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A laboratory stress-test of bid, double and offer auctions

Abstract:
This paper reports on the empirical properties of the bid auction (buyers propose prices), offer auction (sellers suggest prices) and double auction (both buyers and seller initiate price quotes). These trading institutions are stress-tested using a nonstationary monopolistic market environment in which the buyers' demand schedule and the single seller's supply curve shift unpredictably between trading periods. The principal result is threefold. First, double-auction prices tend to be greater than offer-auction prices which again tend to be greater than bid-auction prices. Second, the listed ranking reflects tendencies only. The laboratory data do not support statistically significant behavioral differences between the three auctions. Third, trading is highly efficient regardless of auction type.

Keywords: Sequential auctions, experimental economics.

JEL classification: D44, C90.

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1. Introduction

A trading institution is a set of rules that govern economic transactions amongst market participants. Such rules specify the market participants' admissible messages (for instance, a message could be an offer to buy, an offer to sell or an acceptance of any such offer), regulate the dissemination of this information to the market and define how messages are converted into binding contracts (Friedman, 1993). An institution is deemed sequential when traders negotiate prices continuously during real-time sequences.

The bid, offer and double auctions are examples of sequential trading institutions (Davis and Holt, 1993). A bid auction enables buyers only to submit bids to buy. Every bid is displayed to all market participants and a trade is executed if a seller chooses to accept a bid. Conversely, an offer auction allows only sellers to announce offers to sell. All offers are common knowledge. Trading takes place, conditional upon an offer being accepted by a buyer. The double auction is a combination of these two one-sided auctions that lets both sellers and buyers suggest and accept offers. Each of the three sequential auction types provides public display of all confirmed contract prices.

The behavioral properties of the double auction - reliable and rapid convergence to competitive equilibrium - are well documented in the experimental economics literature (see Holt, 1995 for a summary of these results). However, the total number of laboratory studies of the bid and offer auctions is comparatively small and these analyses appear to have yielded but tentative conclusions.

Smith (1964) reported the original experimental evaluation of the (oral, non-computerized) bid, offer and double auction trading institutions. The subjects in Smith's experiments were one-way traders, that is, either buyers who could not resell or sellers who were not allowed to repurchase. Smith conjectured that confining the ability to generate price signals to just one side of the market might affect (the time path of) contract prices as follows: Offer auction rules could yield competition for trading opportunities amongst sellers and hence result in relatively low prices, whereas in the bid auction the competitive pressure would affect the buyers and thereby imply increasing offers to buy as well as relatively high prices. Using six laboratory sessions and a symmetric environment with an equal number of buyers and sellers, Smith found supportive evidence for his *a priori* hypothesis that (mean and equilibrium) bid auction prices tend to be greater than double auction prices, which again tend to be greater than offer auction prices[1].

Walker and Williams (1988) examined the robustness of Smith's results. They conducted two sets of computerized experiments, twenty-one laboratory sessions in all. Each session employed an equal number of buyers and sellers. The first set consisted of four double-auction control sessions, plus nine sessions in which the subjects traded on all three auctions in different sequences, each of which lasted 3-5 trading periods. The core result was an ordering of mean prices that differed from Smith's whereby double auction prices are greater than offer auction prices, which tend to be greater than bid auction prices. None of these differences were statistically discernible at conventional significance levels.

The second set of experiments comprised nine sessions using similar demand and supply parameters as those of the initial runs. However, there were no alterations of auction rules within any one session. Mean prices in the initial trading periods were ranked double auction > offer auction > bid auction, whereas time effects rendered prices during the last trading periods weakly consistent with Smith's results. Importantly, the observed market behavior varied across subject groups in a manner that was seemingly unrelated to differences in auction types. Walker and Williams concluded that Smith's original findings had not received sufficient support to be regarded as an experimentally generated stylized fact.

The objective of the present study is to enlarge the body of experimental evidence on sequential one-sided and double auctions. The reported experiment is not a reproduction of the outlined studies on bid-double-offer auctions, but differs from Smith's as well as Walker and Williams' studies with regard to laboratory environment and experimental design as follows.

First, this study constitutes a stress-test in that bid-double-offer auction behavior is investigated within an "extreme" laboratory environment characterized by imperfect competition and markedly volatile market demand and supply (Smith, 1982 contains a methodological classification of economic experiments). Specifically, trading on the bid, double and offer auctions is observed within an asymmetric market environment characterized by a single seller and four buyers, as well as by market

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[1] In these experiments each buyer (seller) could at most buy (sell) a single unit of a fictitious good in each trading period. Although not considering the double and offer auctions, Plott and Smith (1978) concluded that the (oral) bid auction also tends to yield supra-competitive prices when subjects have the capacity to trade multiple units per trading period.

demand and supply schedules which shift unpredictably between trading periods[2]. Hence, this study also extends Smith (1981) who compared the offer auction (just one laboratory session) and the double auction (three sessions) in a stationary monopolistic environment. Moreover, it relates to Jamison and Plott's (1997) original study of the effect of unpredictable demand and supply shifts on the performance of the double auction.

Second, this experimental investigation utilizes a balanced ABA crossover design (Friedman and Sunder, 1994). This means that during each laboratory session a group of subjects participate in three trading sequences on two different auctions. In general, any session first implements auction rule A, then switches to auction rule B before reverting to auction rule A anew. Below, trading during a total of six sessions is reported in the form of observations of prices, quantities, efficiency levels and division of trade gains, which treated econometrically as panel data. The ABA crossover design, in conjunction with a linear econometric model for panel data, facilitates an improved control for, and quantitative evaluation of, subject group and sequence effects. The purpose of this approach is to disentangle group and time effects from the impact of alterations in auction rules, and thereby allow for a focused institutional comparison of the bid, double and offer auctions.

Third, this study can be classified as exploratory experimentation as opposed to a theory-driven process (Steinle, 1997). Thus, the principal null hypotheses tested below assert no behavioral differences between the three auction types, and the two-sided alternative hypotheses do not specify rankings of the auctions. This research strategy is based on the fact that economic theory does not yield concise predictions of the behavioral properties of the three auction types when each agent demands/supplies multiple units under inherently uncertain market information conditions (Klemperer, 1999). At the same time, this approach contrasts with Smith's initial analysis, which tested an (empirical) *a priori* hypothesis based upon pilot experiments as well as Walker and Williams' reexamination of Smith's proposition.

The remainder of this paper is organized in five sections. Section 2 presents the experimental design. The variables, econometric model and hypotheses used to evaluate the laboratory data are described in Section 3. The two subsequent sections present the experimental results and contain a discussion of the findings respectively. The last section concludes and offers suggestions for further research.

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[2] Walker and Williams' first set of laboratory sessions also employed demand and supply shifts, but only between sequences that consisted of three and five trading periods, i.e., two shifts per session. Shifts are considered unpredictable if demand and supply schedules are shifted (up or down) by non-constant amounts between trading periods, as opposed to studies of non-stationary environments in which demand and/or supply cycle (see, for instance, Davis et al., 1993).

2. Experimental design and procedures

In each laboratory session four buyers constituted the demand side of the market whereas a single seller represented the market's supply side. The market participants' trading roles were predetermined as either buyer or seller. Therefore, speculation in the form of repurchase and resale was disallowed.

Endowing the four buyers with individual unit valuations for multiple units of a fictitious homogenous good induced market demand. A transaction gave a buyer a profit in experimental dollars equal to the value of the difference between the induced value of the traded unit and the agreed price. On the other hand, assigning the seller unit costs over a range of units induced market supply. The seller's profit from any transaction equaled the difference between price and induced cost of the traded unit.

Figure 1 depicts the basic configuration of the induced aggregate demand, supply and the marginal revenue schedule derived from the market demand. Table I contains the individual cost and valuation arrays for the seller and the buyers respectively. All costs and values are denoted in experimental dollars.

Figure 1. **Aggregate demand, supply and marginal revenue schedules**

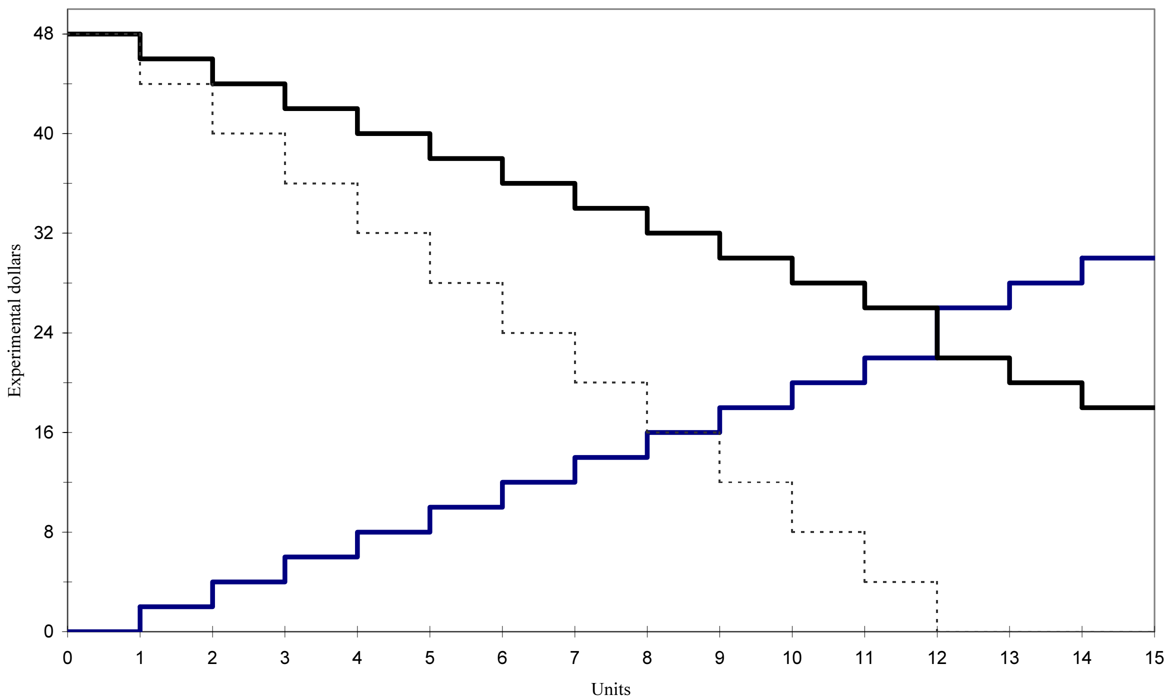


***Table I.* Individual demand and supply schedules**

Trading role	Unit															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Buyer 1	48	-	-	-	-	-	-	34	32	-	-	-	-	-	-	16
Buyer 2	-	46	-	-	-	-	36	-	-	30	-	-	-	-	18	-
Buyer 3	-	-	44	-	-	38	-	-	-	-	28	-	-	20	-	-
Buyer 4	-	-	-	42	40	-	-	-	-	-	-	26	22	-	-	-
Seller	0	2	4	6	8	10	12	14	16	18	20	22	26	28	30	-

In the competitive theoretic equilibrium, 12 units are traded at the market clearing price level of 24 experimental dollars[3]. The equilibrium quantity is evenly split between the buyers who purchase three units each. Equivalently, all market participants have both intra-marginal and extra-marginal units. In equilibrium trade, gains are completely exhausted, hence trading efficiency equals 100%. The induced demand and supply schedules are symmetric. Thus, in equilibrium the aggregate trade gains of 312 experimental dollars are equally divided between the seller and the buyer side of the market.

There are two relevant theoretical market power benchmarks in this experiment: The efficient first-order discrimination outcome and the inefficient single-price monopoly solution. In lieu of the chosen demand and supply parameters, first-degree price discrimination would imply prices in the range [48, 26]. The efficient trade gains - 312 experimental dollars - are accrued by the seller.

The price-quantity pair [32, 9] gives the single-price standard monopoly prediction. Hence, the monopoly price mark-up has been specified as eight experimental dollars. The monopoly profit is 216 experimental dollars, or 75% of the potential aggregate trade gains implied by the standard monopoly outcome. The quantity distortion is three units, 25% of the competitive equilibrium volume. This outcome yields an efficiency of 92%. A summary of the theoretical benchmarks is given in Table II.

***Table II.* Benchmarks**

	Price‡	Trading volume	Efficiency	Seller's relative trade gains
Competitive equilibrium	24	12	100%	50%
First-degree price discrimination	[48, 26]	12	100%	100%
Single-price monopoly outcome	32	9	92%	75%

‡ Denoted in experimental dollars.

[3] The midpoint in the equilibrium price tunnel [22, 26] has been deemed the competitive price prediction.

Six laboratory sessions were conducted, each of which consisted of 15 separate trading periods in the sense that no intertemporal carry-over between periods was allowed. Non-constant vertical shifts in the aggregate demand and supply were accomplished between all trading periods in each experimental session. The magnitude and direction of these shifts are relative to the basic configuration in Table I. Thus, the relative location of the buyers on the demand arrays did not change. Neither the magnitude nor the direction of the shifting demand and supply schedules were common knowledge, although each buyer (seller) was informed that his own demand (supply) schedule would shift between trading periods. A description of the shifts, by trading period, is given in Table III.

***Table III*. Constants added to the entries in Table I, by trading period**

Trading period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Amount added	0	6	24	15	36	33	18	9	30	39	42	27	45	12	21

These vertical shifts implied a variation in the competitive price level between 24 and 69 experimental dollars. The residual benchmarks (the single-price monopolistic mark-up, the feasible first-degree price discrimination range relative to the competitive price level, trading volume, efficiency and the seller's relative trade gains) as depicted in Table II were invariant with respect to the demand and supply shifts and remained constant across the 15 trading periods in each laboratory session.

The bid, double and offer auctions were tested within the described laboratory environment on computerized networks using experimental software downloaded from the University of Arizona, Tucson[4]. The double-auction rules allowed buyers (sellers) to post bids (asks) at any time during a trading period[5]. A bid (an ask) consisted of a price-quantity pair. An improvement rule required that new bids (asks) from any buyer (the seller) needed to specify higher (lower) prices in order to replace a former bid (ask) of his. This requirement was lexicographic in terms of affecting only the price and not the quantity element of a bid/an ask.

The highest bid and lowest ask, as well as queues of inferior asks and bids, were shown on all traders' computer screens. The seller (a buyer) might accept the best bid (ask) at all times before the end of the trading period. If the specified quantity was greater than one unit, sellers (buyers) had the option of accepting parts of a market bid (ask). In the event of a trader proposing or accepting a bid (ask)

[4] The applied software package is called ESLDA 1.43 and is accessible at http://www.econlab.arizona.edu.

[5] Asks and bids were required to be non-negative and strictly lower than 100 experimental dollars: The software generated error messages which were displayed on the computer screen if an experimental subject violated any of these constraints.

implying a negative profit, he was warned by the program and given an opportunity to alter his message. There was a continuously updated listing of contracts (stating agreed price and quantity) on all computer screens, as well as a clock showing seconds remaining of each trading period. Each buyer (seller) could also see his demand (supply) schedule and profits derived from transactions during the prevailing trading period.

The computerized one-sided auctions were similar to the described double-auction procedures except that the bid (offer) auction allowed buyers (the seller) only to announce bids (asks).

The experimental design is outlined in Table IV. The employed triple ABA crossover design implies that subjects participated in three sequences of trading, each of which consisted of five trading periods.

***Table IV*. Experimental design**

Session‡‡	Trading period			
	3 + 3	1 2 3 4 5	6 7 8 9 10	11 12 13 14 15
040400a	Practice	Offer auction	Double auction	Offer auction
040400b	Practice	Double auction	Offer auction	Double auction
040400c	Practice	Bid auction	Double auction	Bid auction
050400d	Practice	Double auction	Bid auction	Double auction
050400e	Practice	Bid auction	Offer auction	Bid auction
050400f	Practice	Offer auction	Bid auction	Offer auction

‡‡ Sessions 040400c and 050400f were briefly interrupted due to software failure at the start of trading period 3 and 8 respectively.

Each experimental session ran as follows. Upon arriving in the laboratory, subjects were randomly assigned a trader role as either a buyer or a seller, roles they retained throughout the session. They were then given instructions to read[6]. Afterwards they completed a self-paced interactive introduction to the utilized computer software and an unpaid training session lasting six trading periods. These practice sessions commenced with trading on the relevant one-sided auction and ended with three trading periods using double-auction rules. The training session also implemented shifts in demand and supply schedules between trading periods. No data from this part of the experiment were recorded. Lastly, subjects traded for fifteen periods and finally were paid their tax-free aggregate earnings in private at the conclusion of the session. The length of a trading period was three minutes and each laboratory session lasted approximately two hours.

[6] The appendix contains the experimental instructions.

The experimental subjects were 2nd - 5th year economics students at the University of Oslo. None of the participants had any previous experience with laboratory experiments. All subjects volunteered to participate following classroom announcements. The buyers received an average payoff of 24 US$, with max and min values equal to 35 US$ and 14 US$. The mean payoff earned by sellers equaled 36 US$ (max = 45 US$, min = 24 US$)[7].

3. Empirical modeling framework

Four empirical performance measures are used to organize the laboratory data: Mean error deviation in contract price from the competitive level, aggregate trading volume, efficiency and the seller's relative proportion of realized trade gains.

The adopted unit of observation is a single trading period and is constant across the different performance measures. Any observation of each performance measure is indexed relative to session i ($i \in \{1,2, .. , 6\}$) and trading period t ($t \in \{1,2, .. , 15\}$).

The following one-way fixed-effects panel data model will be used as a 'workhorse' to describe and analyze the variation in each of the outlined performance measures (Greene, 1997):

$$(1)\quad Y_{i,t} = \alpha_i + \beta_{S2} D_{i,t}^{S2} + \beta_{S3} D_{i,t}^{S3} + \beta_B D_{i,t}^{B} + \beta_O D_{i,t}^{O} + \left(\beta_{S-B} D_{i,t}^{B} + \beta_{S-D} D_{i,t}^{D} + \beta_{S-O} D_{i,t}^{O}\right) X_{i,t}^{Shift} + \varepsilon_{i,t}$$

First, consider the left-hand side of the equation. Since the model is applied to all performance measures, the dependent variable subsumes the following four variables:

[7] The subjects' aggregate profits denoted in experimental dollars were converted to, and paid in, Norwegian kroner (NOK). The employed conversion rate between experimental dollars and NOK was 0.3 (0.1) for buyers (sellers). The listed values in U.S. dollars are based on the US$/NOK exchange rate that prevailed at the time of the experiment (April 4th and 5th, 2000).

$$
(2) \quad Y_{i,t} = \begin{cases} MD_{i,t} = \dfrac{1}{Q_{i,t}} \displaystyle\sum_{q=1}^{Q_{i,t}} \left(P_{i,t}^{q} - P_{i,t}^{CE} \right) \equiv \text{mean deviation in contract price from the competitive level} \\ V_{i,t} = \displaystyle\sum_{q=1}^{Q_{i,t}} v_q \quad \equiv \text{trading volume} \\ E_{i,t} = \dfrac{\sum_{j=1}^{j=5} \Pi_{i,t}^{j}}{\sum_{j=1}^{j=5} \Pi_{i,t}^{j(CE)}} \cdot 100 \ \equiv \text{efficiency} \\ TG_{i,t} = \dfrac{\Pi_{i,t}^{Seller}}{\sum_{j=1}^{j=5} \Pi_{i,t}^{j}} \cdot 100 \ \equiv \text{seller's relative trade gains} \end{cases}
$$

In the definition of mean error deviation in contract price from the competitive level, Q denotes the total number of contracts in trading period (i,t); P^q is the q-th contract price and P^{CE} the relevant competitive equilibrium prediction. Trading volume (V) equals the aggregate number of units specified in contracts confirmed within any one trading period, with the number of units shifted in the q-th contract given by v_q. In the concept for efficiency E the expression Π^j measures the realized profits of trader (buyer or seller) j whereas $\Pi^{j(CE)}$ denotes the competitive equilibrium level of profit for trader j. The seller's relative trade gains (TG) are defined as the ratio between the seller's profit (Π^{Seller}) and the aggregate profits accrued by all five market participants in trading period (i,t).

Next consider the right-hand side of the equation. The session-specific constant terms are denoted α_i. The exogenous regressors D^{S2} and D^{S3} are binary variables that assume the value 1 during the second sequence (trading periods [6, 7, .. , 10]) and the third sequence (trading periods [11, 12, .. ,15]) of each laboratory session. D^B is a binary variable that takes the value 1 when bid-auction rules are implemented. Similarly, the binary variables D^D and D^O equal 1 whenever trading is governed by double-auction and offer-auction rules respectively. The variable X^{Shift} measures the numerical change in supply and demand schedules relative to the preceding trading period over the course of each laboratory session[8]. Lastly, ε(i,t) is a classical disturbance term with $E[\varepsilon(i,t)]=0$ and $Var[\varepsilon(i,t)]=\sigma^2(\varepsilon)$, $\forall i \ \forall t$.

[8] This variable has been constructed on the basis of the constants added to demand and supply between the trading periods listed in Table III. Thus, the mean value (standard deviation) is 1.40 (15.62) whereas the max (min) value of X^{Shift} is 21 (-33) experimental dollars.

The specification of individual constant terms means that differences between the experimental sessions (subject groups) are viewed as parametric shifts of the regression function. The coefficients β_{S2} and β_{S3} measure the (time) effect of sequences two and three relative to the first sequence of trading in the ABA crossover design.

In addition the model allows for two separate kinds of institutional effects. First, β_B and β_O measure the effect of auction rules on the level of the performance measure in question. Second, the estimates of the residual coefficients $\beta_{S\text{-}B}$, $\beta_{S\text{-}D}$ and $\beta_{S\text{-}O}$ quantify the auction specific effect of the shifting demand and supply schedules.

The subsequent section contains results from the estimated model in equation (1) using the different performance measures as dependent variables. In addition, the four parameter restrictions listed in Table V are tested in order to investigate the impact of subject, sequence and institutional effects on the mean of each performance measure. In each case the alternative hypothesis is the negation of the null hypothesis.

***Table V*. Empirical null hypotheses**

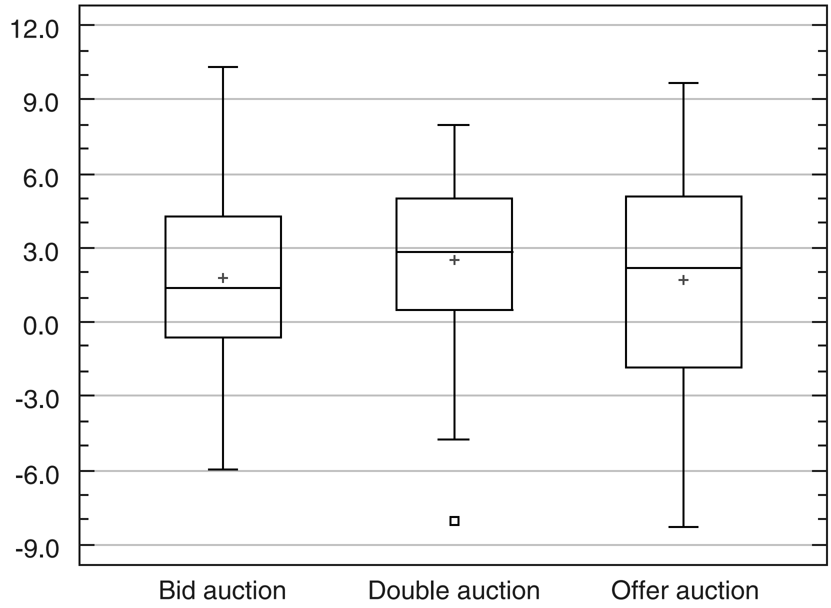
Analytical formulation:	Interpretation of null hypothesis:
$\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = \alpha_6$	No session effects
$\beta_{S2} = \beta_{S3} = 0$	No sequence effects
$\beta_B = \beta_O = 0$	No institutional differences in terms of level
$\beta_{S\text{-}B} = \beta_{S\text{-}D} = \beta_{S\text{-}O}$	No institutional differences in terms of adjustment to shifts

4. Experimental results

4.1. Mean price deviations

Pooling across all ninety trading periods from the six laboratory sessions, the median deviation of mean prices from the competitive level is 2.195 experimental dollars. The median price error in the bid, double and offer auction is 1.365, 2.855 and 2.155 experimental dollars, respectively. Since the experimental design induced an equilibrium price range of four experimental dollars, a deviation from the competitive level within ± 2 experimental dollars is consistent with the competitive equilibrium benchmark. For comparison, the mean price deviations predicted by single-price monopoly and perfect price discrimination are 8 and 13 experimental dollars. The box-and-whisker plot in Figure 2 shows the distribution of mean price deviations from equilibrium price levels from all trading periods stratified according to auction type.

***Figure 2.* (Mean price - competitive price) deviations, by auction type**



The rectangular part of the plot extends from the lower quartile to the upper quartile, covering the center half of the sample. The centerline within the box shows the location of the sample median. The plus sign indicates the location of the sample mean, whereas the whiskers extend from the minimum and maximum values in the sample, except for outside points. These are points that lie more than 1.5 times the interquartile range below the box and are shown as small squares. Each of the three auction samples contains 30 observations.

Table VI contains regression estimates for the model in equation (1) above, using mean error deviation in contract price from the competitive level as the dependent variable. The upper part of the table depicts the estimated session-specific constant terms, which vary in the interval [-2.059, 7.074] experimental dollars. At the bottom of the table the results from the restriction tests show the overall session effect to be highly statistically significant. The listed R^2 values further indicate that the session effects outweigh the residual effects in numerical terms.

The estimated sequence effects in the form of coefficients b_{S2} and b_{S3} show that mean prices deviate weakly less (more) from the competitive level during trading periods 6-10 (11-15). However, it is evident that the null hypotheses of no such time effects cannot be rejected (p-value=0.6411).

Table VI. **Estimated parameters for the model**

$$MD_{i,t} = \alpha_i + \beta_{S2} D_{i,t}^{S2} + \beta_{S3} D_{i,t}^{S3} + \beta_B D_{i,t}^{B} + \beta_O D_{i,t}^{O} + \left(\beta_{S-B} D_{i,t}^{B} + \beta_{S-D} D_{i,t}^{D} + \beta_{S-O} D_{i,t}^{O}\right) X_{i,t}^{Shift} + \varepsilon_{i,t}$$

1. Session effects						
Estimated coefficient	a_1	a_2	a_3	a_4	a_5	a_6
Estimate	-2.059	4.619	3.574	2.421	2.450	7.074
2. Sequence effects						
Estimated coefficient	b_{S2}	b_{S3}				
Estimate	-0.3925	0.2878				
P-value	0.5932	0.7030				
3. Auction type effects						
Estimated coefficient	b_B	b_O	b_{S-B}	b_{S-D}	b_{S-O}	
Estimate	-1.6872	-1.1032	-0.0869	-0.0675	-0.0068	
P-value	0.0595	0.2151	0.0130	0.0520	0.8410	

Number of observations:	90	Estimated autocorrelation of e:	0.21
Mean value of MD (experimental dollars):	2.01	Standard deviation of MD:	3.92
R^2:	0.57	R^2 (session effects only):	0.47

4. Tests of restrictions				
	Session effects	Sequence effects	Auction (level)	Auction (adjustment)
Null hypothesis	$\alpha_1=\alpha_2=\alpha_3=\alpha_4=\alpha_5=\alpha_6$	$\beta_{S2} = \beta_{S3} = 0$	$\beta_B = \beta_O = 0$	$\beta_{B-S} = \beta_{D-S} = \beta_{O-S}$
P-value	0.0000	0.6411	0.1591	0.2226

The estimated auction type effects reveal that mean price deviations from the competitive level are smaller under the one-sided auctions relative to the double auction. The point estimate of the bid (offer) auction relative to the double auction is -1.68 (-1.10) experimental dollars. However, these effects are not jointly statistically significant, although they are weakly so in the bid auction case (p=0.0595)[9].

The estimated values of coefficients b_{S-B} and b_{S-D} are both negative and individually significantly different from zero. Thus, the shifts in the demand/supply schedules induce a weak hysteresis effect in that bid- and double-auction mean prices do not completely adjust to the new equilibrium. However, the value of b_{S-O} cannot be ascertained to differ from zero, meaning that offer-auction mean prices are not markedly affected by shifting demand and supply. At the same time the restriction of equal adjustment factors across auction types cannot be discarded at conventional levels of significance (p=0.2226).

[9] The listed probability values are the values for two-tailed tests of the hypothesis that the coefficient equals zero.

Result 1:

The average deviation of mean prices from competitive levels is positive, but not to the extent predicted by either market power benchmark. When controlling for session, sequence and uncertain demand/supply effects, the regression results suggest the following ranking of mean prices: Double-auction prices > offer-auction prices > bid-auction prices. Therefore, prices in the one-sided auctions are comparatively closer to the competitive level than double-auction price levels. The data do not support statistically significant institutional differences between the bid, double and offer auctions.

4.2. Trading volume

The single-price monopoly benchmark predicts a trading volume equal to nine and hence a quantity restriction of three units below the competitive level of 12 units per trading period. The pooled median trading volume was 12. As depicted in Table VII, the median trading volume was the efficient 12 during offer auction trading and 11.5 units when bid- and offer-auction rules applied.

Table VII. **Summary statistics of trading volume, by auction type**

	Bid auction	Double auction	Offer auction
Mean	11.47	11.6	11.93
Median	11.5	11.5	12
Mode	12	11	12
Standard deviation	0.57	0.67	0.94
Maximum	12	13	13
Minimum	10	11	8
No. observations	30	30	30

The regression estimates listed in Table VIII facilitate a more detailed analysis of the variability in trading volumes. The estimated session-specific constant terms display a variation of more than one unit with the estimate of α_1 in fact exceeding the equilibrium level. The outcome of the restriction tests indicates that the null hypothesis of no session effects can be rejected.

Sequence effects are operative in a statistically significant manner (p=0.0261). The estimated coefficients b_{S2} and b_{S3} are both negative, meaning that, *ceteris paribus*, average trading volume declines during laboratory sessions. Nevertheless, the limited economic magnitudes of these effects do not suggest evidence of quantity withholding to the extent implied by the single-price monopoly prediction.

Table VIII. **Estimated parameters for the model**

$$V_{i,t} = \alpha_i + \beta_{S2} D_{i,t}^{S2} + \beta_{S3} D_{i,t}^{S3} + \beta_B D_{i,t}^{B} + \beta_O D_{i,t}^{O} + \left(\beta_{S-B} D_{i,t}^{B} + \beta_{S-D} D_{i,t}^{D} + \beta_{S-O} D_{i,t}^{O}\right) X_{i,t}^{Shift} + \varepsilon_{i,t}$$

1. Session effects						
Estimated coefficient	a_1	a_2	a_3	a_4	a_5	a_6
Estimate	12.64	11.62	11.90	11.55	11.57	11.71
2. Sequence effects						
Estimated coefficient	b_{S2}	b_{S3}				
Estimate	-0.4651	-0.2429				
P-value	0.0070	0.1637				
3. Auction type effects						
Estimated coefficient	b_B	b_O	b_{S-B}	b_{S-D}	b_{S-O}	
Estimate	0.0040	0.1793	-0.0026	0.0145	0.0039	
P-value	0.9843	0.3794	0.7342	0.0682	0.6128	

Number of observations:	90	Estimated autocorrelation of e:	0.045
Mean value of V (units):	11.67	Standard deviation of V:	0.76
R^2:	0.39	R^2 (session effects only):	0.28

4. Tests of restrictions	Session effects	Sequence effects	Auction (level)	Auction (adjustment)
Null hypothesis	$\alpha_1=\alpha_2=\alpha_3=\alpha_4=\alpha_5=\alpha_6$	$\beta_{S2} = \beta_{S3} = 0$	$\beta_B = \beta_O = 0$	$\beta_{B-S} = \beta_{D-S} = \beta_{O-S}$
P-value	0.0000	0.0261	0.6029	0.2906

The estimated auction-type effects that relate to trading volume levels (b_B and b_O) are economically minuscule and statistically insignificant. The residual estimates and restriction test of coefficients b_{S-B}, b_{S-D} and b_{S-O} reveal that demand and supply shifts neither affect observed trading volumes nor differ in this regard across auction types.

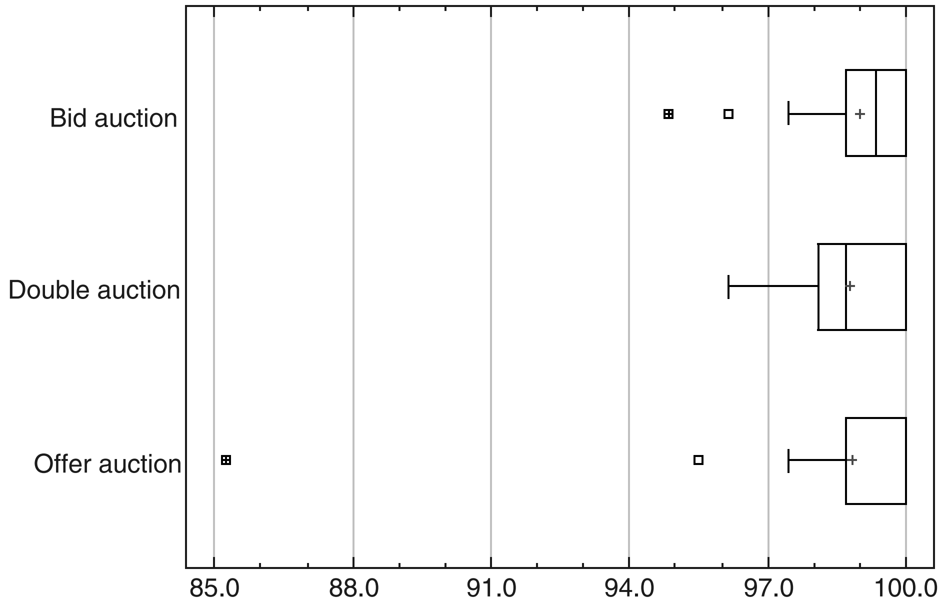
Result 2:
Mean bid-, double- and offer-auction trading volumes do not generally deviate from the competitive equilibrium benchmark in an economically important way. Simultaneously, trading volumes differ in a statistically significant manner both across and within laboratory sessions but are invariant with respect to changes in auction types.

4.3. Efficiency

The pooled median efficiency level is 98.72%. This corresponds to the double auction's median efficiency level, whereas the bid and offer auctions' median efficiencies are 99.36 and 100 percent. For comparison, the single-price monopoly benchmark is 92%.

Figure 3 provides horizontal box-and-whisker plots of efficiencies observed during bid-, double- and offer-auction trading. Again the centerline within the box depicts the sample median, whereas the plus sign corresponds to the sample mean. Far outside points are points that lie more than three times the interquartile range below the box and are shown as small squares with plus signs through them. In the case of the two single-sided auctions, there are two outside points and two far outside points.

***Figure 3*. Efficiency levels, by auction type**



The estimated regression coefficients and the hypothesis tests listed in Table IX reveal no statistically discernible session effects. The estimated sequence effects are weakly negative, although statistically insignificant.

The estimated auction type effects that relate to efficiency levels - b_B and b_O - are similarly small in value and neither individually nor jointly significant.

Lastly, the estimated values of b_{S-B}, b_{S-D} and b_{S-O} indicate that efficiencies are practically unaffected by the unpredictable demand and supply shifts.

Table IX. **Estimated parameters for the model**

$$E_{i,t} = \alpha_i + \beta_{S2} D_{i,t}^{S2} + \beta_{S3} D_{i,t}^{S3} + \beta_B D_{i,t}^{B} + \beta_O D_{i,t}^{O} + \left(\beta_{S-B} D_{i,t}^{B} + \beta_{S-D} D_{i,t}^{D} + \beta_{S-O} D_{i,t}^{O}\right) X_{i,t}^{Shift} + \varepsilon_{i,t}$$

1. Session effects						
Estimated coefficient	a_1	a_2	a_3	a_4	a_5	a_6
Estimate	99.16	99.24	99.61	98.54	98.68	99.59
2. Sequence effects						
Estimated coefficient	b_{S2}	b_{S3}				
Estimate	-0.5944	-0.1278				
P-value	0.2436	0.8065				
3. Auction type effects						
Estimated coefficient	b_B	b_O	b_{S-B}	b_{S-D}	b_{S-O}	
Estimate	0.1183	-0.1639	-0.0014	-0.0097	-0.0067	
P-value	0.8468	0.7889	0.9518	0.6813	0.7772	

Number of observations:	90	Estimated autocorrelation of e:	0.069
Mean value of E (percent):	98.87	Standard deviation of E:	1.85
R^2:	0.07	R^2 (session effects only):	0.046

4. Tests of restrictions				
	Session effects	Sequence effects	Auction (level)	Auction (adjustment)
Null hypothesis	$\alpha_1=\alpha_2=\alpha_3=\alpha_4=\alpha_5=\alpha_6$	$\beta_{S2} = \beta_{S3} = 0$	$\beta_B = \beta_O = 0$	$\beta_{B-S} = \beta_{D-S} = \beta_{O-S}$
P-value	0.5379	0.4604	0.8979	0.9679

Result 3:

Trading on the bid, double and offer auction is efficient and yields an almost complete exhaustion of the potential trade gains. The data reveal that the high efficiency levels are independent of session and sequence effects as well invariant with regard to changes in auction rules.

4.4. Seller's relative trade gains

Pooling across the laboratory sessions, the median value of the seller's relative trade gains is 57.53%. The median relative trade gains accrued by a seller during double auction trading is 60.36%. The corresponding values for the bid and offer auctions are 55.29% and 56.41%. Single-price monopoly and perfect price discrimination would have implied the seller accruing 75% and 100% of the available trade gains.

The empirical distributions of the seller's trade gains are depicted by auction type in Figure 4.

Figure 4. **Seller's relative trade gains, by auction type**

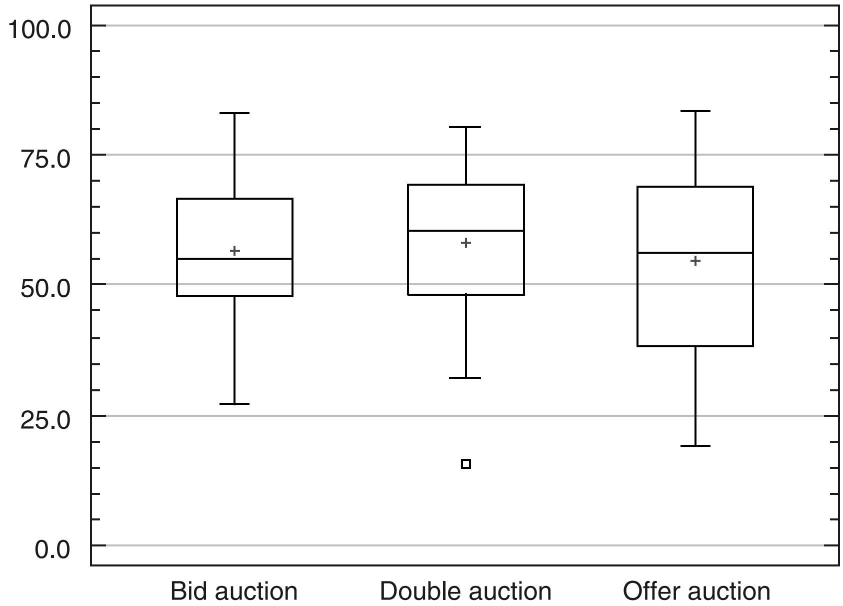


Table X reports the result of a regression analysis using the seller's relative trade gains as the dependent variable.

Consider first the session effects. Across the six sessions, estimated session-specific constant terms vary between 38.65% and 76.24%. However, in five sessions these terms are greater than 58%.

The hypothesis test reported at the bottom of the table indicates that the null hypothesis of no session effect of the mean of seller's relative trade gains can easily be rejected.

The estimated sequence effects depict two contrasting marginal effects. *Ceteris paribus*, the seller's proportion of realized trade gains decreases during trading periods 6-10, relative to the initial five trading periods. During the last five trading periods of a laboratory session this proportion increases and cancels out the former effect. Nevertheless, the restriction tests reveal these joint effects to be statistically insignificant (p=0.6791).

The point estimates of the auction effects in terms of level show that relative to double-auction rules, sellers obtain smaller relative trade gains during bid- and offer-auction trading; -6.32 and -4.06 percentage points respectively. This effect is weakly statistically significant in the bid auction case (p=0.063), even though the null hypothesis of no differences between the three auction types cannot be rejected (p= 0.1686).

***Table X.* Estimated parameters for the model**

$$TG_{i,t} = \alpha_i + \beta_{S2} D_{i,t}^{S2} + \beta_{S3} D_{i,t}^{S3} + \beta_B D_{i,t}^{B} + \beta_O D_{i,t}^{O} + \left(\beta_{S-B} D_{i,t}^{B} + \beta_{S-D} D_{i,t}^{D} + \beta_{S-O} D_{i,t}^{O}\right) X_{i,t}^{Shift} + \varepsilon_{i,t}$$

1. Session effects						
Estimated coefficient	a_1	a_2	a_3	a_4	a_5	a_6
Estimate	38.55	65.49	63.16	58.77	59.11	76.15
2. Sequence effects						
Estimated coefficient	b_{S2}	b_{S3}				
Estimate	-1.0823	1.3438				
P-value	0.6980	0.6394				
3. Auction type effects						
Estimated coefficient	b_B	b_O	b_{S-B}	b_{S-D}	b_{S-O}	
Estimate	-6.3179	-4.0607	-0.3175	-0.2874	-0.0753	
P-value	0.063	0.2295	0.0168	0.0299	0.5641	

Number of observations:	90	Estimated autocorrelation of e:	0.19
Mean value of TG (percent):	56.51	Standard deviation of TG:	15.45
R^2:	0.59	R^2 (session effects only):	0.51

4. Tests of restrictions	Session effects	Sequence effects	Auction (level)	Auction (adjustment)
Null hypothesis	$\alpha_1=\alpha_2=\alpha_3=\alpha_4=\alpha_5=\alpha_6$	$\beta_{S2} = \beta_{S3} = 0$	$\beta_B = \beta_O = 0$	$\beta_{B-S} = \beta_{D-S} = \beta_{O-S}$
P-value	0.0000	0.6791	0.1686	0.3507

The marginal effect of shifting demand/supply schedules is significantly different from zero during bid- and double-auction trading. In these cases a positive shift in demand/supply curves of one experimental dollar induces an approximate 0.3% decline in the seller's relative trade gains. No such effect is discernible in the case of the offer auction.

Result 4:

On average, the seller accrues 56% of generated trade gains, but this proportion varies extensively across sessions/subject groups. Controlling for session, sequence and uncertainty effects, the data imply the following ordering of the seller's relative trade gains: Double auction > offer auction > bid auction. Hence, the division of trade gains is comparatively more equitable under one-sided auction rules. These institutional differences are not statistically significant.

5. Discussion

The bid, double and offer auctions are similar in that trading is sequential and all trading contracts are displayed to the entire market. Simultaneously, the institutional variation between the sequential auctions implies a potential variation in transaction costs, that is, the cost or difficulty of searching for market information, identifying trading partners and agreeing upon terms of trade (see, e.g., Joyce 1983). Since messages from both sides of the market are permitted, the double auction may exhibit less transaction costs than either one-sided auction alternative. Nonetheless, the core result originating from this study is that the laboratory data do not support statistically significant bid-double-offer auction behavioral differences. Thus, market behavior is invariant with regard to which side of the market the ability to generate price quotes is restricted.

However, there is a weakly statistically significant difference between the bid and double auction in that the former generates lower mean prices and smaller relative trade gains accrued by the seller than the latter auction. Hence, in a single-seller case, the reported experiment indicates that buyers benefit from trading rules that prohibit the seller from actively initiating price quotes. Smith (1964) conjectured that competitive pressures amongst buyers would imply comparatively high bids and prices. The body of evidence presented in this paper suggests that buyers trading on a bid auction may succeed in tacit collusion against a seller to a degree that in fact dominates competitive pressure effects. Conversely, a single seller appears to gain from trading rules that facilitate maximum information flows - bids to buy and offers to sell - amongst the traders. Taken together, these observations suggest that the buyers' ability to tacitly collude is hampered when the seller engages in price negotiations by means of explicit signals to the market.

Disregarding the lack of statistical significance, the reported analysis of mean prices suggests that double-auction prices tend to be greater than offer-auction prices, which tend to be greater than bid-auction prices. This rank ordering is consistent with the result obtained by Walker and Williams in their initial set of experiments. It also corresponds to price behavior in the initial trading rounds of their second set of experiments. In all of their experiments the number of buyers and sellers was identical and shifts in demand and supply schedules coincided with shifts in auction rules. This laboratory investigation reproduces their ordering of sequential auction prices within an asymmetric market environment characterized by markedly stronger uncertainty.

Another finding is that the observed data are more closely aligned to the competitive theoretical equilibrium than to any of the two imperfect competition benchmarks. The seller extracts, on average, 56% of the generated trade gains, compared to the imperfect competition range of [75%, 100%]. Mean prices deviate positively from the competitive price range, but not to the extent predicted by the single-price monopoly solution or perfect price discrimination. Also, observed trading efficiencies approximate 100%. Equivalently, monopoly power is not exercised in the form of quantity withholding. Specifically, the bid and offer auctions both generate lower mean prices and a more equitable distribution of trade gains than trading under double auction rules. This is consistent with previous monopoly experiments reported in Smith (1981) who concluded that the offer auction outperformed the double auction in terms of yielding comparatively lower prices as well as higher efficiency. The present study extends Smith's result by showing that the bid auction compares favorably with the double and offer auctions in terms of restricting monopoly power. Nevertheless, an unexplored issue is whether the revealed ability to bargain effectively against a single seller during bid auction trading will extend to laboratory environments characterized by larger groups of actively involved buyers.

The reported data analysis discloses statistically significant subject group or session effects and indicates that these exert a stronger influence on the considered performance measures than alterations of institutional auction rules. Walker and Williams record similar findings whereas Smith (1964) was unable to detect significant interaction between a subject group variable and the trading institution variable. In this experiment subject, group effects were considerably poignant in terms of division of trade gains. Across sessions or subject groups mean relative seller's trade gains varied between 39% and 76%. The immediate interpretation is that subjects' bargaining strengths, as well as bargaining successes generally, differ and emerge in a particularly transparent manner in asymmetric market environments: The degree to which a single seller is "weak" or "strong" importantly shapes and affects the trading process (also see Ledyard et al., 1994). Such effects may decrease with the number of conducted laboratory sessions. However, a related topic is whether the behavior of a monopolist depends upon the manner in which this role is (perceived to be) assigned. Winning the right to be a monopolist through a fair competitive process, or purchasing it at an auction, might induce relatively increased aggressive behavior *vis-à-vis* buyers compared with the performance of single sellers, following an explicitly random assignment of trader roles.

Finally, this study provides evidence that reconfirms sequential trading institutions as being highly efficient. The median efficiency level in the offer-auction case - when just one of five traders may initiate trading contracts - is 100%. Thus, confining the ability to suggest terms of trade to a (single) seller is sufficient to yield efficient sequential trading processes. Pooling across the three auction types, the median efficiency level 98.72%. This is consistent with Walker and Williams' experiments in which they observed a median efficiency level of 99.08%. Also, the potential trade gains are exploited despite uncertainty in the form of shifting demand and supply schedules. Jamison and Plott (1997) report similar efficiency results (mean = 97.2%; median = 100%) for double-auction trading under unpredictable demand and supply conditions. The experimental results reported above indicate that the one-sided bid and offer auctions exhibit similar efficiency characteristics under uncertainty, even within an asymmetric market environment.

6. Conclusion

The bid, double and offer auctions constitute sequential trading institutions that differ with regard to the market participants' message spaces. The bid and offer auctions are one-sided and restrict the possibility of generating price quotes to the buyer and seller sides respectively. The double auction combines the one-sided auctions and permits all market participants to suggest and confirm prices.

The reported study has investigated the extent to which these institutional differences transform into behavioral dissimilarities in a monopolized laboratory environment characterized by non-stationary demand and supply schedules. The key result is negative in as much as the laboratory data fail to support statistically significant bid-double-offer auction behavioral variations. However, the results reveal economic differences in that mean prices and seller's relative trade gains are lower in the one-sided auctions compared with the double auction.

In this experiment the considered sequential auctions were exogenously superimposed upon simplified computerized markets in order to facilitate a clean institutional comparison. One extension of the reported research could be to investigate institutional competition amongst the bid, double and offer auctions. This issue could be analyzed as a game in which traders participate in referenda in which they cast votes for their preferred institutional alternative(s) and subsequently trade on the collectively chosen trading institution. An alternative approach is to study a coordination game in which the three auctions compete across consecutive rounds in terms of attracting the population of traders and thereby emerge as a convention. These avenues are left for further research.

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Experimental instructions

A.1. General

You are about to participate in an experiment where you will have an opportunity to earn money. The experiment is estimated to last approximately 2 hours. The money that you earn is tax-free and will be paid to you in cash immediately after the conclusion of the experiment. The size of the payment depends upon the decisions you make during the experiment.

Professor Wilhelm Keilhau's Memorial Fund has provided funding for this experiment.

The plan for the experiment is as follows:

1. First, read these instructions carefully. If you have any queries, please be so kind as to raise your hand and the experimenter will assist you. *You are not allowed to speak to any of the other participants during this experiment.*

2. When everyone has finished reading, you will take part in 2 test runs and practice your role as a market participant. These tests include an interactive introduction to the computer program that is used to conduct the experiment. No profits are earned during these test runs.

3. After the 2 test runs you will participate in 3 experimental markets. Your final payment equals the sum of your profits in these 3 markets.

Specific instructions for sellers:

A.2. Your trading role

In this experiment you are going to be a seller of a fictitious good on a computerized market.

Apart from you there are 4 buyers on this market.

Your supply curve for this good is shown numerically on your computer screen.

Example

A discrete supply curve for 4 units of the good may look like this (but will assume different values during the experiment):

11
22
33
44

If you sell 2 units of the good at a price equal to 30 per unit, your profit in this example becomes (30 - 11) + (30 - 22) = 27.

Exercise 1: What is your profit if you sell the first unit for a price equal to 51, the second unit for 42 and the third unit for the price 35?

Exercise 2: What is your profit if you sell the 4 units at the constant unit price 50?

All the experimental markets (1, 2 and 3) consist of a series of trading periods. Note that your supply curve will shift between each of these trading periods.

A.3. Trading rules (session 040400a)

The rules that govern trading are going to vary between the 3 experimental markets:

- In **markets 1 and 3** sales of the good occur if a buyer chooses to accept an offer of yours to sell. You formulate such an offer (an ask) by specifying both price per unit and the number of units offered (quantity). A sale occurs if a buyer accepts (parts of) your ask.

- In **market 2** you may still sell when a buyer accepts your ask. However, in addition the buyers can themselves formulate bids to buy in which they specify price per unit as well as the number of wanted units (quantity). Now a sale can take place if you choose to accept (parts of) such a bid.

You will practice both sets of trading rules in the 2 test runs prior to the experiment.

A.3. Trading rules (session 040400b)

<u>The rules that govern trading are going to vary between the 3 experimental markets:</u>

- In **markets 1 and 3** you can sell units of the good in two ways. First, sales of the good occur if a buyer chooses to accept an offer of yours to sell. You formulate such an offer (an ask) by specifying both price per unit and the number of units offered (quantity). A sale occurs if a buyer accepts (parts of) your ask. Second, in addition the buyers can themselves formulate bids to buy in which they specify price per unit as well as the number of wanted units (quantity). Now a sale can take place if you choose to accept (parts of) such a bid.

- In **market 2** you are only permitted to sell when a buyer accepts (parts of) your ask.

You will practice both sets of trading rules in the 2 test runs prior to the experiment.

A.3. Trading rules (session 040400c)

<u>The rules that govern trading are going to vary between the 3 experimental markets:</u>

- In **markets 1 and 3** sales of the good occur if you choose to accept a bid to buy from a buyer. Such a bid specifies both price per unit and the number of wanted units (quantity). A sale occurs if you accept (parts of) a buyer's bid.

- In **market 2** you may still sell by accepting a bid. However, in addition you can formulate offers to sell (asks) in which you specify price per unit as well as the number of offered units (quantity). Now a sale can take place if a buyer chooses to accept (parts of) your ask.

You will practice both sets of trading rules in the 2 test runs prior to the experiment.

A.3. Trading rules (session 050400d)

<u>The rules that govern trading are going to vary between the 3 experimental markets:</u>

- In **markets 1 and 3** you can sell units of the good in two ways. First, sales of the good occur if a buyer chooses to accept an offer of yours to sell. You formulate such an offer (an ask) by specifying both price per unit and the number of units offered (quantity). A sale occurs if a buyer accepts (parts of) your ask. Second, in addition the buyers can themselves formulate bids to buy in which they specify price per unit as well as the number of wanted units (quantity). Now a sale can take place if you choose to accept (parts of) such a bid.

- In **market 2** you are only permitted to sell by accepting (parts of) a bid from a buyer.

You will practice both sets of trading rules in the 2 test runs prior to the experiment.

A.3. Trading rules (session 050400e)

<u>The rules that govern trading are going to vary between the 3 experimental markets:</u>

- In **markets 1 and 3** sales of the good occur if you choose to accept a bid to buy from a buyer. Such a bid specifies both price per unit and the number of wanted units (quantity). A sale occurs if you accept (parts of) a buyer's bid.

- In **market 2** you can formulate offers to sell (asks) in which you specify price per unit as well as the number of offered units (quantity). Now a sale can take place if a buyer chooses to accept (parts of) your ask.

You will practice both sets of trading rules in the 2 test runs prior to the experiment.

A.3. Trading rules (session 050400f)

<u>The rules that govern trading are going to vary between the 3 experimental markets:</u>

- In **markets 1 and 3** sales of the good occur if a buyer chooses to accept an offer of yours to sell. You formulate such an offer (an ask) by specifying both price per unit and the number of units offered (quantity). A sale occurs if a buyer accepts (parts of) your ask.

- In **market 2** the buyers can themselves formulate bids to buy in which they specify price per unit as well as the number of wanted units (quantity). Now a sale can take place if you choose to accept (parts of) such a bid.

You will practice both sets of trading rules in the 2 test runs prior to the experiment.

A.4. Profit and payment

All transactions in the 3 experimental markets will be nominated in experimental dollars. Your profit in experimental dollars is automatically calculated by your computer and updated after each trading period. At the conclusion of the experiment the aggregated profit is converted to Norwegian kroner and paid to you in cash by the experimenter.

In your case the conversion factor between experimental dollars and Norwegian kroner equals 0.1. I.e., 100 experimental dollars equals 10 Norwegian kroner.

Specific instructions for buyers:

A.2. Your trading role

In this experiment you are going to be a buyer of a fictitious good on a computerized market.

Apart from you there are 3 buyers and 1 seller on this market.

Your demand curve for this good is shown numerically on your computer screen.

Example

A discrete demand curve for 4 units of the good may look like this (but will assume different values during the experiment):

55
44
33
22

If you buy 2 units of the good for a price equal to 20 per unit, your profit in this example becomes (55 - 20) + (44 - 20) = 59.

Exercise 1: What is your profit if you buy the first unit for a price equal to 30, the second unit for 14 and the third unit for the price 13?

Exercise 2: What is your profit if you buy the 4 units at the constant unit price 10?

All the experimental markets (1, 2 and 3) consist of a series of trading periods. Note that your demand curve will shift between each of these trading periods.

A.3. Trading rules (session 040400a)

The rules that govern trading are going to vary between the 3 experimental markets:

- In **markets 1 and 3** the seller can formulate an offer to sell (an ask). Every offer to sell specifies both price per unit and the number of offered units (quantity). A purchase of the good occurs if you choose to accept (parts of) the seller's offer.

- In **market 2** you may still buy units of the good by accepting the seller's ask. However, in addition you are now allowed to formulate bids to buy in which you have to specify price per unit as well as the number of wanted units (quantity). Then a purchase can take place if the seller chooses to accept (parts of) such a bid.

You will practice both sets of trading rules in the 2 test runs prior to the experiment.

A.3. Trading rules (session 040400b)

The rules that govern sales of the good are going to vary between the 3 experimental markets:

- In **markets 1 and 3** you can buy units of the good in two ways. First, the seller can formulate an offer to sell (an ask). Every offer to sell specifies both price per unit and the number of offered units (quantity). A purchase of the good occurs if you choose to accept (parts of) the seller's offer. Second, you are allowed to formulate bids to buy in which you have to specify price per unit as well as the number of wanted units (quantity). Then a purchase can take place if the seller chooses to accept (parts of) such a bid.

- In **market 2** you are only permitted to buy units of the good by accepting (parts of) the seller's ask.

You will practice both sets of trading rules in the 2 test runs prior to the experiment.

A.3. Trading rules (session 040400c)

The rules that govern trading are going to vary between the 3 experimental markets:

- In **markets 1 and 3** you can formulate bids to buy. Every bid specifies both price per unit and the number of wanted units (quantity). A purchase of the good occurs if the seller chooses to accept (parts of) your bid.

- In **market 2** you may still buy units of the good if the seller accepts (parts of) your bid. However, in addition the seller is now allowed to formulate offers to sell (asks). An ask specifies price per unit as well as the number of offered units (quantity). Then a purchase can take place if you choose to accept (parts of) such an ask.

You will practice both sets of trading rules in the 2 test runs prior to the experiment.

A.3. Trading rules (session 050400d)

The rules that govern sales of the good are going to vary between the 3 experimental markets:

- In **markets 1 and 3** you can buy units of the good in two ways. First, the seller can formulate an offer to sell (an ask). Every offer to sell specifies both price per unit and the number of offered units (quantity). A purchase of the good occurs if you choose to accept (parts of) the seller's offer. Second, you are allowed to formulate bids to buy in which you have to specify price per unit as well as the number of wanted units (quantity). Then a purchase can take place if the seller chooses to accept (parts of) such a bid.

- In **market 2** you can only purchase units of the good if the seller chooses to accept (parts of) your bid.

You will practice both sets of trading rules in the 2 test runs prior to the experiment.

A.3. Trading rules (session 050400e)

The rules that govern trading are going to vary between the 3 experimental markets:

- In **markets 1 and 3** you can formulate bids to buy. Every bid specifies both price per unit and the number of wanted units (quantity). A purchase of the good occurs if the seller chooses to accept (parts of) your bid.

- In **market 2** the seller is allowed to formulate offers to sell (asks). An ask specifies price per unit as well as the number of offered units (quantity). Then a purchase can take place if you choose to accept (parts of) such an ask.

You will practice both sets of trading rules in the 2 test runs prior to the experiment.

A.3. Trading rules (session 050400f)

The rules that govern trading are going to vary between the 3 experimental markets:

- In **markets 1 and 3** the seller can formulate an offer to sell (an ask). Every offer to sell specifies both price per unit and the number of offered units (quantity). A purchase of the good occurs if you choose to accept (parts of) the seller's offer.

- In **market 2** you may formulate bids to buy in which you have to specify price per unit as well as the number of wanted units (quantity). Then a purchase can take place if the seller chooses to accept (parts of) such a bid.

You will practice both sets of trading rules in the 2 test runs prior to the experiment.

A.4. Profit and payment

All transactions in the 3 experimental markets will be nominated in experimental dollars. Your profit in experimental dollars is automatically calculated by your computer and updated after each trading period. At the conclusion of the experiment the aggregated profit is converted to Norwegian kroner and paid to you in cash by the experimenter.

In your case the conversion factor between experimental dollars and Norwegian kroner equals 0.3. I.e., 100 experimental dollars equals 30 Norwegian kroner.