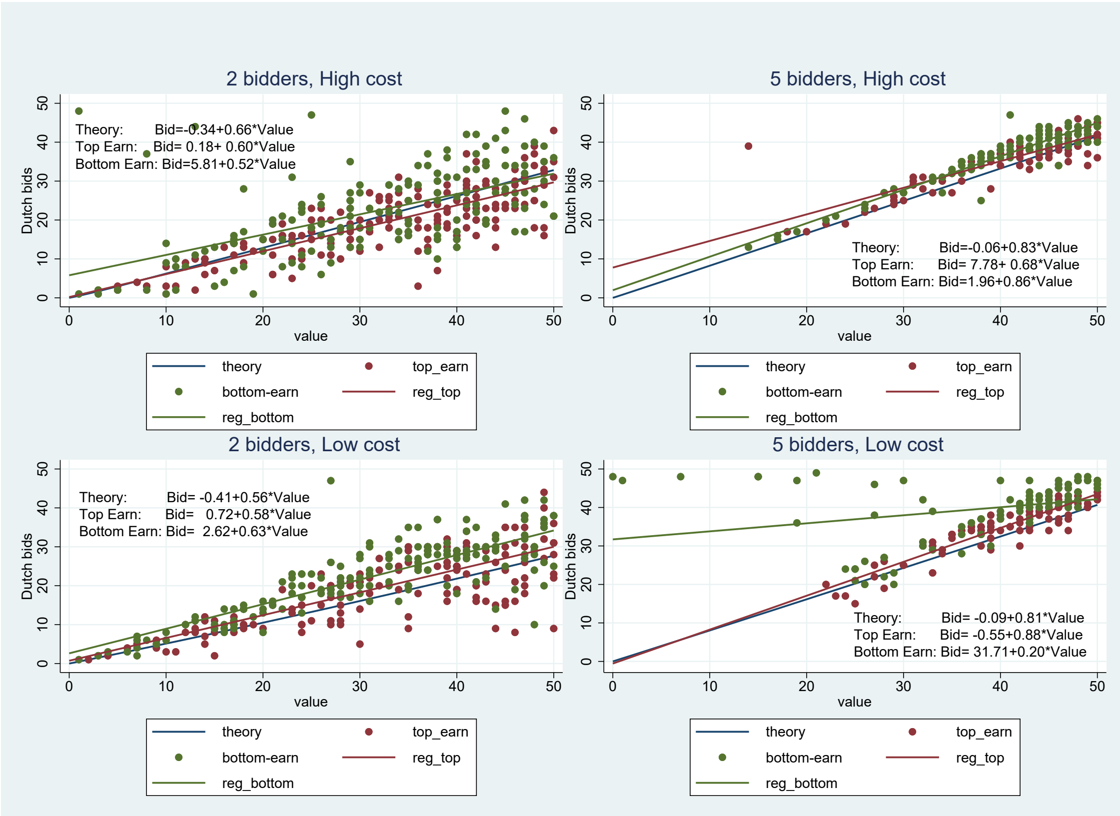


Figure 6: Dutch bids by value, by treatment

2-bidder auctions and $p < 0.001$ for 5-bidder auctions).[23] Another interesting observation is that bidding is significantly ($p < 0.01$) closer to theory in the High-cost treatment (with the average over-bidding at 0.75 points only) than in the low-cost treatment (with the average over-bidding at 4.39 points).

Katok and Kwasnica (2008) document more overbidding in slower Dutch clock auctions, attributing this phenomenon to the bidder's intrinsic cost of time. While the speed of the virtual clock is the same in all treatments in our experiment, the higher induced cost of time translates into faster payoff shrinkage and, therefore, may have a similar effect on behavior as a faster clock, leading to less overbidding than under the lower cost of time treatments. Alternatively, less overbidding in treatments with high cost of time may be simply due to higher predicted bids in these treatments. Based on the regression estimation of bids on value (Table D.4 in Appendix D), the null hypothesis that the bids as a function of value are not statistically different in high- and low-cost treatments cannot be rejected for either 2-bidder and 5-bidder auctions for both Top and Bottom earners ($p > 0.1$) (with the exception of the 5-bidder auctions for Bottom earners, where the differences are caused by

[23]Reported p-values are obtained by regressing the bid deviations from the predictions on the payoff segment dummies, with bootstrapped standard errors clustered on the session.

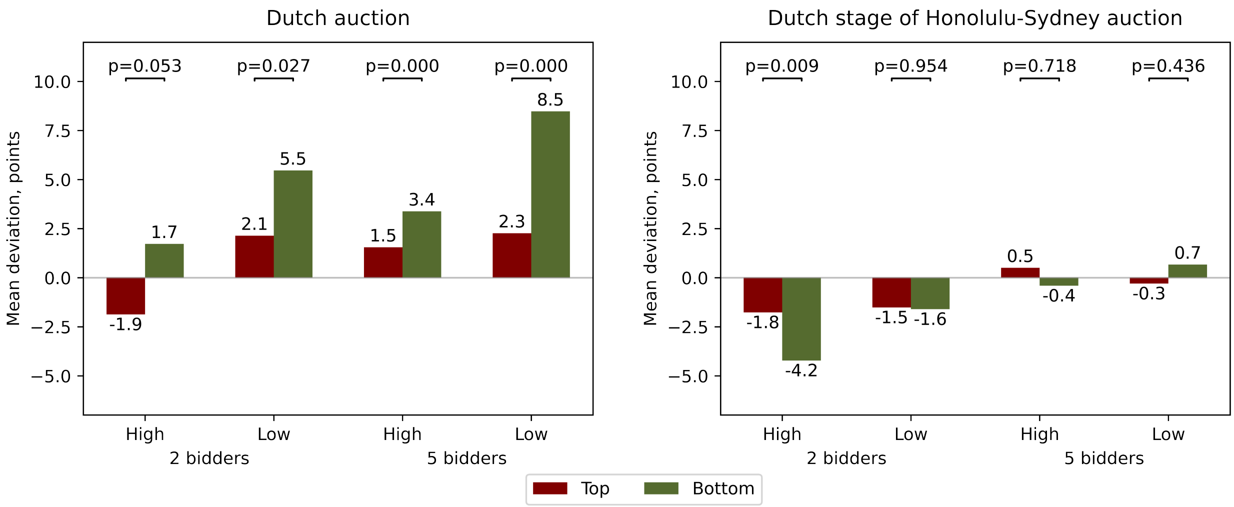
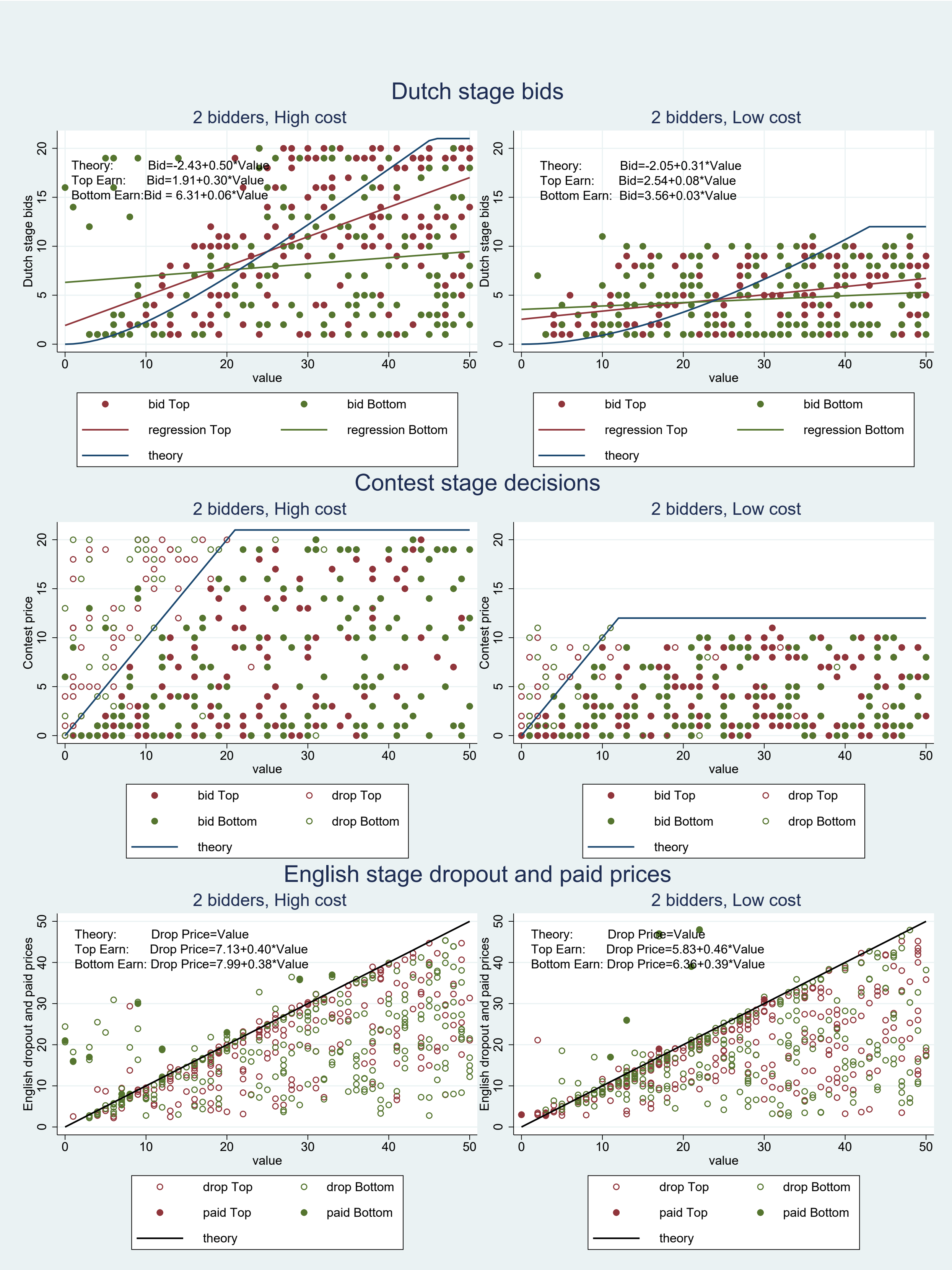


Figure 7: Bid deviations from theory in Dutch auctions and at the Dutch stage of Honolulu-Sydney auctions, for Top and Bottom earners

extreme overbidding in 5L treatment; see Figure 6). This suggests that bidders did not fully adjust their behavior in response to the increased induced cost of time, and less overbidding compared to predictions under the high cost of time is likely due to higher predicted bids. However, the observed bidding is consistent with the presence of positive time costs (either induced or intrinsic), as no time costs are predicted to result in even lower bids.

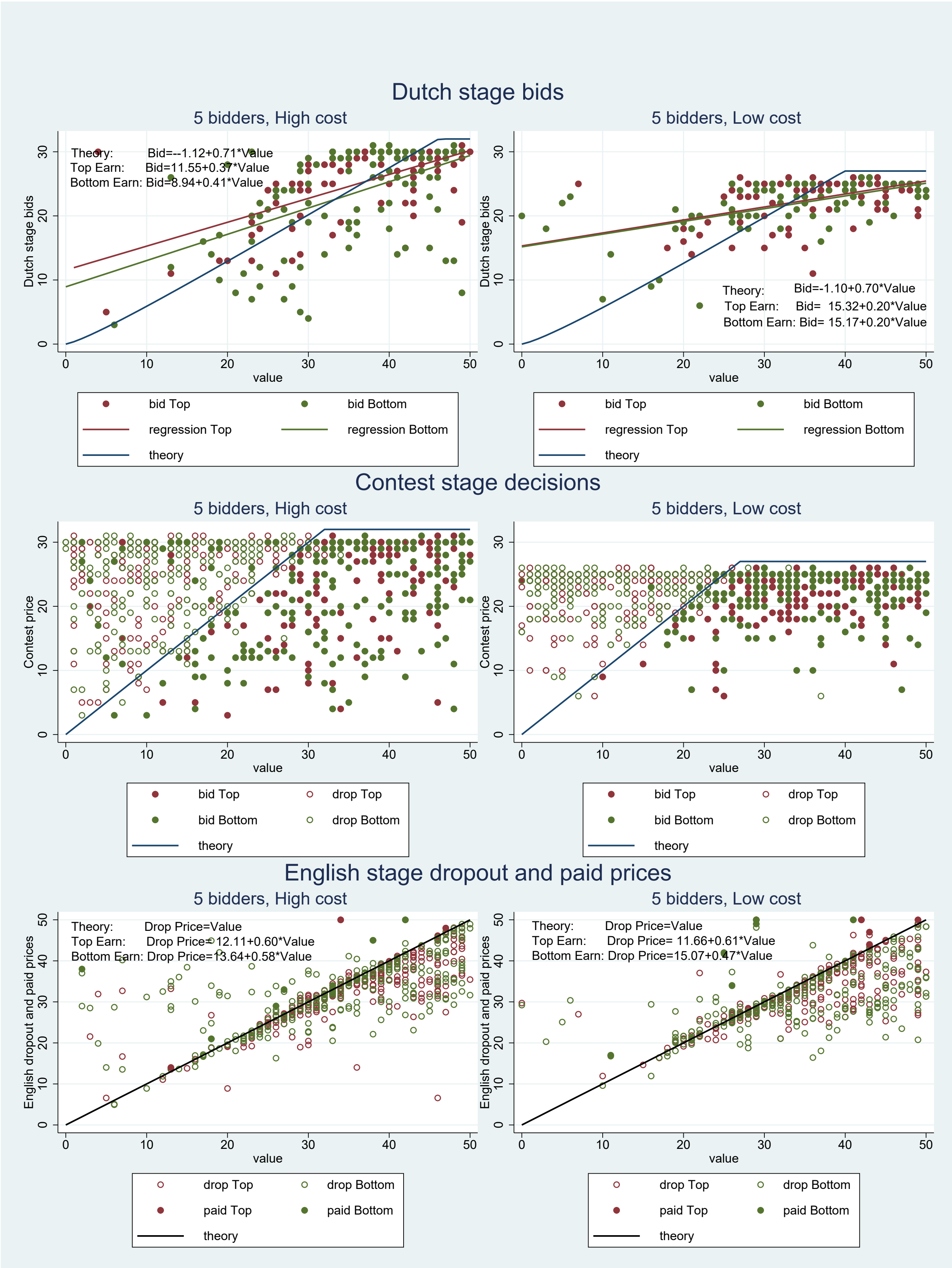
Result 8. *Bidders overbid in all but one treatment in the Dutch auctions. Bidding closer to the theoretical prediction is associated with significantly higher bidder earnings, whereas overbidding is associated with lower earnings. Bidders overbid significantly less in auctions with the high cost of time.*

Bidding patterns in Honolulu auctions Figures 8 and 9 illustrate bidding behavior by stage against the theoretical predictions in 2-bidder and 5-bidder Honolulu auctions, respectively. The figures present evidence of both over-bidding and under-bidding compared to predicted at the Dutch stage, and a sizeable share of early dropouts at the final English stage. In our analysis, we aim to disentangle to what extent such behaviors may be attributed to bounded rationality, and bidder under-valuing time in particular, and to what extent to the bidder attempts to suppress price competition and gain from lower auction prices. Lower than competitive prices that benefit bidders may be supported as equilibria in a multi-period super game even with random rematching (Kandori, 1992).



Note: For the English stage, the only paid prices displayed are those above value.

Figure 8: Honolulu auction bidding behavior by stage, 2 bidder treatments



Note: For the English stage, the only paid prices displayed are those above value.

Figure 9: Honolulu auction bidding behavior by stage, 5 bidder treatments

First, observe that the overwhelming majority of Dutch-stage bids (72% of bids in 2-bidder auctions and all bids in 5-bidder auctions) are at prices above zero.[24] Excluding the bids that are predicted to be near zero in equilibrium, the share of near-zero bids not consistent with the equilibrium prediction is only 20% in 2-bidder auctions. Recalling that in the absence of positive time costs, it is a weakly dominant strategy for bidders to allow the prices to drop to zero in the Dutch stage, we conclude:

Result 9. *The overwhelming majority of decisions at the Dutch stage of Honolulu auctions with two bidders, and all decisions with five bidders, are consistent with the presence of positive time costs.*

Yet, in drastic contrast to bids in Dutch auctions, conditional on bidding, submitted Dutch-stage bids are, on average, at prices no higher or lower than predicted for both Top and Bottom earners in all treatments (Figure 7, right panel). Further, bids are flatter in value than predicted, with over-bidding compared to the prediction at low values and under-bidding at high values, as indicated by simple regression estimations included in the top panels of Figures 8- 9 (see additional Dutch-stage bid estimation results in Tables D.6- D.7 in Appendix D). The overall effect is dominated by high-value bidders bidding at lower-than-predicted prices, resulting in the Dutch stage lasting, on average, over 4 price ticks longer than predicted in all treatments. In two-thirds (68%) of all auctions with two bidders, and in almost three-quarters (74%) of all auctions with five bidders, the Dutch stage lasted more than two price ticks longer than predicted.

Result 10. *Longer-than-predicted duration of Honolulu auction is explained by Dutch-stage bidding delays by high-value bidders.*

On the auction level, Dutch-stage bidding delays are associated with significantly lower purchase prices in both 2-bidder and 5-bidder auctions. On average, one price-tick increase in the Dutch-stage duration above the prediction is associated with 0.48 point reduction in the purchase price from the equilibrium level for 2-bidder auctions, and 0.21 point reduction for 5-bidder auctions ($p < 0.001$ in both cases).[25] This suggests an anti-competitive motive for delayed bidding. Alternatively, bidders may delay bidding simply because they underestimate the cost of time.

To understand the likely motives behind such delays, we link bidder actions at the Dutch stage with their decisions in later stages. A Dutch-stage individual decision is considered a delay if a bidder does not bid at the predicted price, thus allowing the Dutch-stage price to

[24] Bids within 2 points of zero are considered "near zero."

[25] Based on regressing the purchase price deviation on bidding delay, with bootstrapped standard errors clustered on session.

drop lower. A Dutch-stage delay followed by an early below-value dropout in the Contest or English stage is consistent with non-competitive behavior, whereas a Dutch-stage delay followed by bidding until the price reaches one's value in the English stage is competitive and may be attributed to under-valuing time.[26] Finally, a Dutch-stage delay followed by a purchase below the predicted equilibrium price is consistent with both non-competitive behavior, and competitive behavior combined with under-valuing time.

Table 6 displays frequencies of various individual decision-outcome patterns in Honolulu auctions, sorted on the Dutch-stage bidder delays. Overall, 41% of individual Dutch-stage decisions with two bidders are classified as delays, as compared to only 18% of decisions with five bidders. These differences between 2-bidder and 5-bidder auctions are highly significant ($p < 0.01$) based on the regression estimation presented in Table 7 below.[27] Among all occurrences of Dutch-stage delays in 2-bidder auction, about a half (23% out of 41% in 2H treatment, and 17% out of 41% in 2L treatment) are followed by low-price drop or buy outcomes and are therefore consistent with non-competitive behavior, and the other half – by competitive decisions at the Contest or English stage. In comparison, three-quarters of Dutch-stage delays in 5-bidder auctions (14% out of 19% under 2H, and 13% out of 17% under 2L treatment) are followed by competitive behaviors at later auction stages (Table 6). Keeping in mind that Dutch-stage delays followed by low-price purchases may be attributed to both competitive and non-competitive behavior, we conclude:

Table 6: Decision-outcome patterns in Honolulu auctions

	2-bidder auctions		5-bidder auctions		All
Decision-outcome pattern	2H	2L	5H	5L	
Delay, Low Price Buy	17.36	12.13	2.57	2.45	7.54
Delay, Low Price Drop	5.56	4.82	2.38	1.43	3.26
Delay, Competitive Drop or Buy	17.92	24.12	14.00	13.47	16.69
No Delay, Low Price Buy	2.64	3.51	0.95	1.63	2.01
No Delay, Low Price Drop	5.00	6.73	2.86	3.88	4.37
No Delay, Competitive Drop or Buy	47.78	46.35	72.48	73.78	62.46
No Delay, Overbid	3.75	2.34	4.76	3.37	3.67
Total, percent	100.00	100.00	100.00	100.00	100.00

"Delay:" Dutch-stage non-bid at the predicted bid price; "Low Price:" below equilibrium prediction; "Competitive:" at or above equilibrium prediction; "Overbid:" bid above value. Bidding above value following Dutch-stage delays is extremely rare (7 out of 3434 observations) and is lumped with the "Competitive" category. Decisions within 2 points of the corresponding prediction are considered "at prediction."

[26] Our estimate of the share of non-competitive behavior is therefore conservative, as some Dutch-stage delays followed by competitive bidding could indicate failed attempts to lower prices.

[27] The delays are much less frequent at the individual level than at the auction level, as the auction-level Dutch-stage outcomes are driven by the behavior of a subset of bidders who bid first.

Result 11. *Dutch-stage bidding delays are significantly more frequent in auctions with two bidders, with up to a half of the delays attributable to non-competitive behavior. In 5-bidder auctions, the delays occur less frequently, and at most a quarter of these delays are attributable to non-competitive behavior. Overall, between 17 and 24 percent of all decisions in Honolulu auctions are consistent with competitive behavior with under-valuing time.*

Table 6 provides further evidence for weaker competition in 2-bidder auctions as compared to 5-bidder auctions, documenting an additional sizeable share of low-price dropouts following no delays at the Dutch stage; see also Table 5 for overall frequencies of "Leave below value" decisions. The share of bidder decisions resulting in low price dropouts or purchases is significantly higher in 2-bidder auctions than in 5-bidder auctions ($p = 0.02$[28]). And yet, almost a half of individual decisions in auctions with two bidders and almost three-quarters of decisions in auctions with five bidders are consistent with the equilibrium behavior with no Dutch-stage delays (Table 6, "No Delay, Competitive Drop or Buy" category).[29]

Regression estimations of behavior presented in Table 7 confirm that under-bidding at the Dutch stage is more prevalent for bidders with high-value draws, but is significantly less common in 5-bidder auctions ($p < 0.01$ in both cases). Dutch-stage bidding delays persist in later rounds ($p < 0.05$), suggesting again an anti-competitive motive behind many of the delays. Bidders are significantly more likely to stay above value in 5-bidder auctions than in 2-bidder auctions ($p < 0.01$), possibly due to a lower risk of buying above value in auctions with more than two active bidders. Overall, the precedence of both leaving the auction at a price below value, and bidding above value, is reduced significantly in later rounds ($p < 0.01$), indicating participant learning. Consistent with the theoretical prediction, the cost of time parameter does not have a significant effect on bidding at the English stage.

Finally, the table documents significant differences in behavior between Top and Bottom earners. Compared to Bottom earners, Top earners are significantly less likely to delay their bids at the Dutch stage ($p < 0.05$), and both to drop out early and over-bid at the English stage ($p < 0.01$ in both cases). An English-stage dropout price regression estimation (Table D.9 in Appendix D) confirms that Top earners' dropout prices are closer to the value than those of the Bottom earners. We further address heterogeneity in bidder behavior using multi-dimensional clustering based on similarity method. The analysis provides an additional support that the behavior of high earners is qualitatively different and closer to the equilibrium bidding strategy, especially at the Contest and English stages, than that of

[28]Wilcoxon Mann-Whitney test using sessions averages as units of observation.

[29]Moreover, the modal behavior is consistent with equilibrium for all individuals. We therefore do not sort individuals into behavioral types, but instead look for behavioral differences between Top and bottom earners.

Table 7: Regression estimation of individual decisions in Honolulu auctions, by stage

	(1) Dutch stage		(2) Contest stage		(3) English stage		(4) Final outcome	
Bid/leave below equilibrium								
item value	0.13***	(0.01)	0.01	(0.01)	0.02***	(0.00)	0.01*	(0.00)
5 bidders	-1.89***	(0.28)	-0.97	(0.63)	-0.34	(0.38)	-0.19	(0.37)
high cost	0.02	(0.29)	-0.23	(0.43)	0.10	(0.46)	-0.00	(0.38)
5 bidders high cost	0.18	(0.50)	0.26	(0.85)	-0.20	(0.57)	-0.05	(0.54)
Dutch auction first	0.13	(0.32)	0.25	(0.43)	-0.14	(0.34)	-0.01	(0.30)
round	0.03**	(0.01)	-0.03	(0.02)	-0.04***	(0.01)	-0.04***	(0.01)
Top earner	-0.37**	(0.16)	-0.36	(0.23)	-0.67***	(0.17)	-0.63***	(0.15)
Constant	-4.12***	(0.38)	-2.55***	(0.54)	-1.76***	(0.45)	-1.41***	(0.35)
Competitive bid/leave: base outcome								
Bid above value								
item value	-0.13	(0.10)	-0.10**	(0.05)	-0.14***	(0.01)	-0.22***	(0.01)
5 bidders	0.97	(9.95)	11.95***	(3.43)	2.50***	(0.88)	4.85***	(0.54)
high cost	1.80	(9.00)	13.47***	(2.21)	0.53	(0.86)	1.36***	(0.49)
5 bidders high cost	-2.08	(10.98)	-10.74***	(4.05)	-0.47	(1.03)	-1.29**	(0.61)
Dutch auction first	-2.36	(6.09)	-2.21	(2.21)	-0.90	(0.56)	-0.48	(0.37)
round	-0.01	(0.07)	-0.07	(0.07)	-0.03**	(0.01)	-0.03***	(0.01)
Top earner	-2.21	(4.32)	-1.85	(2.59)	-1.31***	(0.39)	-0.20	(0.18)
Constant	-2.77	(8.71)	-14.36***	(2.12)	0.45	(0.97)	0.50	(0.46)
Observations	3434		2381		2064		3434	
Pseudo R^2	0.360		0.137		0.171		0.423	

Multinomial logit estimation. Bootstrapped standard errors clustered on session in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

low earners who tend to either over-bid or under-bid (see Appendix F for details.)

Two interesting observations are due in relation to the apparent bidder attempts to lower prices through bidding delays and early dropouts. First, these attempts do not pay off equally for all bidders; while Top earners earn, on average, above the prediction in Honolulu auctions, the Bottom earners earn below the prediction (Figure 5); overall, the bidders are no better off than they would be under the predicted behavior in any of the treatments (Table 3). Second, these deviations from the predicted behavior do not distort the allocative efficiency of Honolulu auctions (Result 2).

Result 12. *Almost a half of all individual decisions in Honolulu auctions with two bidders, and an overwhelming majority of decisions with five bidders, are consistent with the theoretical predictions, with the frequency of such decisions increasing in later rounds. Compared to Bottom earners, Top earners bid closer to the equilibrium predictions at all stages.*

We summarize the bidding behavior and its link to the auction performances as follows:

Conclusion 2. *Overall, competitive bidding consistent with the theoretical predictions is the modal behavior in Honolulu auctions. Observed under-performance of Honolulu auctions* *relative to Dutch for the auctioneer is explained, on one hand, by consistent overbidding in the Dutch auctions, and, on the other hand, by bidding delays and non-competitive dropouts in a sizeable share of instances in Honolulu auctions.*

5.3 Participant feedback

To evaluate what mattered to participants in their bidding decisions, and to assess their post-auction affective states, we conducted short surveys soliciting participant feedback immediately following each auction institution. Consistent with the observed behavior, participants reported that they cared more about buying fast in Dutch than in Honolulu auctions, and cared more about getting a lower price in Honolulu than in Dutch. Further, they reported experiencing significantly less winner and loser regret in Honolulu than in Dutch auctions (Figures 10- 11). Finally, participants felt about equally happy when they made a purchase in Honolulu and in Dutch, but felt significantly less unhappy when they did not buy in Honolulu as compared to Dutch; see Table D.10 in Appendix D. These responses suggest that, in addition to having a speed advantage over Dutch auctions when the number of bidders is small, Honolulu auctions reduce bidder regret and make the participants happier.

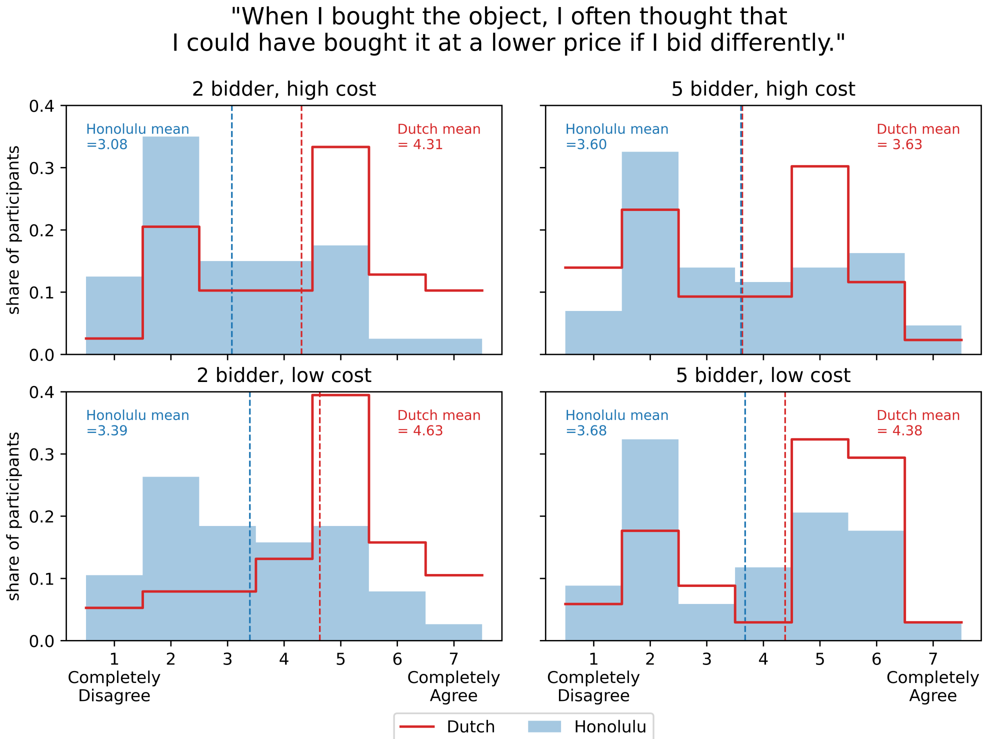


Figure 10: Post-auction questionnaire, Dutch vs Honolulu: Winner Regret

Figure 11: Post-auction questionnaire, Dutch vs Honolulu: Loser Regret

6 Conclusions

In this paper, we study a distinctive auction mechanism used in several fish markets around the world, including Honolulu and Sydney fish markets. This auction facilitates the rapid sale of premium quality fish—a necessity given the perishable nature of the goods in question. This hybrid auction format, blending the traits of both Dutch and English auctions, has shown its efficacy not only in real-world markets but also in our theoretical model and in the laboratory.

Our theoretical framework highlights the pivotal role of "time costs." Our results show that the Honolulu-Sydney auction format is more favorable for the auctioneer (as compared to the standard Dutch auction format) in scenarios where there's a limited number of bidders or when these bidders bear high time costs. This is substantiated by our experimental data, revealing that Honolulu-Sydney auctions conclude significantly faster than their Dutch counterparts when there is a low number of bidders. The individual bidder behavior is overwhelmingly consistent with the presence of time costs.

In our experimental results, we observe overbidding in Dutch auctions, a trend advantageous for the auctioneer. However, as time costs increase, bidding patterns in the Dutch format shift closer to risk-neutral predictions. Moreover, the Honolulu-Sydney auction consistently outperforms the Dutch in terms of bidder welfare, and appears to reduce the feeling of both winner and loser regret. This suggests that not only does the hybrid format expedite the auction process, but it also offers better outcomes for bidders.

An unanticipated albeit not surprising insight provided by our experiments is the evidence of bidder attempts to suppress price competition in Honolulu auctions, especially when the number of bidders is small. Bidder collusion has been studied in the context of procurement auctions (Hendricks and Porter, 1989); school milk contracts (Pesendorfer, 2000), cattle (Phillips et al., 2003) and spectrum (Kwasnica and Sherstyuk, 2007) auctions, among others. Concerns about collusion in fish markets have also been raised (Graddy, 2006; Fluvia et al., 2012). Our laboratory experiment confirms that attempts to tacitly lower prices may be present in such markets, especially given that many buyers are professionals who participate in these auctions on a day-to-day basis.

In our laboratory experiment under the hybrid Honolulu-Sydney auction format, the apparent attempts to lower prices manifest themselves through delayed bidding at the descending-price stage, and dropping out of the auction early at the ascending-price stage; such attempts are especially noticeable in small two-bidder auctions. However, in our experiments, these departures from competitive bidding do not increase the overall welfare of the bidders. While bidders who frequently delay their bids and drop out of the competition early suffer from lower earnings, the benefits of their actions are acquired by those bidders who behave more competitively and bid closer to the equilibrium prediction, often collecting higher than predicted earnings. It is an open question whether professional repeat buyers in fish markets could be able to better tacitly coordinate on a bid rotation scheme and distribute the benefits among themselves more evenly.

We further obtain evidence that the hybrid Honolulu auctions result in superior allocative efficiency compared to the Dutch auctions, in spite of the observed departures from equilibrium behavior.

In sum, the Honolulu-Sydney auction represents a creative solution for markets where time is of the essence.

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Appendix

A Fish auctions around the world

Many fish and flower auctions around the world are characterized by large volumes of highly perishable and highly variable in quality goods that are auctioned off sequentially, by individual units or lots. Speed of sales is of the essence given large volumes; however, competitive bidding on each item is also an essential requirement for price discovery, given the large variability in quality and other characteristics of each item. Graddy (2006) specifically attributes the need for a centralized market to heterogeneity of fish; she further notes that "many... major fish markets, including Tsukiji, Sydney, Portland and Boston are auction markets" (p. 219). Because of the variability, the buyers are typically given a chance to examine each unit of the good for sale (fish or flowers) before or at the time of bidding, with the bidding process then taking only a few seconds per unit.

These auctions are organized under a variety of formats, including purely ascending, purely descending or a combination of both, with each of these arguably providing for competitive bidding and speed.[1] For example, the Tokyo (formerly Tsukiji) fish market, arguably one of the most famous fish auctions around the world, uses an ascending price auction format, where buyers, after having inspected fish before the auction, use sign language to signal their bids to the auctioneer; the auctioneer calls out the highest bid, and bidders then may sign higher bids. Cassady (1967) notes the advantage of allowing many bidders to submit bids at the same time: "The auction system is potentially very fast...It is amazing to realize how quickly the auctioneer can interpret the bids and decide which is the highest... Because speed is essential in the sale of fish, the auctioneer must knock each lot down as quickly as possible" (p. 66).

Many other auctions where large amounts of goods are auctioned have elements of descending, or Dutch, format. Aside from the famous Dutch flower auction, Cassady (1967) gives examples of descending oral auction method used "... in some other Continental, and even British, communities, in certain Middle eastern countries [such as Israel], and elsewhere" (p. 60). He further writes (p. 63): "The oral method of the Dutch auction (but not the clock method) is used mainly for the sale of nonstandardized items where quality differences require flexibility..." It is instructive that Cassady (1967) explicitly refers to the trade-off between the starting price and the speed of auction: "The auctioneer must start

[1] Plott (2017) emphasizes the role of speed and competition: "...When items are perishable (fish and flowers) reserve prices play no role... Many of auction procedures are related to the need to have the auction over quickly... Efficiency both in terms of gains from trade and in terms of "market making" time is a big driver of auction rules and procedures."

the quotation at a sufficiently high level to permit the bidder with the highest demand price to register his maximal bid. On the other hand, *he should not start too high, particularly in market situations where speed is essential* (p. 60; the emphasis is ours).

Honolulu fish auction, run by the United Fishing Agency since 1952, is claimed to be based on the Japanese fish market auction;[2] however, it is really a combination of descending (Dutch) and ascending (English) auctions. Feldman (2006) provides the following description (p. 326, footnote 39): "At the Honolulu Fish Exchange... a modified form of the Dutch auction is used, with the auctioneer starting at a high price and then dropping it until a buyer places the first bid. The auctioneer then calls out a higher price with the hope of getting other buyers to start bidding..."

Such a hybrid descending-ascending auction format is not unique to the fish auction in Honolulu, with variations of it encountered in different parts of the world. Guillotreau and Jiménez-Toribio (2006) document a similar format used in fish sales in two French ports: " In the ... port [of Lorient], offshore boats have been selling fish in a trading room with descending-ascending auctions... An opening price is proposed by the auctioneer before going down around the clock. When a buyer makes a bid the clock stops... During this signalled delay, other bidders may intervene with a higher bid, until a single buyer remains in the auction.... The second example is given by seven ports of south Brittany... One of these ports – Saint Gue´nole´ – implemented a Dutch system... Six neighboring shout auction systems – including that of Le Guilvinec – were equipped...in April 2002 by mobile ECAS [Electronic clock auction systems], with a descending-ascending bidding process, similar to the offshore fish market in Lorient..." (pp.525-6). Finally, Laksá and Marszalec (2020) provide a description of a very similar descending-then-ascending price clock auction mechanism used at the Faroe Fish market in Denmark.

The above indicates that fish and flower auctions have evolved to meet the essential criteria of combining speed and price efficiency, and that the descending-ascending auction format is a viable institution under these criteria.

[2] "The Honolulu Fish Auction is based on the famous Tokyo auction, where large fish are sold individually rather than by the boatload to a wholesaler. The auction provides a marketing service for fisherman and helps them with quality improvement to get the best prices for their catch" (Hawaii-Seafood.org, 2015).

B Numerical results and prediction details

Note that the starting price is chosen by the auctioneer to maximize its utility, so for the expected utility for the auctioneer EU_A, the differences between Dutch and Honolulu auctions are always changing smoothly in the 2D parameter space (b, c). In fact, for given (b, c), $EU_A(s)$ is a function of the starting price $s \in [0, 1]$ such that it is first increasing, then possibly decreasing, and finally may be increasing again. So, the optimal s can either be some interior value at the peak of the increasing then decreasing inverse U-shaped curve, or simply be at the boundary when the functional value finally increases and exceeds the previous peak (see Figure B.1 for a visual demonstration). Such a jump in the optimal starting price results in discontinuity in the relative performance of the Dutch and Honolulu-Sydney auctions in terms of expected duration, selling prices and bidder expected utility. This is the reason for a sharp change in the relative performances displayed in the top left corner of these plots.

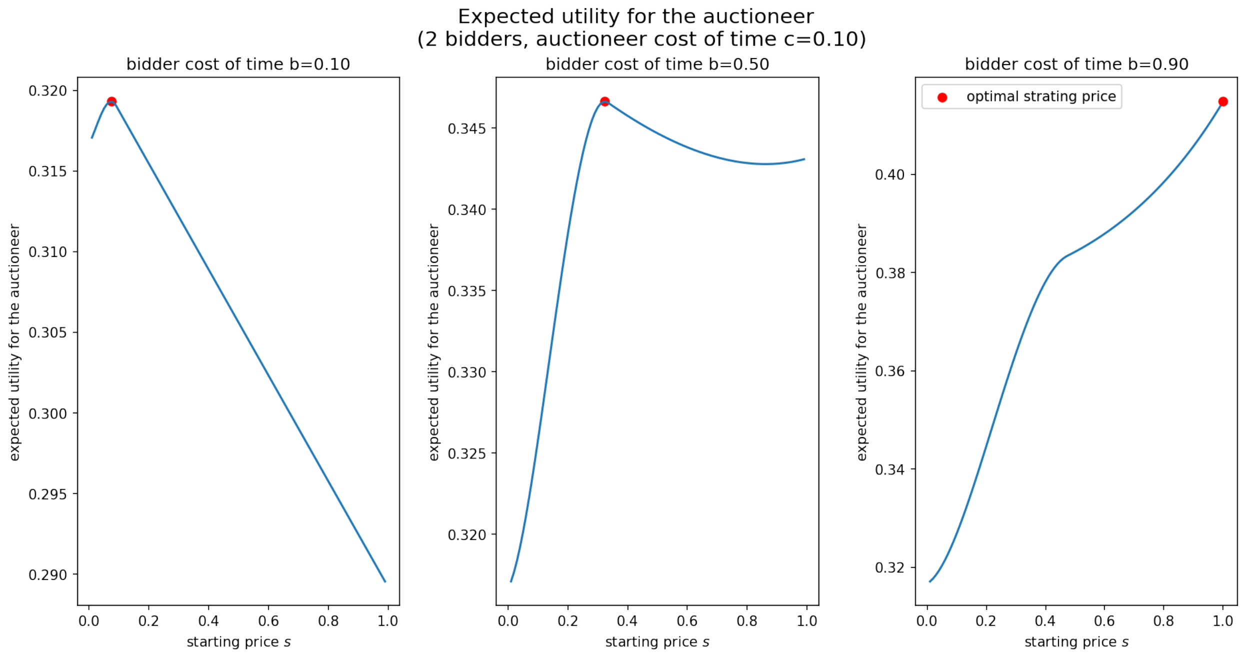


Figure B.1: Auction duration

The performance difference between Dutch and Honolulu-Sydney auctions can take drastic changes when the optimal starting price jumps from an interior point to 1. For example (Figure B.2), Honolulu-Sydney auctions are always shorter than Dutch under 2-bidder auctions when the optimal starting price is in the interior, while this pattern is completely reversed to Dutch auctions are always shorter when the optimal starting price jumps to 1. We mainly focus on the vast right-hand side area where the optimal starting price is an interior solution. The meaning of the words "under a wide range of parameter values" in the premise of Prediction 1 is to exclude such cases which relate to the aforementioned top-left corner of those plots.

B.1 Theoretical performance comparison

The table below is the theoretical revenue comparison between the two auction formats for each treatment.

Table B.1: Theoretical performance comparison re-scaled for experimental setting

Treatment	2H	2L	5H	5L
n – Number of bidders	2	2	5	5
b – Bidder unit cost of time	0.95	0.45	0.95	0.45
c – Auctioneer unit cost of time	0.95	0.95	0.95	0.95
s^* – Optimal Honolulu-Sydney auction starting price	0.4104	0.2370	0.6317	0.5405
Expected auction duration				
Dutch	0.5654	0.6382	0.3074	0.3232
Honolulu	0.2456	0.2729	0.1991	0.2582
Honolulu/Dutch ratio	43.4%	42.8%	64.8%	79.9%
Expected selling prices				
Dutch	0.4346	0.3618	0.6926	0.6768
Honolulu	0.3922	0.3526	0.6899	0.6773
Honolulu/Dutch ratio	90.2%	97.5%	99.6%	100.1%
Expected utility for the auctioneer				
Dutch	0.2245	0.1593	0.5034	0.4816
Honolulu	0.2964	0.2342	0.5581	0.5039
Honolulu/Dutch ratio	132.0%	147.0%	110.9%	104.6%
Expected utility for the bidder				
Dutch	0.0596	0.1117	0.0205	0.0270
Honolulu	0.1176	0.1452	0.0253	0.0289
Honolulu/Dutch ratio	197.3%	130.0%	123.4%	107.0%

Note: The calculations in this table are based on the value range of $[0, 1]$, as in the theoretical model setting.

B.2 Auction duration

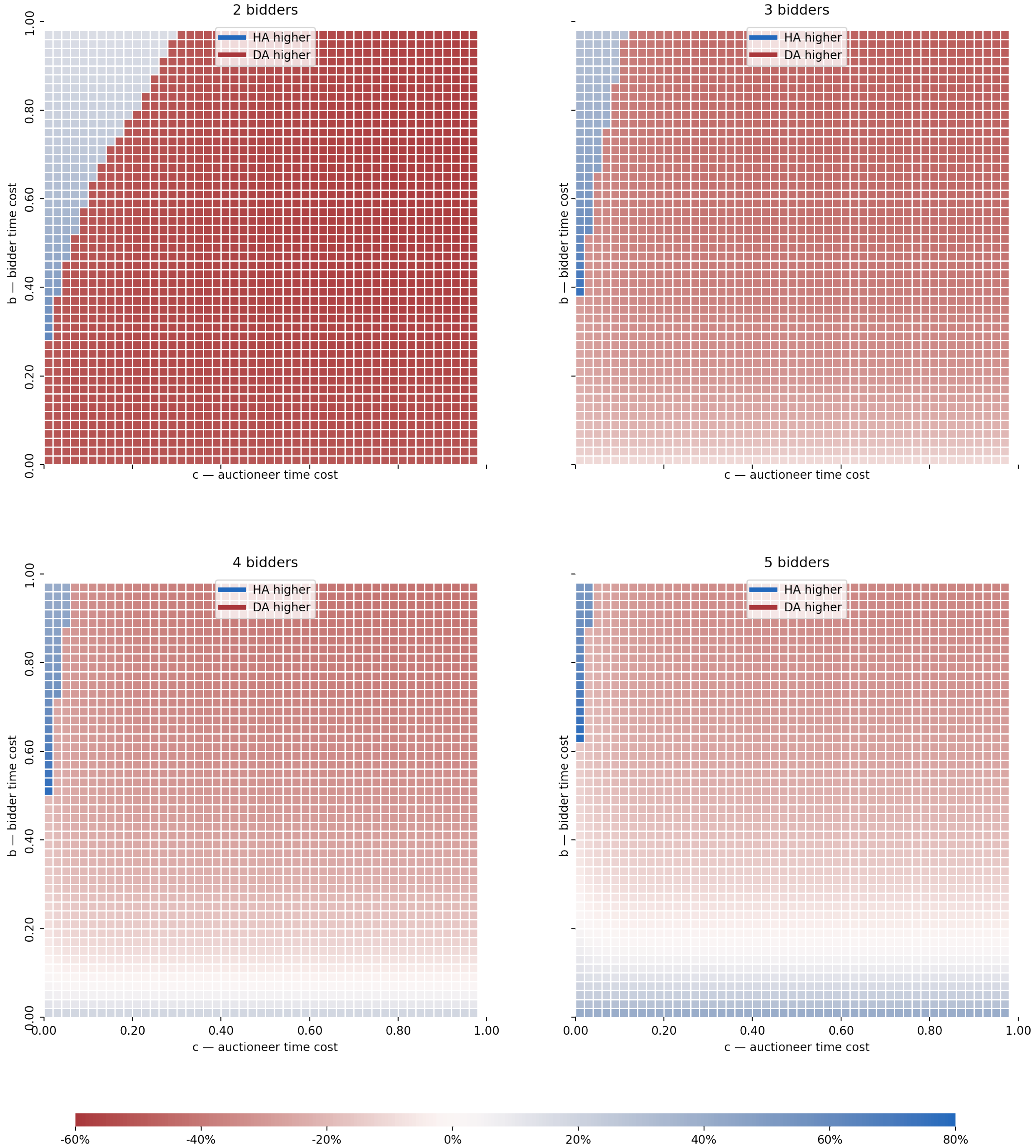


Figure B.2: Auction duration

The observations below are made for the wide range of parameters resulting in an interior solution of the optimal starting price, i.e., the top-left corner of the plots is excluded.

The general observation is that Honolulu-Sydney auctions are faster than Dutch auctions in most cases, which is evident from the overwhelming red color on the graphs. In all four treatments we use in the experiment, Honolulu-Sydney auctions are at least 20% faster than Dutch.

Focusing on the same (b, c) parameter configuration on each panel of the graph for different numbers of bidders, we find that the relative advantage of Honolulu-Sydney auctions over Dutch decreases as the number of bidders increases. The dark red color on the 2-bidder graph fades, and even turns blue on 4- and 5-bidder graphs for very low bidder cost of time. Specifically, Dutch auctions are faster when the bidder cost of time is lower than 0.1 in 4-bidder case and lower than 0.2 in 5-bidder case. Such comparison relates to $2H$ versus $5H$ and $2L$ versus $5L$ in Table B.1, where Honolulu-Sydney auctions are almost 60% shorter than Dutch for 2 bidders while it shrinks to roughly 30% shorter when the number of bidders increases to 5.

For a given bidder cost of time, which is a fixed horizontal slice of the graph, the relative advantage of Honolulu-Sydney auctions over Dutch slightly increases with higher auctioneer cost of time. The greatest increment when comparing between the lowest and highest auctioneer cost of time on the graph does not exceed 10% in all cases.

For a given auctioneer cost of time, which is a fixed vertical slice of the graph, the relative advantage of Honolulu-Sydney auctions over Dutch increases with higher bidder cost of time under 4- and 5-bidder cases — Honolulu-Sydney auctions are 35.2% faster than Dutch under $5H$ but only 20.1% faster under $5L$, while it first increases then decreases under 2- and 3-bidder cases. Further, this possible decrease is always small — the greatest decrement does not exceed 5% and 1% in 2- and 3-bidder auctions, respectively. Our treatment $2H$ is on the decreasing interval, the relative time advantage of Honolulu-Sydney auctions over Dutch shrinks very little by 0.6% as compared to $2L$.

B.3 Selling prices

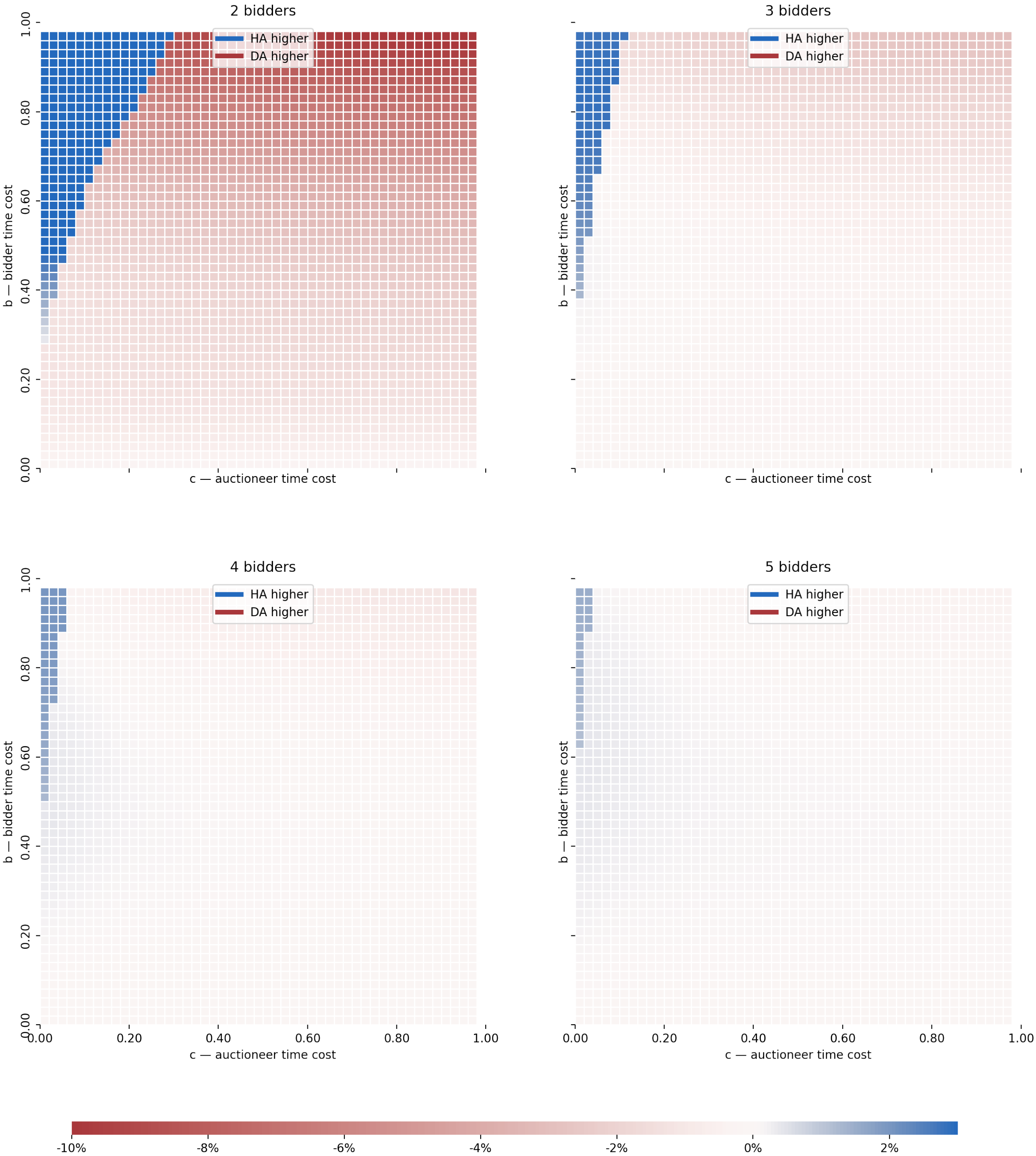


Figure B.3: Selling prices

The observations below are made for the wide range of parameters resulting in an interior solution of the optimal starting price, i.e., the top-left corner of the plots is excluded.

Since we assume the presence of positive time costs for the bidder and the auctioneer in the model, the revenue equivalence theorem no longer holds. However, the expected unadjusted revenue for the auctioneer, which is equivalent to the expected selling price, differs only slightly between the Dutch and Honolulu-Sydney auction formats.

This difference never exceeds 10% in either positive or negative directions, and is usually smaller than 3% when the number of bidders is greater than 2. The range of this difference shrinks quickly as the number of bidders increases, e.g., the maximum differences are 10%, 3%, 1% and 0.5% for 2, 3, 4 and 5 bidders respectively. Referring to our experimental settings in Table B.1, Honolulu-Sydney expected selling prices are 9.8% and 2.5% lower than Dutch in 2-bidder treatments, while they are 0.4% lower or 0.1% higher than Dutch in 5-bidder treatments. This is because the auction becomes faster as competition increases, which offsets the role of time cost.

After excluding the top-left corner of the plots, Dutch selling prices are always higher than Honolulu-Sydney for 2-bidder auctions. This advantage vanishes as the number of bidders increases. For auctions with more than 3 bidders, a light blue area where Honolulu-Sydney selling prices are higher than Dutch emerges in the left middle of the plot and is expanding as the number of bidders increases — our $5L$ treatment lies in this area, where Honolulu-Sydney expected selling prices are 0.1% higher than Dutch.

B.4 Utility for the auctioneer

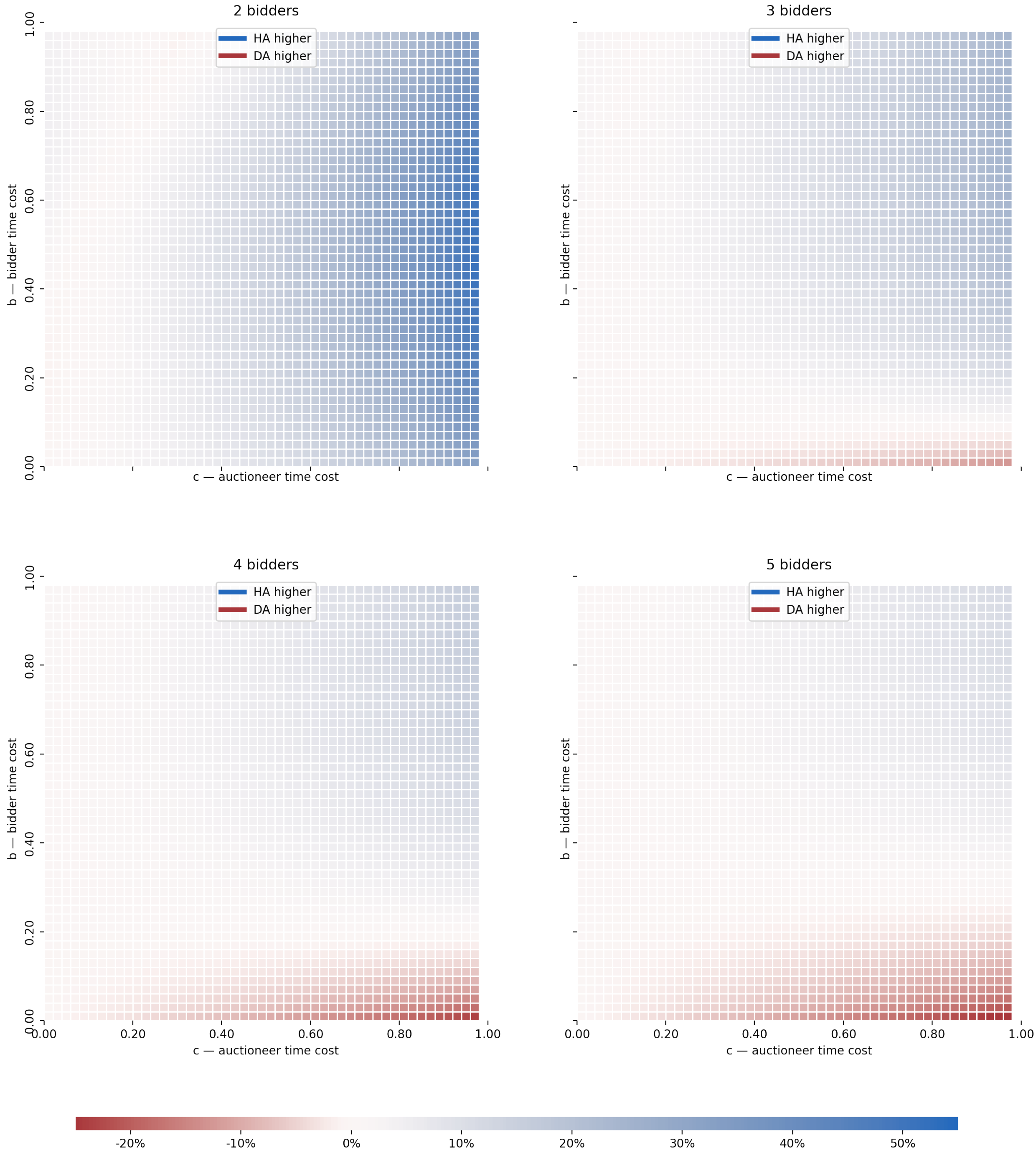


Figure B.4: Utility for the auctioneer

The utility for the auctioneer is the only auction performance indicator that changes smoothly on the whole domain of parameters. Thus, we consider the entire graph for our analysis.

We find that the comparison between Dutch and Honolulu-Sydney auctions is overall indistinguishable when the time cost of the auctioneer is relatively low (less than 0.3) — it never exceeds 6%, as represented by the very light red or blue area on the left of each graph.

The remaining observations are made for the auctioneer cost of time greater than 0.3.

Honolulu-Sydney auctions are always preferred by the auctioneer in the 2-bidder case, while Dutch auctions become more preferred with low bidder cost of time and when the number of bidders increases. Specifically, Dutch auctions are preferred when the bidder time cost is smaller than 0.1, 0.2 and 0.24 in 3-, 4- and 5-bidder auctions, respectively.

Focusing on the same (b, c) parameter configuration on each panel of the graph for different numbers of bidders, the relative advantage of Honolulu-Sydney auctions over Dutch usually decreases as the number of bidders increases. Further, related to our experimental parameter choices (Table B.1), this advantage is always decreasing when the auctioneer cost of time is greater than 0.6. Thus, we have this relative advantage of Honolulu-Sydney auctions drops from 32% under treatment $2H$ to 10.9% under treatment $5H$, and from 47% under $2L$ treatment to 4.6% under $5L$ treatment.

For a given auctioneer cost of time, which is a fixed vertical slice of the graph, the relative advantage of Honolulu-Sydney auctions over Dutch is increasing with higher bidder cost of time, except for very impatient bidders whose time cost exceeds a threshold ranges from 0.5 to 0.9 depending on the number of bidders. This threshold is increasing with more bidders. Therefore, we have treatment $2L$ close to the end of the increasing interval at 0.5 where Honolulu-Sydney auctions bring 47% higher expected utility for the auctioneer than Dutch, while this advantage shrinks to 32% after moving alone the decreasing interval a lot to treatment $2H$. In contrast, treatment $5H$ is close to the threshold around 0.9, such a minor decrease makes the Honolulu-Sydney advantage of 10.9% still higher than that of 4.6% under treatment $5L$.

For a given bidder cost of time, which is a fixed horizontal slice of the graph, as the auctioneer cost of time goes up, the differences between Dutch and Honolulu-Sydney auctions become more pronounced and could go in either direction: Honolulu auctions become relatively more advantageous for bidder cost of time high enough, but Dutch auctions may become relatively more advantageous for the auctions with more than two bidders, and low bidder cost of time (Figure B.4) [3]

[3]Thus we chose a high value of auctioneer cost of time for experimental design to obtain a greater expected difference between Dutch and Honolulu auctions.

B.5 Utility for the bidder

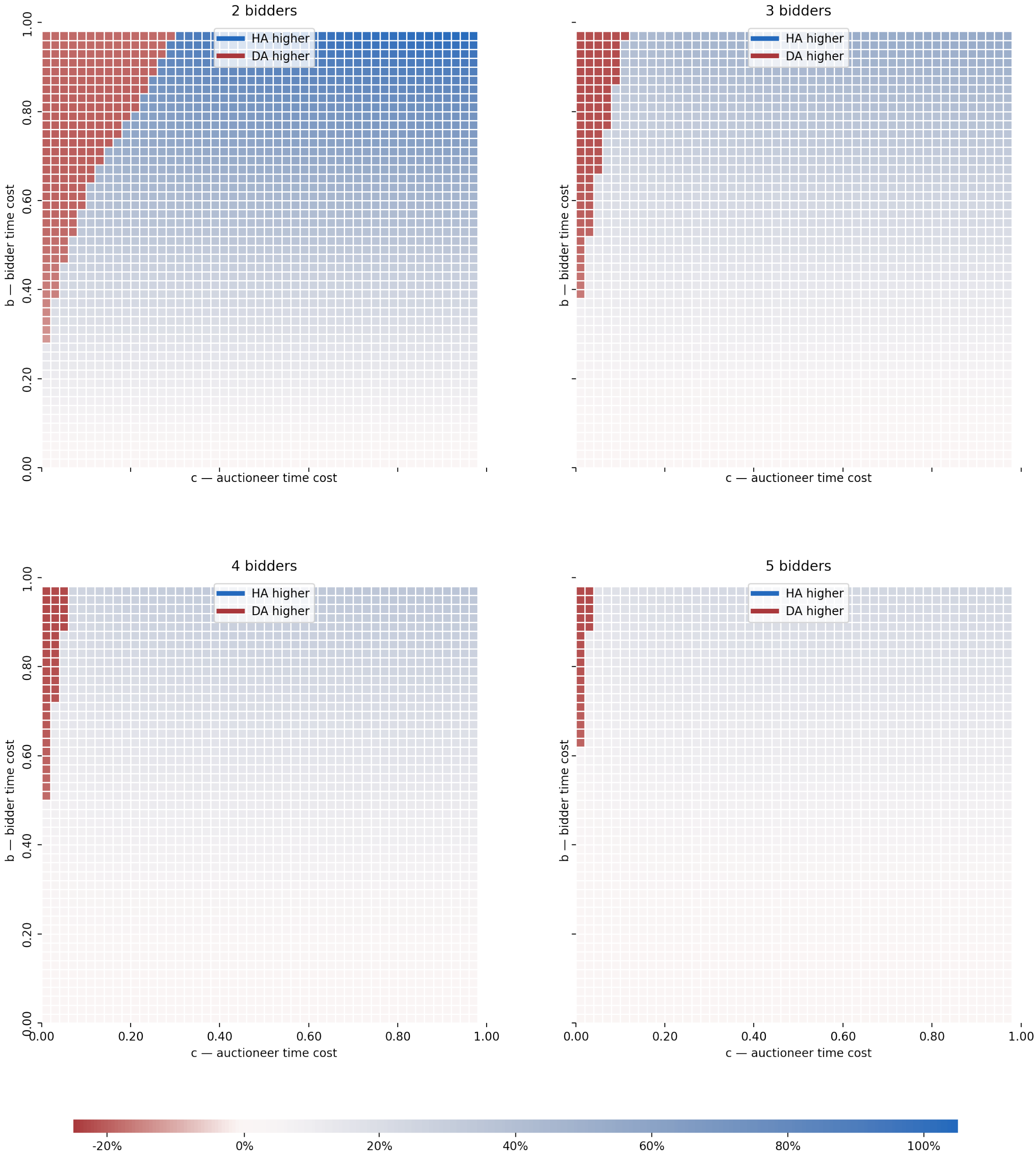


Figure B.5: Utility for the bidder

The observations below are made for the wide range of parameters resulting in an interior solution of the optimal starting price, i.e., the top-left corner of the plots is excluded.

Buyers prefer Honolulu-Sydney auctions to Dutch under a wide range of parameter values. Specifically, after excluding the top-left corner, Honolulu-Sydney auctions are always preferred when there are no more than 4 bidders, and are preferred under 5-bidder case when the bidder cost of time is not too small (greater than 0.02). Under our experimental settings (Table B.1), the expected utility for the bidder is 7% to 97.3% higher in Honolulu-Sydney auctions than in Dutch under different treatments.

For a given auctioneer cost of time, which is a fixed vertical slice of the graph, the darker blue color from bottom to top indicates that the advantage of Honolulu-Sydney auctions over Dutch in terms of buyer utility increases with bidder cost of time. The buyer's expected relative benefit in Honolulu-Sydney auctions increases from 30% under treatment $2L$ to 97.3% under treatment $2H$, and increases from 7% under treatment $5L$ to 23.4% under treatment $5H$.

Focusing on the same (b, c) parameter configuration on each panel of the graph, the blue color is fading as the number of bidders increases, which means that the relative advantage of Honolulu-Sydney auctions over Dutch decreases with the number of bidders. Therefore, we have this relative advantage drops from 97.3% to 23.4% when increasing the number of bidders from 2 to 5 under the high-cost treatments, and drops from 30% to 7% under the low-cost treatments.

C Hypotheses tests of experimental auction comparative performances

This section provides details of hypotheses testing on comparative performances of Honolulu and Dutch auctions. The hypotheses as based on the theoretical predictions given in Remarks 1 - 2 and Prediction 1. These prediction and the corresponding hypotheses are listed below, with D and H denoting the corresponding performance characteristics under Dutch and Honolulu auctions, respectively:

1. (Efficiency: Remarks 1 - 2) Both auctions are efficient.

   Corresponding hypotheses

   (a) $D = H$ for 2-bidder and 5-bidder auctions, high and low cost

2. (Auction duration: Prediction 1(1)) Honolulu-Sydney auctions are faster than Dutch auctions, i.e., their average duration is shorter. The relative advantage of Honolulu-Sydney auctions over Dutch in terms of duration decreases with the number of bidders.

   Corresponding hypotheses

   (a) $D > H$ for 2-bidder and 5-bidder auctions, high and low cost

   (b) $H^5/D^5 > H^2/D^2$, high cost

   (c) $H^5/D^5 > H^2/D^2$, low cost

3. (Selling prices: Prediction 1(2)) The difference in average selling prices between Honolulu and Dutch auctions is small; it does not exceed 5-10 percent.

   Corresponding hypotheses (based on the actual value draws as given in Table 3):

   (a) $H^2/D^2 = 0.917$, high cost

   (b) $H^2/D^2 = 1.011$, low cost

   (c) $H^5/D^5 = 0.988$, high cost

   (d) $H^5/D^5 = 0.991$, low cost

4. (Auctioneer utility: Prediction 1(3)) Assume the auctioneer cost of time is relatively high. Then Honolulu-Sydney auctions are always preferred to Dutch in the two-bidder case. For auctions with more than two bidders, Honolulu-Sydney auctions are preferred to Dutch when bidder cost of time is high, and Dutch auctions are preferred to Honolulu-Sydney when bidder cost of time is low.

Corresponding hypotheses:

(a) $H^2 > D^2$, high cost

(b) $H^2 > D^2$, low cost

(c) $H^5 > D^5$, high cost

(d) $H^5 > D^5$, low cost[4]

5. (Buyer utility: Prediction 1(4)) Buyers prefer Honolulu-Sydney auction to Dutch under a wide range of parameter values. For auctions with a small number of bidders, the advantage of Honolulu-Sydney auctions over Dutch in terms of buyer utility increases with bidder cost of time. The relative advantage of Honolulu-Sydney auctions over Dutch decreases with the number of bidders.

   Corresponding hypotheses:

   (a) $H > D$, high and low cost, 2 and 5 bidders

   (b) $H^h/D^h > H^l/D^l$, 2 bidders

   (c) $H^2/D^2 > H^5/D^5$, high cost

   (d) $H^2/D^2 > H^5/D^5$, low cost

To test the above hypotheses, we regressed auction efficiency, duration, selling prices, and auctioneer and buyer utilities on auction type and treatment dummies, as displayed in Tables C.1 - C.2 below. We then used the regression coefficients to estimate the test statistic equal to the difference between LHS and the RHS expressions in the corresponding hypotheses, $coeff \equiv (LHS - RHS)$ (e.g., $coeff \equiv H^5/D^5 - H^2/D^2$ for high cost for hypotheses 2(b) above), and bootstrapped standard errors on the statistic to test each hypotheses. The hypotheses tests results are given in Table 4 in the main text.

[4] The bidder cost of time in the "low"-cost treatment is high enough so that the prediction is still $H^5 > D^5$. However, given the predicted difference is small, and based on earlier experimental evidence of over-bidding relative to the risk-neutral predictions in Dutch auctions, we may expect to observe $H^5 < D^5$ under the low cost.

Table C.1: Baseline regression estimation for hypotheses testing, by the number of bidders

	Efficiency			Auctioneer payoff		Buyer payoff	
	pooled	2 bidders	5 bidders	2 bidders	5 bidders	2 bidders	5 bidders
REGRESSION							
HNL auction	1.54***	1.32	3.02***	-3.14***	-7.30***	6.10***	6.30***
	(0.57)	(1.16)	(0.93)	(0.55)	(0.82)	(0.65)	(0.66)
high cost		-0.62	3.12***	-0.19	-2.04**	-3.55***	1.78***
		(1.14)	(0.92)	(0.54)	(0.81)	(0.64)	(0.65)
high cost HNL		0.60	-3.17**	2.05***	1.70	-0.95	-5.25***
		(1.61)	(1.30)	(0.77)	(1.15)	(0.91)	(0.92)
Constant	95.85***	95.44***	95.48***	11.01***	29.30***	8.10***	1.50***
	(0.40)	(0.82)	(0.66)	(0.39)	(0.58)	(0.46)	(0.47)
Observations	2216	1404	812	1404	812	1392	812
R^2	0.003	0.003	0.020	0.029	0.141	0.144	0.106
PREDICTION							
H^h – HNL high cost		96.74	98.45	9.73	21.66	9.69	4.33
H^l – HNL low cost		96.76	98.49	7.86	22.01	14.20	7.80
D^h – Dutch high cost		94.82	98.60	10.82	27.27	4.54	3.28
D^l – Dutch low cost		95.44	95.48	11.01	29.30	8.10	1.50

OLS estimation. Standard errors clustered by session in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table C.2: Baseline regression estimation for hypotheses testing, by bidder cost of time

	Auction duration		Selling price		Buyer payoff	
	high cost	low cost	high cost	low cost	high cost	low cost
REGRESSION						
HNL auction	-9.26***	-9.85***	-3.61***	-5.47***	5.15***	6.10***
	(0.77)	(0.73)	(0.69)	(0.72)	(0.50)	(0.68)
5 bidders	-15.60***	-16.48***	15.62***	16.49***	-1.26**	-6.59***
	(0.90)	(0.85)	(0.81)	(0.85)	(0.53)	(0.80)
5 bidders HNL	13.34***	12.35***	0.73	0.10	-4.10***	0.20
	(1.27)	(1.21)	(1.14)	(1.20)	(0.82)	(1.12)
Constant	29.90***	29.49***	20.63***	21.07***	4.54***	8.10***
	(0.55)	(0.52)	(0.49)	(0.51)	(0.36)	(0.48)
Observations	1140	1076	1140	1076	1133	1071
R^2	0.239	0.310	0.421	0.444	0.133	0.199
PREDICTION						
H^5 – HNL 5 bidders	18.38	15.50	33.37	32.30	4.33	7.80
H^2 – HNL 2 bidders	20.64	19.63	17.02	15.61	9.69	14.20
D^5 – Dutch 5 bidders	14.30	13.00	36.26	37.57	3.28	1.50
D^2 – Dutch 2 bidders	29.90	29.49	20.63	21.07	4.54	8.10

OLS estimation. Standard errors clustered by session in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

D Additional tables

Table D.1: Wilcoxon signed-rank tests on price dynamics in Honolulu auctions

Treatment	Alternative hypothesis	Price dynamics	Statistic	p-value	# of Obs*
All treatments	Actual > Predicted	Dutch then English	119.0	0.00006	15
	Actual < Predicted	Dutch only	22.5	0.02974	
		English only	0.0	0.00049	
	Actual ≠ Predicted	Dutch then English	1.0	0.00012	
		Dutch only	12.5	0.05947	
		English only	0.0	0.00098	
2-bidder	Actual > Predicted	Dutch then English	36.0	0.00391	8
	Actual < Predicted	Dutch only	11.0	0.19141	
		English only	0.0	0.00391	
	Actual ≠ Predicted	Dutch then English	0.0	0.00781	
		Dutch only	11.0	0.38281	
		English only	0.0	0.00781	
2H	Actual > Predicted	Dutch then English	10.0	0.06250	4
	Actual < Predicted	Dutch only	0.0	0.06250	
		English only	0.0	0.06250	
	Actual ≠ Predicted	Either	0.0	0.12500	
2L	Actual > Predicted	Dutch then English	10.0	0.06250	4
		Dutch only	8.5	0.18750	
	Actual < Predicted	English only	0.0	0.06250	
	Actual ≠ Predicted	Dutch then English	0.0	0.12500	
		Dutch only	1.5	0.37500	
		English only	0.0	0.12500	
5-bidder	Actual > Predicted	Dutch then English	27.0	0.01563	7
	Actual < Predicted	Dutch only	2.5	0.04630	
		English only	0.0	0.01385	
	Actual ≠ Predicted	Dutch then English	1.0	0.03125	
		Dutch only	2.5	0.09259	
		English only	0.0	0.02771	
5H	Actual > Predicted	Dutch then English	9.0	0.12500	4
	Actual < Predicted	Dutch only	1.0	0.14252	
		English only	0.0	0.05440	
	Actual ≠ Predicted	Dutch then English	1.0	0.25000	
		Dutch only	1.0	0.28505	
		English only	0.0	0.10881	
5L	Actual > Predicted	Dutch then English	6.0	0.12500	3
	Actual < Predicted	Dutch only	0.0	0.12500	
		English only	0.0	0.12500	
	Actual ≠ Predicted	Either	0.0	0.25000	

*The tests compare actual and predicted frequencies, with session averages as units of observation.

Table D.2: Frequencies of strictly and weakly dominated decisions, by treatment

		2H		2L		5H		5L	
Stage	Decision	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
DUTCH AUCTION									
	Bid above value	0	9	0	1	0	2	0	15
		0.0%	5.5%	0.0%	0.6%	0.0%	2.2%	0.0%	15.3%
	Undominated bid	189	156	167	170	117	91	98	83
		100.0%	94.5%	100.0%	99.4%	100.0%	97.8%	100.0%	84.7%
HONOLULU AUCTION									
Dutch stage	Bid above value	0	9	0	1	1	3	1	5
		0.0%	5.9%	0.0%	0.6%	1.0%	2.7%	1.0%	5.2%
	Undominated bid	181	144	147	165	96	110	98	92
		100.0%	94.1%	100.0%	99.4%	99.0%	97.3%	99.0%	94.8%
Contest stage	Leave below value	7	12	12	12	7	12	6	11
		10.8%	24.5%	29.3%	32.4%	3.0%	4.8%	2.7%	4.8%
	Undominated leave	58	37	29	25	229	239	214	220
		89.2%	75.5%	70.7%	67.6%	97.0%	95.2%	97.3%	95.2%
	Bid above value[2]	0	6	0	0	5	24	1	1
		0.0%	3.8%	0.0%	0.0%	3.2%	12.1%	0.6%	0.6%
	Undominated bid	114	152	154	139	150	174	156	173
		100.0%	96.2%	100.0%	100.0%	96.8%	87.9%	99.4%	99.4%
English stage	Leave below value	16	41	26	29	13	23	8	27
		7.1%	15.2%	9.8%	10.9%	5.5%	7.7%	3.3%	10.4%
	Stay above value	5	22	3	12	7	45	10	25
		2.2%	8.2%	1.1%	4.5%	2.9%	15.1%	4.1%	9.6%
	Undominated decision	204	203	235	225	218	230	226	208
		90.7%	75.5%	89.0%	84.6%	91.6%	77.2%	92.6%	80.0%
Final outcome	Leave below value -all	23	53	38	41	20	35	14	38
		6.4%	14.7%	11.1%	12.0%	4.1%	6.2%	2.9%	7.5%
	- foregone purchase[3]	*23*	*53*	*38*	*41*	*13*	*21*	*7*	*24*
		6.4%	*14.7%*	*11.1%*	*12.0%*	*2.7%*	*3.7%*	*1.5%*	*4.8%*
	Bid above value -all	5	25	3	13	7	45	10	25
		1.4%	6.9%	0.9%	3.8%	1.4%	8.0%	2.1%	5.0%
	- actual loss[3]	*0*	*11*	*1*	*6*	*0*	*6*	*1*	*6*
		0.0%	*3.1%*	*0.3%*	*1.8%*	*0.0%*	*1.1%*	*0.2%*	*1.2%*
	Undominated decision	332	282	301	288	461	482	452	441
		92.2%	78.3%	88.0%	84.2%	94.5%	85.8%	95.0%	87.5%

[1] The table lists the number of decisions in each category, and their percentage out of all decisions at the corresponding auction stage. Due to possible delays in bid transmission, decisions within 2 points of bidder value are considered to be "at value."

[2] Dutch stage provisional winners are excluded from the Contest stage decisions

[3] Decisions in the corresponding category where the final auction price was below value (for foregone purchases), or the purchase was made at a price above value (for actual losses).

Table D.3: Wilcoxon signed-rank tests on the share of undominated decisions for Top and Bottom earners

Treatment	Hypothesis	Type of decision	Statistic	p-value	# of Obs*
All treatments	Top > Bottom	Dutch auction bid	45.0	0.00382	15
		Dutch stage bid	19.0	0.03737	
		Contest stage leave	89.0	0.05350	
		Contest stage bid	36.0	0.05487	
		English stage leave	110.0	0.00131	
		Honolulu auction final outcome	113.0	0.00058	
2-bidder	Top > Bottom	Dutch auction bid	10.0	0.03394	8
		Dutch stage bid	6.0	0.05440	
		Contest stage leave	27.0	0.12500	
		Contest stage bid	6.0	0.05440	
		English stage leave	32.0	0.02734	
		Honolulu auction final outcome	33.0	0.01953	
2H	Top > Bottom	Dutch auction bid	6.0	0.05440	4
		Dutch stage bid	3.0	0.08986	
		Contest stage leave	8.0	0.18750	
		Contest stage bid	6.0	0.05440	
		English stage leave	10.0	0.06250	
		Honolulu auction final outcome	10.0	0.06250	
2L	Top > Bottom	Dutch auction bid	1.0	0.15866	4
		Dutch stage bid	1.0	0.15866	
		Contest stage leave	7.0	0.32150	
		Contest stage bid	Not applicable**		
		English stage leave	6.0	0.43750	
		Honolulu auction final outcome	7.0	0.31250	
5-bidder	Top > Bottom	Dutch auction bid	10.0	0.02108	7
		Dutch stage bid	5.0	0.14252	
		Contest stage leave	20.0	0.18750	
		Contest stage bid	14.0	0.23154	
		English stage leave	26.0	0.02344	
		Honolulu auction final outcome	27.0	0.01563	
5H	Top > Bottom	Dutch auction bid	3.0	0.07865	4
		Dutch stage bid	2.0	0.32736	
		Contest stage leave	6.0	0.43750	
		Contest stage bid	8.0	0.18750	
		English stage leave	10.0	0.06250	
		Honolulu auction final outcome	10.0	0.06250	
5L	Top > Bottom	Dutch auction bid	6.0	0.12500	3
		Dutch stage bid	1.0	0.15866	
		Contest stage leave	6.0	0.12500	
		Contest stage bid	0.0	0.91014	
		English stage leave	4.0	0.37500	
		Honolulu auction final outcome	5.0	0.25000	

*The tests compare the share of undominated decisions for top and bottom earners in each session.

**For the contest stage bid decisions under treatment $2L$, all decisions are undominated, so the test is not applicable.

Table D.4: Dutch auction bids regression estimation

	2-bidder auctions			5-bidder auctions		
Earning Category	Theory	Bottom	Top	Theory	Bottom	Top
item value	0.56***	0.63***	0.59***	0.81***	0.21**	0.88***
	(0.00)	(0.06)	(0.05)	(0.00)	(0.08)	(0.03)
item value high cost	0.11***	-0.11	0.00	0.02***	0.65***	-0.19*
	(0.00)	(0.09)	(0.07)	(0.00)	(0.08)	(0.10)
high cost	0.06***	3.18	-0.53	0.04***	-29.79***	8.22*
	(0.01)	(3.89)	(1.95)	(0.00)	(4.38)	(3.88)
Constant	-0.41***	2.63**	0.72	-0.10***	31.71***	-0.55
	(0.01)	(0.86)	(0.72)	(0.00)	(4.27)	(1.30)
Observations	1404	336	356	2030	190	216
Adjusted R^2	1.000	0.484	0.614	1.000	0.488	0.784

OLS estimation. Standard errors clustered by session in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The joint hypothesis that the coefficients on "item value high cost" and "high cost" are both equal to zero cannot be rejected for either Bottom or Top earners ($p > 0.1$) in both 2-bidder and 5-bidder auctions, except for 5L bottom earners. Hence, we cannot reject the hypothesis that bids as a function of value are the same in high-cost and low-cost cases, for both 2-bidder and 5-bidder auctions.

Table D.5: Dutch bids as a function of value, outlier bidders excluded

	2-bidder auctions			5-bidder auctions		
Earning Category	Theory	Bottom	Top	Theory	Bottom	Top
item value	0.56***	0.63***	0.59***	0.81***	0.60***	0.88***
	(0.00)	(0.06)	(0.05)	(0.00)	(0.16)	(0.03)
item value high cost	0.11***	-0.10	0.00	0.02***	0.26	-0.10*
	(0.00)	(0.09)	(0.07)	(0.00)	(0.16)	(0.05)
high cost	0.06***	1.91	-0.53	0.04***	-12.55	4.16*
	(0.01)	(3.55)	(1.95)	(0.00)	(6.59)	(1.75)
Constant	-0.41***	2.63**	0.72	-0.10***	14.18*	-0.55
	(0.01)	(0.86)	(0.72)	(0.00)	(6.53)	(1.30)
Observations	1386	324	356	1903	161	215
Adjusted R^2	1.000	0.517	0.614	1.000	0.703	0.845

OLS estimation. Bidders with 33% or more bids higher than 2 points above value excluded.

Standard errors clustered by session in parentheses.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table D.6: Dutch stage bids regression estimation

Treatment	2L		2H		5L		5H	
	Theory	Actual	Theory	Actual	Theory	Actual	Theory	Actual
item value	0.30***	0.03	0.50***	0.06	0.70***	0.20***	0.71***	0.41***
	(0.00)	(0.03)	(0.00)	(0.04)	(0.00)	(0.02)	(0.00)	(0.04)
item value Top earner		0.04		0.24**		0.00		-0.03
		(0.03)		(0.12)		(0.02)		(0.09)
Top earner		-0.94		-4.41		0.15		2.53
		(1.84)		(3.77)		(0.58)		(4.84)
Constant	-2.05***	3.55**	-2.43***	6.31***	-1.10***	15.17***	-1.12***	8.99***
	(0.06)	(1.47)	(0.05)	(2.42)	(0.02)	(1.03)	(0.01)	(3.04)
Observations	684	313	720	334	980	196	1050	210
Pseudo R^2	0.643	0.014	0.723	0.038	1.004	0.064	1.040	0.055

Tobit estimation, with bid upper bound for each treatment censored at the corresponding starting price.
Standard errors clustered by session in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
The estimation results are robust to excluding "outlier" bidders with more than 33 percent of Dutch stage bids above value; see Table D.7.

Table D.7: Dutch stage bids regression estimation, outlier bidders excluded

Treatment	2L		2H		5L		5H	
	Pred	Actual	Pred	Actual	Pred	Actual	Pred	Actual
item value	0.30***	0.03	0.50***	0.12***	0.70***	0.25***	0.71***	0.46***
	(0.00)	(0.03)	(0.00)	(0.03)	(0.00)	(0.00)	(0.00)	(0.03)
item value Top earner		0.04		0.18**		-0.05		-0.02
		(0.03)		(0.08)		(0.03)		(0.05)
Top earner		-0.94		-1.93		2.41***		2.30**
		(1.84)		(2.53)		(0.76)		(1.13)
Constant	-2.05***	3.55**	-2.44***	3.84***	-1.10***	12.91***	-1.12***	6.60***
	(0.06)	(1.47)	(0.05)	(1.11)	(0.02)	(0.46)	(0.01)	(2.08)
Observations	684	313	702	320	952	184	989	203
Pseudo R^2	0.643	0.014	0.722	0.048	1.004	0.076	1.039	0.071

Tobit estimation. Bids by bidders with 33% or more bids higher than 2 points above value excluded.
Standard errors clustered on session in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table D.8: Dutch stage bids deviations from predictions

	2-bidder auctions		5-bidder auctions	
	Top	Bottom	Top	Bottom
item value	-0.20***	-0.28***	-0.31***	-0.35***
	(0.02)	(0.02)	(0.06)	(0.08)
item value high cost	-0.00	-0.15***	0.01	0.04
	(0.05)	(0.04)	(0.07)	(0.08)
high cost	0.33	2.11	0.45	-1.97
	(1.78)	(2.49)	(2.37)	(3.13)
predicted bidder	-1.02	-0.10	-1.28	-0.25
	(0.65)	(0.32)	(1.04)	(0.72)
Dutch auction first	-1.57	-1.38	0.23	-2.66
	(1.27)	(2.00)	(0.64)	(2.73)
round	-0.04*	-0.12***	-0.02	-0.08***
	(0.02)	(0.03)	(0.05)	(0.02)
Constant	6.31***	8.52***	11.65***	15.00***
	(1.15)	(2.68)	(2.00)	(2.51)
Observations	328	319	196	210
R^2	0.319	0.550	0.425	0.381

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table D.9: English stage dropout price regression estimation

	2-bidder auctions			5-bidder auctions		
Earning Category	All	Bottom	Top	All	Bottom	Top
item value	0.76***	0.67***	0.86***	0.67***	0.57***	0.79***
	(0.04)	(0.07)	(0.04)	(0.05)	(0.09)	(0.04)
item value high cost	-0.12	-0.13	-0.03	-0.04	0.03	-0.08
	(0.12)	(0.15)	(0.10)	(0.13)	(0.19)	(0.09)
high cost	2.75	3.00	1.00	2.09	0.63	2.71
	(2.19)	(2.71)	(1.91)	(4.96)	(7.00)	(2.91)
Constant	2.78***	3.98***	1.53	10.42***	12.98***	7.17***
	(0.48)	(1.14)	(0.91)	(1.97)	(2.65)	(1.01)
Observations	512	270	242	689	380	309
R^2	0.656	0.522	0.856	0.610	0.539	0.739

OLS regression. Standard errors clustered by session in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table D.10: Post-auction survey responses summary

Survey Question	Honolulu mean score μ_H	Dutch mean score μ_D	p-value* for $H_0 : \mu_H = \mu_D$
1. "When I bid, all I cared about was buying as fast as possible"	2.86	3.27	0.054
2. "When I bid, all I cared about was paying the lowest price possible"	4.85	4.07	0.000
3. "When I bought the object, I often thought that I could have bought it at a lower price if I bid differently"	3.43	4.21	0.005
4. "When I did not buy the object, I often thought that I could have bought it and made a profit if I bid differently"	2.63	3.82	0.000
5. "Indicate how you felt when you bought an object in the auction"	5.57	5.51	0.171
6. "Indicate how you felt when you did not buy an object in the auction"	3.88	3.59	0.015

For Questions 1 – 4, the scales are from 1 (Completely Disagree) to 7 (Completely Agree).
For Questions 5 – 6, the scales are from 1 (Extremely Sad) to 7 (Extremely Happy).
* Based on bootstrapped standard errors clustered on session.

E Auction performance with zero-cost prediction

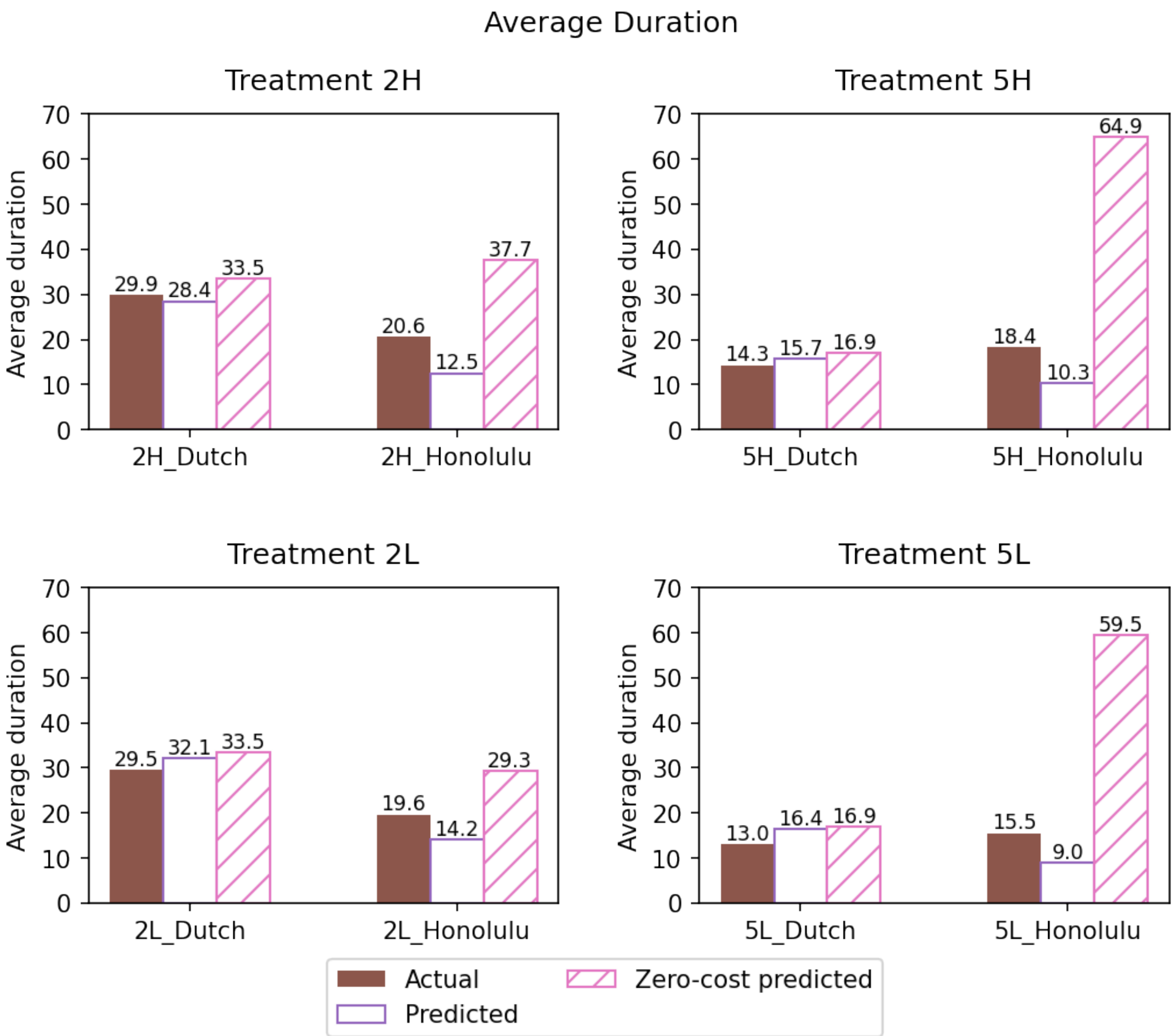


Figure E.1: Auction duration by treatment

F Bidder heterogeneity: clustering based on similarity

We apply a commonly used clustering based on similarity method called K-means algorithm (Lloyd, 1982) to study bidder heterogeneity in Honolulu-Sydney auctions. We characterize each bidder on two aspects, her normalized payoff, and the optimality of her strategy.

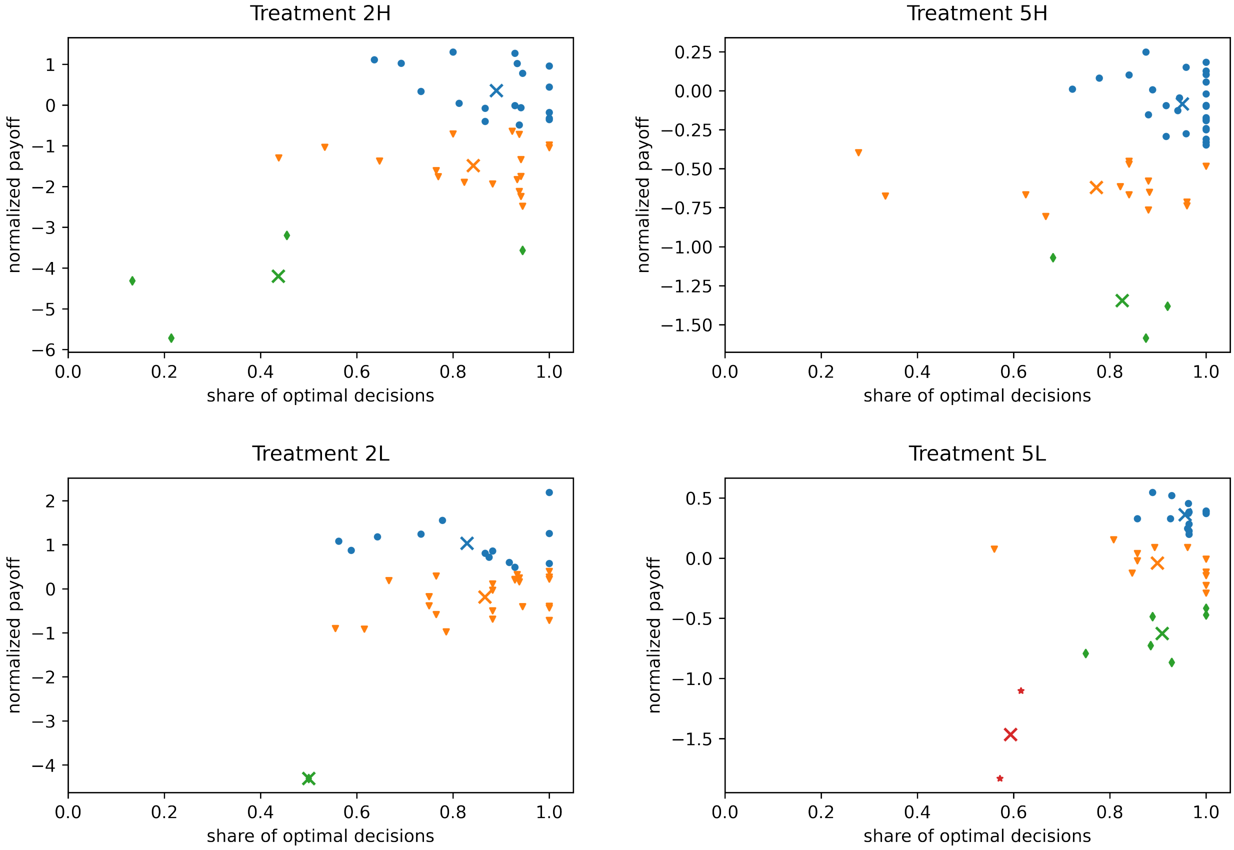
For the normalized payoff, we use the alternative measure mentioned in footnote 23 in Section 5.2, which is the average per period point deviations from the theoretical prediction by period. We avoid censoring of extreme values by using this alternative measure, at the cost of losing cross-treatment comparability. We argue that the benefit of this alternate measure outweighs the cost, because the exact position of each data point affects the global clustering result in K-means algorithm; censoring extreme values would distort the optimally chosen clusters.

For the optimality of bidder strategy, we focus on Contest or English stage decisions, and exclude the individual observations of the Dutch-stage winners who are uncontested and become the auction winner without the follow-up English stage.[5] A bidder's joint decision at the Contest and/or English stage is considered optimal if one of the following three conditions is satisfied: (1) She drops out on the Contest stage when the contest price is higher than her item value; (2) She enters the English stage but drops out at the price equal to her item value; (3) She enters the English stage and wins the item at a price equal to or below her item value. (Decisions within two unit from the value are considered at value.) We measure the optimality of a bidder's strategy by the share of optimal decisions in all of her decisions.

Figure F.1 shows the clustering results by treatment. In all treatments except 2-bidder low-cost (2L), the cluster with the highest average normalized payoff has also the highest optimal decision rate. The average share of optimal decisions in the top-earning cluster exceeds 95% in 5-bidder auctions, and it exceeds 90% in 2-bidder high-cost (2H) auctions. The share of optimal decisions in these three treatments generally decreases when moving from the cluster with the highest average normalized payoff to the one with the lowest payoff. There is a $18\% - 40\%$ gap in the optimal decision rate between the top-earning cluster and bottom-earning cluster. Thus, the clustering result provides evidence for bidder heterogeneity: Top earners employ closer to theoretical optimal strategies, except for the treatment 2L. For the 2-bidder low-cost treatment, clustering based on similarity does not provide much information about the relationship between earnings and optimality of bidding

[5]Applying K-means clustering method to individual decisions for each stage revealed that the optimality of Dutch-stage decisions has a smaller association with individual payoffs than their decisions at later stages. We therefore exclude the cases when the auction ended with an uncontested Dutch-stage bid. In total, 6.4% (219 out of 3434 observations) of all decisions are excluded.

strategies. One possible explanation is the presence of suppressed price competition.



Note: Each dot represents one individual. The dots in the same shape belong to the same cluster, and the clustering center is marked with a cross.

Figure F.1: Clustering based on similarities in bidder characteristics in Honolulu auctions: normalized payoffs and individual decisions at the Contest and English stages

EXPERIMENTAL MATERIALS

A Experimental Instructions

[The sample instructions are for 2H treatment. For 5-bidder ("5") or low-cost ("L") treatments, the number of other bidders is changed from **1** to **4**, and the payoff percent adjustment per tick of the virtual clock is changed from "**1.9**" to "**0.9**" (as indicated in the parentheses). The text in the square brackets is not given to participants.]

Introduction

In this part you are going to participate in a sequence of independent auction periods in which you will be buying a fictitious good. At the beginning of each auction, you will be assigned to a market with **1** (**4**) other participants. You will not be told which of the other participants are in your market. *What happens in your market has no effect on the participants in other markets and vice versa.*

In each auction period you will be able to place bids in an auction to purchase a single unit of a good.

Values, Auction Duration and Earnings

Values and Earnings During each market period you are free to purchase a unit of a good in an auction. You will be assigned a number which describes the value of the good for you. These values may differ among bidders and market periods. Each bidder will receive a value between **0** and **50**, with each number being equally likely. *You are not to reveal your value to anyone. It is your own private information.*

Your earnings from the purchase, which are yours to keep, will depend on the difference between your value for the good and the price you pay, and on how long the auction lasts.

Your raw (unadjusted) earnings or loss from the purchase is equal to the difference between your value and the purchase price: That is:

YOUR UNADJUSTED EARNINGS = YOUR VALUE – PURCHASE PRICE.

Example 1 (All values are hypothetical). If you buy a good for 15 points and your value is 32, then your unadjusted earnings are:

UNADJUSTED EARNINGS = 32 − 15 = 17 points.

Example 2 If you buy the good for 50 points and your value is 32, then your unadjusted earnings are:

UNADJUSTED EARNINGS = 32 − 50 = −18 points.

ARE THERE ANY QUESTIONS?

Auction Duration and Earnings *Your earnings will further decrease in proportion to how long the auction lasts.* The auction duration will be measured by the virtual clock, which will tick every **1** seconds while the auction is open. Your unadjusted earnings, if positive, will shrink by **1.9** (**0.9**) percent with every tick of the virtual clock; your loss, if negative, will increase by **1.9** (**0.9**) percent with every tick of the virtual clock. That is, your time-adjusted earnings will be equal to

$$\text{YOUR EARNINGS} = (\text{YOUR VALUE} - \text{PURCHASE PRICE}) \times (\text{TIME-ADJUSTMENT FACTOR}),$$

where the time-adjustment factor decreases with every tick of the virtual clock for positive earnings, and increases with every tick of the virtual clock for negative earnings. The table below illustrates how your earnings will be adjusted depending on the auction duration:[1]

Elapsed time, in ticks of the virtual clock	Time-adjustment factor for positive earnings	Time-adjustment factor for negative earnings
0	1	1
1	0.981	1.019
2	0.962	1.038
5	0.905	1.095
10	0.81	1.19
20	0.62	1.38
50	0.05	1.95

Example 1 continued (All values are hypothetical). Suppose that your value for a good is 32, and you buy the good for 15. Suppose the time-adjustment factor is as given above. If the auction ends after 6 ticks of the virtual clock, then your positive earnings will shrink to 88.6 percent, and your time-adjusted earnings will be:

$$\text{TIME-ADJUSTED EARNINGS} = (32 - 15) \times 0.886 = 15 \text{ points.}$$

If, on the other hand, the auction ends after 34 ticks, your earnings will shrink to 35.4 percent by the end of the auction, and your time-adjusted earnings will be:

$$\text{TIME-ADJUSTED EARNINGS} = (32 - 15) \times 0.354 = 6 \text{ points.}$$

Example 2 continued Suppose, as in Example 2 above, that your value is 32, you buy the good for 50, and the time-adjustment factor is as given. If the auction ends after 6 ticks of the virtual clock, then your loss from the purchase will grow in magnitude by 11.4 percent, and you adjusted earnings (loss) will be:

$$\text{TIME-ADJUSTED EARNINGS} = (32 - 50) \times 1.114 = -20 \text{ points.}$$

If, on the other hand, your value and the purchase price are the same as above, but the auction ends after 34 ticks, then your loss from the purchase will increase by 64.6 percent.

[1] These are the table and examples appearing in the instructions for the high-cost treatments "H." For the low-cost treatments "L," the numbers in the table and the numerical examples are adjusted accordingly.

Your time-adjusted negative earnings will be:

$$\text{TIME-ADJUSTED EARNINGS} = (32 - 50) \times 1.646 = -29 \text{ points.}$$

If you do not buy the good in a given period, your earnings will be zero in this period irrespective of how long the auction lasts.

At each point of time during the auction, your computer screen will display your value of the good, the current price at which you may buy, the time adjustment factor, and your unadjusted and time-adjusted payoffs (earnings or losses) if you were to buy the good at the current price and time.

ARE THERE ANY QUESTIONS?

Summary of Values, Duration and Earnings

1. You will participate in an auction to buy a fictitious good. If you buy the good, your earnings from the purchase will depend on the difference between the value of the good and the price you pay, and on how long the auction lasts.

2. If you buy the good at a price above your value, your earnings will be negative (you will lose money).

3. If you buy the good at a price below your value, your earnings will be positive (you will make money).

4. The longer the auction takes, the lower will be your earnings from the purchase, other things being equal.

5. If you do not buy, your earnings will be zero.

Test for Understanding This is a test for understanding about the values, auction duration and earnings. **Please answer all questions carefully.** You will not be able to start the auction until you answer all questions correctly.

1. Suppose your value for the good is 41, and the auction ends after several ticks of the virtual clock at the price of 20. The time-adjustment factor is 0.85 for positive earnings, and 1.15 for negative earnings. If you buy the good at this price and time, what is your earning (rounded to the closest integer)?

   [**Answer: 18**]

2. Suppose your value for the good is 31, and the auction ends after several ticks of the virtual clock at the price of 49. The time-adjustment factor is 0.6 for positive earnings, and 1.4 for negative earnings. If you buy the good at this price and time, what is your earning (rounded to the closest integer)?

   [**Answer: -25**]

Auction Organization [Dutch Auction]

The auction is organized as follows. In each auction you and **1** (**4**) other participants will compete to purchase a fictitious good. The price of the good will start at **50** points and will decrease by **1** point with every tick. Any of the bidders can stop the auction and purchase the good at the price displayed on the screen by clicking the **Bid** button. The first person to click the button buys the good and pays the price displayed on the screen, and the other bidders earn 0 for that auction.

After the good is sold, the auction closes for this period. Your results screen will display whether you bought the good or not; your value for the good, sale price, and your unadjusted and time-adjusted payoffs.

If you do not buy, your results screen will report your actual payoffs as zero, and will also display your payoffs if you were to buy the good at the price and time when it was sold.

Your time-adjusted earnings from all previous auctions will be displayed in the history box at the bottom of each auction's results screen.

ARE THERE ANY QUESTIONS?

Summary of Auction Organization

1. When the auction opens, the price will start to go down. The first person to click the **Bid** button will buy the good at the time and price of their bid.
2. If you buy at a price above your value, your earnings will be negative (you will lose money).
3. If you buy at a price below your value, your earnings will be positive (you will make money).
4. The longer the auction takes, the lower will be your earnings from the purchase, other things being equal.
5. If you do not buy, your earnings will be zero.

Test for Understanding

1. Suppose the price of the good is going down, and someone else, not you, is the first person to bid. Check which statement is correct:
   (a) The auctions will end immediately, and the person who bid first will buy the good at the time and price at which they bid.
   (b) The person who bid will be provisionally assigned the good, but you will have another chance to bid and resume the auction.

   [**Answer: (a)**]
2. Suppose the price is going down, and you are the first person to bid at the price of 33. Suppose your value for the good is 25. Check which statement is correct:

(a) Even though the price of 33 is above my value of value 25, I will not lose money if I bid at this price because another person may also bid and buy the good.

(b) Because the price of 33 is above my value of 25, I will lose money if I bid at this price.

[**Answer: (b)**]

Auction Organization [Honolulu-Sydney Auction]

The auction is organized as follows. In each auction you and **1** (**4**) other participants will compete to purchase a fictitious good.

Price is going down The price of the good will start at some value between **0** and **50** points, set by the experimenter, and will go down by **1** point with every tick of the virtual clock. Any of the bidders can stop the auction and provisionally purchase the good at the price displayed on the screen by clicking the **Bid** button. The first person to click the **Bid** button is provisionally assigned the good at the given price and time.

Another chance to bid When a bidder bids and becomes a provisional buyer, other bidders have **10** seconds to challenge the provisional buyer by clicking the **Bid** button. The virtual clock will stop, and bidder payoffs will not change, during this time.

If a bidder decides not to bid at this stage, they may leave the auction by either clicking **Leave** button, or by taking no action. This bidder then becomes inactive and cannot bid any more.

If no bidder challenges the provisionally assigned buyer by clicking the **Bid** button after **10** seconds, then the auction ends. The provisional buyer buys the good at the price and time of their bid. All other bidders earn 0 for that auction.

Price is going up If one or more other bidders challenge the provisional buyer by clicking the **Bid** button, then the auction and the virtual clock will resume, and the price will go up from the previously bid price by **1** point with every tick of the virtual clock. Only the provisional buyer and those bidders who challenged this buyer by clicking **Bid** will be active in the auction at this stage. (The bidders who left the auction will be inactive and will view the auction without taking any action.)

Any active bidder can then leave the auction at any time by clicking the **Leave** button. The auction will continue, with the price and time increasing, as long as there are two or more active bidders in the auction. The auction ends when the next to the last active bidder clicks **Leave** button. The last bidder to stay active in the auction buys the good at the price and time when the next to last bidder left. All other bidders earn 0 for that auction. If two last active bidders drop out at the same time and price, then the object will be allocated randomly to one of these bidders at the price and time when they left.

After the good is sold, the auction closes for this period. Your results screen will display whether you bought the good or not; your value for the good, sale price, and your unadjusted and time-adjusted payoffs.

If you do not buy, your results screen will report your actual payoffs as zero, and will also display your hypothetical payoff if you were to buy the good at the price and time when it was sold.

Your time-adjusted earnings from all previous auctions will be displayed in the history box at the bottom of each auction's results screen.

ARE THERE ANY QUESTIONS?

Summary of Auction Organization

1. When the auction opens, the price will start to go down. The first person to click the **Bid** button will be provisionally assigned the good at the time and price of their bid. After that, all other bidders will be given another chance to bid.

2. Only the bidders who click **Bid**, either when the price is going down, or at "Another Chance to Bid" stage, will have a chance to buy. Bidders who do not bid will not be able to buy the good in this auction and will earn zero.

3. If more than one bidder clicks the **Bid** button, the price will start going up, and all bidders who are active (i.e., they pressed **Bid** earlier) will be considered willing to buy at the current price. You have to press the **Leave** button to exit bidding. The last bidder to stay active in the auction will buy the good at the price and time when the next to last bidder left.

4. If the price is above your value, and you bid (if the price is going down or at "Another Chance to Bid" stage) or you do not leave the auction (if the price is going up), you may end up buying the good at a price above your value, and lose money.

5. If the price is below your value and you do not bid (at "Another Chance to Bid" stage), or you leave the auction (when the price is going up), you may forgo a chance to buy at a price below your value and earn a positive profit.

Test for Understanding This is another test for understanding about the auction organization. **Please answer all questions carefully.** You will not be able to start the auction until you answer all questions correctly.

1. Suppose the price is going down, and you are the first person to bid at the price of 24. Suppose your value for the good is 17. Check which statement is correct:

   (a) Even though the price of 24 is above your value of value 17, I will not lose money if I bid at this price because another person may also bid and buy the good.

   (b) Because the price of 24 is above my value of 17, I may lose money if I bid at this price.

   [**Answer: (b)**]

2. Suppose the price was going down, but then it stopped at 35, and you are given "Another Chance to Bid". Suppose your value for the good is 41. Check which statement is correct:

(a) If I click **Bid**, I will continue bidding and may have a chance to buy and make a positive earning. If I do not click **Bid** or click the **Leave** button, I will forgo a chance to buy and earn money.

(b) I should not bid. Instead, I should leave the auction because the price is too high.

[**Answer: (a)**]

3. Suppose again that the price was going down, but then it stopped at 18, and you are given "Another Chance to Bid". Suppose now your value for the good is 11. Check which statement is correct:

   (a) If I click **Bid** I will continue bidding and may have a chance to buy and make a positive earning. If I do not click **Bid** or click the **Leave** button, I will forgo a chance to buy and earn money.

   (b) Because the price is above my value, I should not bid if I want to avoid losses. If I click **Bid**, I may buy at the current price or higher, and I will lose money if I buy.

   [**Answer: (b)**]

4. Suppose the price of the good is going up and is currently at 14. Suppose you are an active bidder, and your value of the good is 28. Check which statement is correct:

   (a) I have to click **Bid** with every price increase to remain active in the auction and have a chance to buy the good.

   (b) If I click the **Leave** button at this price, I will forgo my chance to buy at a price below my value and earn a positive payoff.

   (c) Even if I click the **Leave** button at this price, I will still have a chance to bid at a later point and buy in this auction.

   [**Answer: (b)**]

5. Suppose the price of the good is going up and is currently at 14. Suppose you are an active bidder, and your value of the good is 9. Check which statement is correct:

   (a) If I do not leave, I will continue bidding, and may buy the good at a price below my value and earn money. If I click the **Leave** button at this price, I will forgo my chance to buy at a price below value and earn a positive payoff.

   (b) Because the price of 14 is above my value of 9, and the price is going up, I will not be able to buy and make money in this auction. If I do not click **Leave**, I will continue bidding, I may buy the good at a price below my value and lose money.

   [**Answer: (b)**]

Matching

You will be randomly re-matched with new participants in every auction. You will not be told which of the other participants you are matched with in any given auction, and they will not be told that you are matched with them. What happens in your auction has no effect on what happens in any other auction, and vice versa.

This will continue for a number of periods. Your total earnings in this part of the session are given by the sum of your period earnings. Your cumulative earnings in all parts will be displayed on your computer screen at all times during the auction.

The first **2** periods will be practice. You will receive no earnings for these periods. If you have a question, please raise your hand and I will answer your question in private.

ARE THERE ANY QUESTIONS?

B Experimental Auction Screenshots [5H treatment]

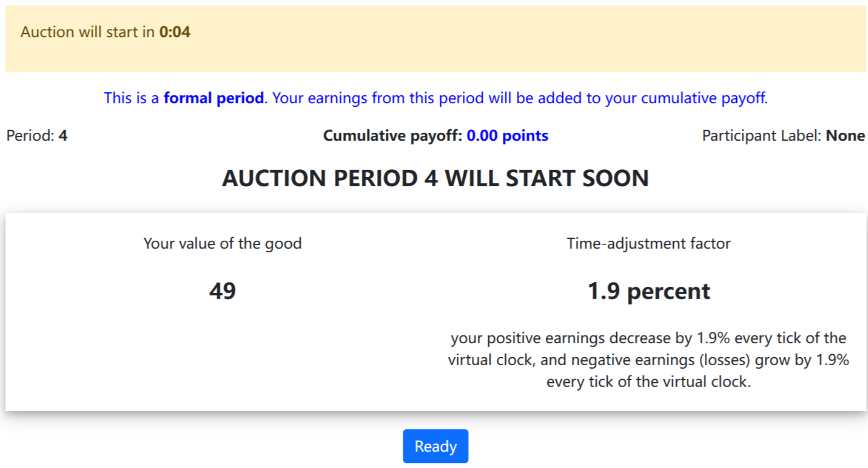


Figure B.1: Auction start page

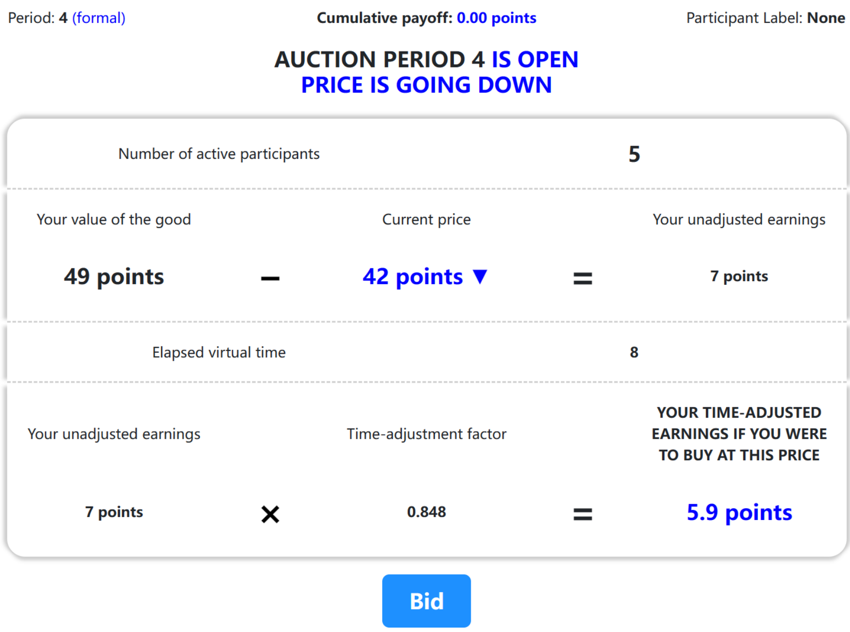


Figure B.2: Dutch auction or Dutch Stage

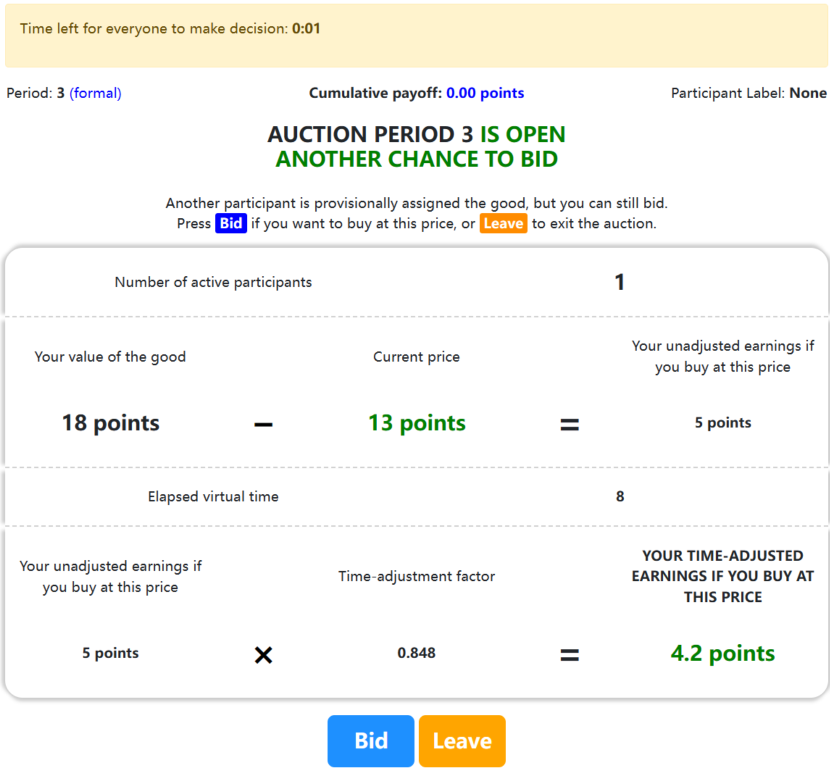


Figure B.3: Contest Stage

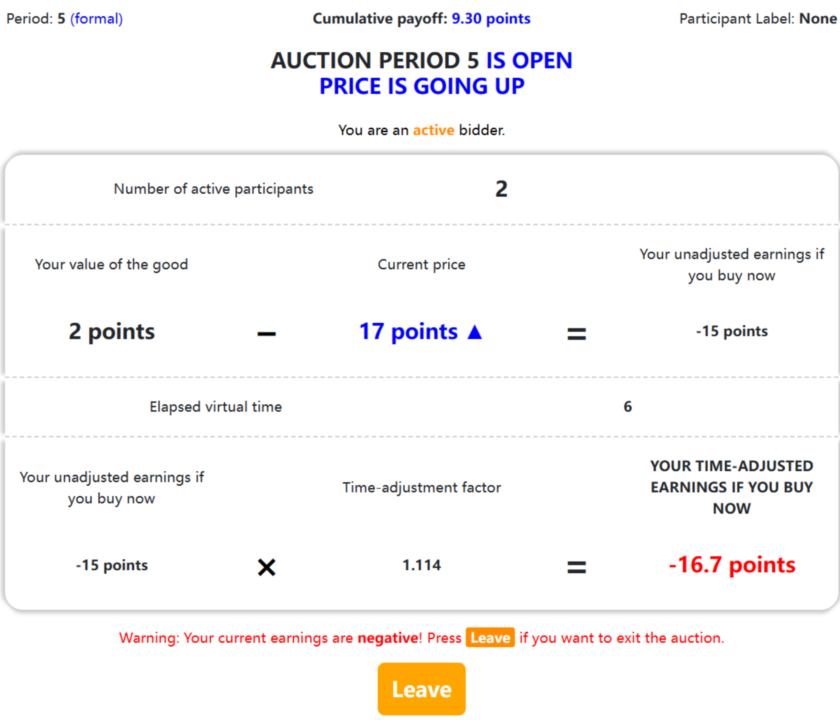


Figure B.4: English Stage

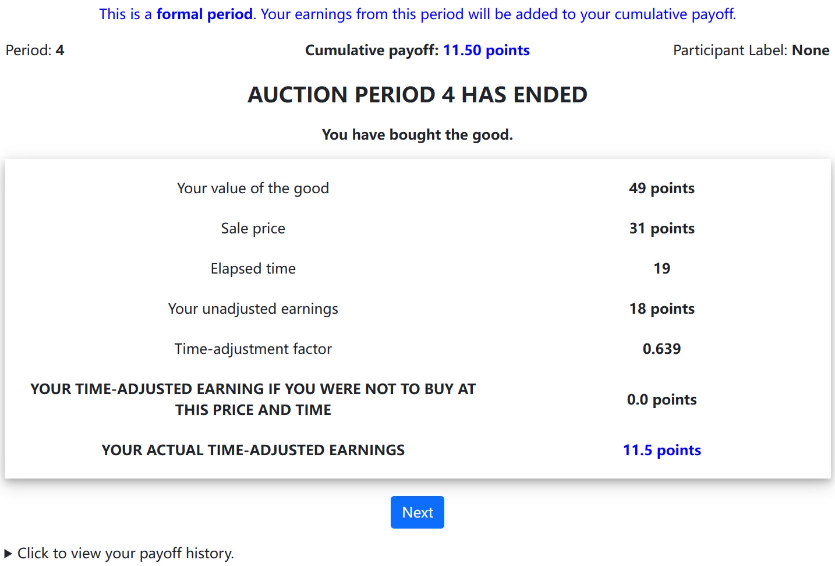


Figure B.5: Auction result page

C Post-auction questionnaire

0. For every period in the auction, I

   1 always bought the object [– Hide questions 5 and 7]

   2 sometimes bought the object, and sometimes not.

   3 never bought the object [– Hide questions 4 and 6]

1. When I bid, all I cared about was buying as fast as possible.

   1 Completely Disagree

   2 Disagree

   3 Somewhat Disagree

   4 Neither Agree Nor Disagree

   5 Somewhat Agree

   6 Agree

   7 Completely Agree

2. When I bid, all I cared about was paying the lowest price possible.

   1 Completely Disagree

   2 Disagree

   3 Somewhat Disagree

   4 Neither Agree Nor Disagree

   5 Somewhat Agree

   6 Agree

   7 Completely Agree

3. When I bought the object, I often thought that I could have bought it at a lower price if I bid differently.

   1 Completely Disagree

   2 Disagree

   3 Somewhat Disagree

   4 Neither Agree Nor Disagree

   5 Somewhat Agree

   6 Agree

   7 Completely Agree

4. When I did not buy the object, I often thought that I could have bought it and made a profit if I bid differently.

1 Completely Disagree

2 Disagree

3 Somewhat Disagree

4 Neither Agree Nor Disagree

5 Somewhat Agree

6 Agree

7 Completely Agree

5. When I bought an object in the auction, I felt:

   1 Extremely Sad

   2 Sad

   3 Somewhat Sad

   4 Neither Happy Nor Sad

   5 Somewhat Happy

   6 Happy

   7 Extremely Happy

6. When I did not buy an object in the auction, I felt:

   1 Extremely Sad

   2 Sad

   3 Somewhat Sad

   4 Neither Happy Nor Sad

   5 Somewhat Happy

   6 Happy

   7 Extremely Happy