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Morten Søberg

Imperfect competition, sequential auctions, and emissions trading: An experimental evaluation

Abstract:
This paper reports an experiment that studies the behavior of a monopolist on sequential auction markets for tradable permits. Using six sessions in a triple ABA crossover design, we investigate the cost-effectiveness of permit allocations and the division of trade gains on sequential bid, offer, and double auction markets. The main result is that cost-effectiveness and supra-competitive profits accrued by the monopolist are observed on all the three auction markets.

Keywords: Market power, tradable permits, and experimental economics.

JEL classification: L12, Q25, and C91.

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Address: Morten Søberg, Statistics Norway, Research Department, P.O. Box 8131 Dep., N-0033 Oslo, Norway. (E-mail: morten.soberg@ssb.no)

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Statistics Norway
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Telephone: +47 62 88 55 00
Telefax: +47 62 88 55 95
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1. Introduction

During the last decade tradable emission permits as a supplement to command-and-control standards have moved to the center stage of market-based environmental policy. An illustrative body of evidence is the tradable SO_2 permit scheme that was initiated by the 1990 Clean Air Act Amendments as well as Southern California's Regional Clean Air Incentives Market (RECLAIM) program[1]. "Grandfathering" is an important feature of this policy shift in as much as regulated emissions sources are allotted permits free of charge on the basis of historic emissions levels[2]. Allowing allocated permits to be traded retains the certainty of pollution levels implied by the command-and-control approach, but increases the probability that emissions are allocated in a cost-effective manner. The theoretical rationale is that permit trading is presumed to equalize firms' marginal control costs. This result is independent of the initial allocation of permits (Montgomery 1972).

However, a sizeable literature has emerged that identifies factors that can impair the stated theoretical properties of tradable permits, e.g., transaction costs and imperfect competition in the permit market[3]. The main source of transaction costs stems from lack of information, the implication of which may be costly search and bargaining processes (Dahlman 1979). The potential for strategic price behavior and trading inefficiencies is positively correlated with the divergence between firms' initial permit allotments and their cost-effective permit holdings (Hahn 1984, Tietenberg 1985). In theory, both phenomena may hamper cost-effectiveness and render equilibrium emissions allocations sensitive to initial permit allotments. The exertion of market power by one or more firms also implies inequity in the form of supra-competitive profits. If corroborated in practice, such market imperfections can reduce the political feasibility of tradable permit schemes.

The theoretical models of imperfect competition in permit markets are void of specifications of the institutional context within which permit trading occurs. Whereas the models assume that trading occurs simultaneously at a singular equilibrium price, actual trades in US emissions trading programs usually are sequential and conducted at non-uniform prices (Schmalensee et al. 1998 and Tietenberg 1990). Moreover, trading institutions affect transaction costs in that they specify the rules governing exchange, including information flows between market participants (Cason and Gangadharan 1998).

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[1] Confer http://www.epa.gov/acidrain and http://www.aqmd.gov.

[2] The alternative approach is to auction tradable permits. This may facilitate efficiency gains relative to a gratis allocation if the collected revenue can be used to replace existing distortionary taxes (Stavins 1998).

[3] An extensive bibliography of the literature is available at http:\\www.colby.edu/personal/thtieten.

The objective of the present study is to illuminate the interaction between imperfect competition, transaction costs, and trading institutions for tradable permits. In general, small-scale experiments can be useful for inducing empirical 'stylized facts' describing how market behavior is shaped by differing institutional contexts[4]. This paper reports such an experiment.

The analyzed market is characterized by monopolistic permit supply, and is constant across the considered trading institutions. One interpretation of such a market is that exactly one firm - or a perfect coalition of firms - has been allotted permits in excess of its cost-effective holdings. This firm then commands the net market supply of permits, whereas firms with permit allotments below their cost-effective volumes make up the net permit demand[5].

A trading institution specifies the rules that are to govern trading. Such rules define the market participant's admissible messages (e.g., a message could be a bid to buy, an offer to sell, or an acceptance), the information available to the market of such messages as well as rules for the conversion of messages into contracts and allocations of resources (Friedman 1993 and Smith 1982).

In this paper three trading institutions are compared, to wit, one-sided offer and bid auctions as well as the double auction. An offer auction allows only the seller to post offers to sell. In addition all asks are common knowledge. Trading is conditional upon such an offer being accepted by a buyer. Conversely, the bid auction enables the buyers to submit bids to buy. The bids are displayed to all market participants. If the seller chooses to accept a bid, a trade is executed. The double auction is a combination of the offer and bid auction that allows both the seller and the buyers to propose and accept terms of trade (Davis and Holt 1993).

Each of the three auction types allows for sequential trading, that is, the market participants negotiate terms of trade and confirm contracts on continuous as opposed to sealed-bid auctions. This aspect of the considered trading institutions mirrors the presumption that firms trade permits in real time, typically during the period between the permit allotment and the date when firms need to possess permit holdings that at least correspond to their recorded emissions.

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[4] Confer Friedman and Sunder (1994) for a discussion on the use and validity of experiments in economics, and Bjornstad et al. (1999) for a case study of the policy relevance of emissions trading experiments.

[5] An alternative interpretation is a situation in which a coalition of firms with grandfathered permits represent the permit supply whereas potential entrants into the regulated industry constitute the demand for permits.

The linkage between the sequential auction types and transaction costs is an empirical matter. The auctions are similar in that all trading contracts are displayed to the entire market. Also, no direct, financial costs of trading occur[6]. Simultaneously, the institutional variation between the sequential auctions implies a potential variation in transaction costs, particularly the cost or difficulty of searching for market information (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. Nevertheless, any differences between the auction types in terms of size as well as accuracy of information flows are determined endogenously by the market participants.

In sum, this study seeks, first, to gauge the impact of imperfect competition on emissions trading under each of the alternative auction types and, second, to investigate whether there are significant differences between the auctions in this regard. Three performance measures are invoked to facilitate this discussion. First, the accuracy and volatility of permit prices, i.e., the extent to which observed prices reflect the optimal marginal control cost in the industry affected by the tradable permit scheme. Second, trading volume and efficiency: How much of the difference between the initial and the cost-effective permit allocation trading succeeds in abolishing. Third, the division of trade gains: The degree to which the seller manages to transform her permit allotment into supra-competitive profits.

1.1. Relation to previous experimental literature

The reported laboratory experiment is related to at least two strands of the experimental economics literature, namely analysis of one-sided versus double auctions, and experimental tests of market power within the context of emissions trading. Elements of these are outlined below.

Smith (1964) conducted the original experimental evaluation of the bid, offer, and double auction trading institutions. Using a competitive environment with an equal number of buyers and sellers, he 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.

Walker and Williams (1988) examined the robustness of Smith's results. However, their data appear to suggest a different rank ordering of mean prices where double auction prices are greater than offer auction prices which tend to be greater than bid auction prices. The authors note that their subjects' behavior vary in a manner that is seemingly unrelated to the trading rules.

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[6] See Stavins (1995) for a theoretical analysis.

Furthermore, a de facto research program has emerged that evaluate the effects of market power on emissions trading markets[7]. Ledyard and Szakaly-Moore (1994) provide an example of institutional comparison. They evaluated a double auction and a Hahn and Noll Revenue Neutral Auction (RNA) under monopoly and competitive market conditions. Both institutions exhibit high efficiencies under competitive conditions. In the monopoly case prices and quantities in the Hahn and Noll RNA converge to (standard, single price) monopoly predictions, whereas the double auction results are inconclusive. One of the three experimental sessions converges towards the monopoly outcome, another converges to the competitive solutions, while prices and quantities in the third are between the monopoly and competitive benchmarks. Again the obtained results are sensitive with regard to who acted as the monopolist in these sessions.

A cluster of papers in this research program focuses on whether the double auction institution is robust vis-à-vis monopolistic or monopsonistic manipulation (see, e.g., Godby 1999). A recent example is Muller et al. (1999). Noticeably, unlike all previous experiments this test employs a within-subjects design that allows for a more precise control for subject effects than is possible in a between-subjects design. Thus, in any one session subjects participated in both a market power and a competitive environment. The principal result is that market power outcomes are frequently observed and that monopolists are more effective than monoposonists in exerting market power. However, widespread price discrimination implies that trading efficiency is not hampered, whereas income distribution effects emerge as the most important consequence of imperfect competition.

The present study seeks to add to the literature on sequential one-sided versus double auctions, and can be interpreted as a stress test of these institutions in an asymmetric market environment with one seller only. Furthermore, it extends the experimental economics literature on market power and emissions trading in as much as one-sided sequential auctions have hitherto not been contrasted with the double auction. Lastly, in line with the Muller et al. (ibid.), the reported experimental design controls for subject effects by invoking a between-subjects design: In each of the six conducted laboratory sessions, subjects participated in two of the considered trading institutions. This allows for a powerful comparison of the considered sequential auctions.

The remainder of paper is organized in three sections. Section 2 presents the experimental design and procedures. The observed results are reported in Section 3. Concluding remarks as well as suggestions for further research are given in the last section.

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[7] Godby, Muller, and Mestelman (1999) provide a comprehensive survey of this literature.

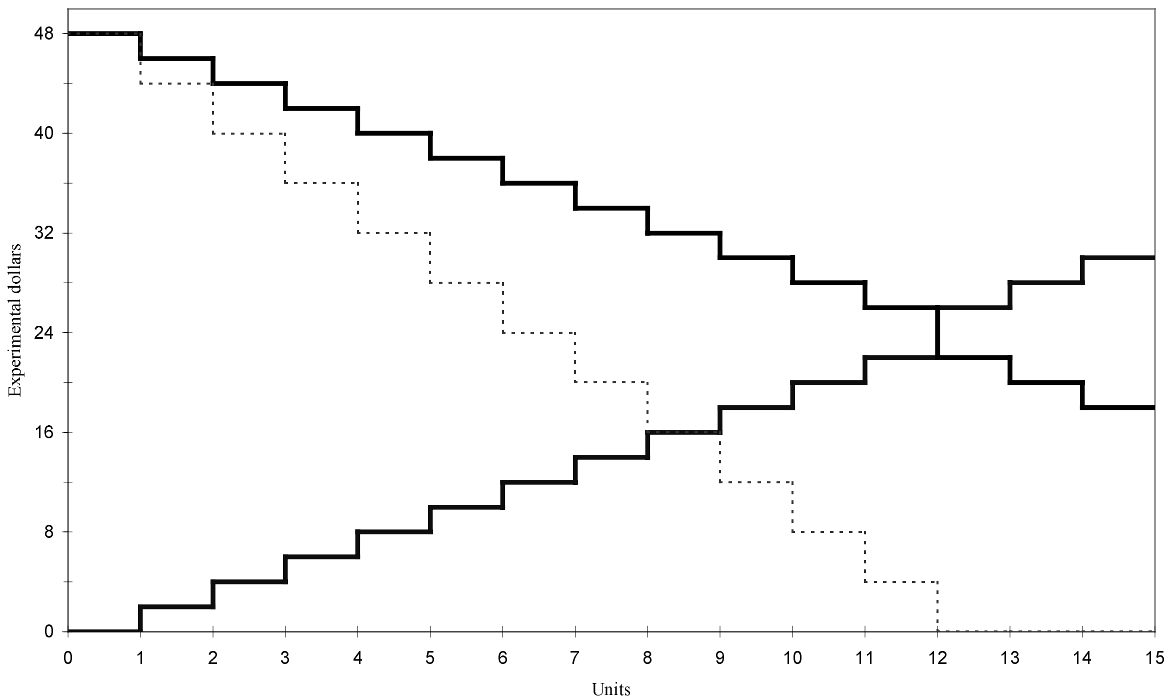
2. Experimental design and procedures

Table I and Figure 1 provide a numerical and a graphical depiction of the basic configuration of the experiment's aggregate permit demand and supply[8]. Four buyers constituted the demand side of the market. The market participants' trading roles were predetermined as either buyers or seller. By implication, speculation (the option of repurchase and resale) was disallowed.

***Table I.* Permit 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	-

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



[8] Permit demand and supply are depicted *as if* relative to a grandfathered allocation of permits.

The cost-effective allocation corresponds to the competitive equilibrium. In this case the market-clearing price and traded quantity pair equals 24 experimental dollars and 12 permits[9]. The equilibrium quantity is evenly split between the buyers who purchase 3 permits each. Moreover, in equilibrium trade gains are exhausted, whence trading efficiency equals 100%[10]. The demand and supply schedules are symmetric. Thus, evaluated at the market-clearing permit price, the aggregate trade gains of 312 experimental dollars are equally divided between the monopolist and the four buyers.

Each of the three considered institutions allows for sequential trading where each trading contract is binding. Thence, in contrast to theoretical analyses of monopolistic market power, the seller is not restricted to conducting permit trades at a single price. Equivalently, first-degree price discrimination becomes a feasible option, the implication of which is both a cost-effective emissions allocation and the monopolist's realization of the aggregate potential trade gains.

The two theoretical market power benchmarks in this experiment are as follows. First-degree price discrimination would imply prices in the range [48, 24], the equilibrium quantity of 12 permits and monopolistic trade gains equal to 312 experimental dollars.

The price-quantity pair [32, 9] gives the single-price standard monopoly prediction. Hence, the monopoly price mark-up has been specified as 8 experimental dollars. The implied monopoly profit is 216 experimental dollars, an increase of 38.5% relative to competitive level of 156 dollars. The quantity distortion is 3 permits, or 25% of the competitive equilibrium volume. The implied trading efficiency is 92%. Table II gives a summary of the theoretical benchmarks.

Table II. **Benchmarks**

	Permit price‡	*Trading volume*	*Efficiency*	*Seller's trade gains*‡
Initial allocation	-	0	0%	0
Cost-effective allocation	24	12	100%	156
Standard monopoly prediction	32	9	92%	216
First-degree price discrimination	[48, 24]	12	100%	312

‡ Denoted in experimental dollars.

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

[10] A cost-effective allocation of permits obtains when all regulated firms' marginal abatement costs equal the equilibrium permit price. Such an allocation is not necessarily efficient in the sense corresponding to a level of pollution determined by a cost-benefit comparison. However, in this paper efficiency refers to realization of trade gains.

A total of six experimental sessions was conducted, each of which consisted of 15 separate trading periods. Alternatively, no intertemporal carry-over between periods was allowed[11].

Non-constant vertical shifts in the aggregate permit 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 permit demand arrays did not change. 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**

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

The accomplished vertical shifts implied a variation of the competitive permit price between 24 and 69 experimental dollars. The monopolistic mark-up remained constant at 8 experimental dollars each period. Similarly, the feasible first-degree price discrimination range with a maximum value at 24 experimental dollars above the competitive level was invariant as well. Lastly, the trading volume and seller's profits benchmarks as depicted in Table II were constant across the 15 trading periods.

Neither the magnitude nor the direction of the shifting demand and supply schedules were common knowledge, although the experimental subjects were informed that their own demand/supply schedule would shift between trading periods. Thus, relative to the conventional stationary replication approach, this experimental set-up yields new observations of prices and quantities each period[12].

The design of the reported experimental sessions is outlined in Table IV[13]. The invoked triple ABA crossover design implies that subjects participate in trading under two different auction rules in any one session (also see Friedman and Sunder 1994). However, their (randomly) assigned trader roles did not change across the auction alternatives.

In all sessions a single trading period lasted 3 minutes. The practice section involved an interactive introduction to the utilized computer software as well as unpaid trading over 6 trading periods evenly

[11] Equivalently, permit trading is analyzed within a static framework, and the issue of banking is disregarded.

[12] Jamison and Plott (1997) adopted a similar design. However, while their paper addresses the convergence properties of the double auction in a constantly shifting and unpredictable setting, this study is not concerned with the shifting schedule itself.

[13] The sessions were conducted on April 4th and 5th 2000 at Statistics Norway, Oslo.

split between the relevant one-sided auction and the double auction[14]. Including a digestion of the written instructions, each laboratory session lasted approximately 2 hours[15].

Table IV. **Experimental design**

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

Under the double auction buyers (sellers) were free to post bids (asks) at any time during a trading period, but the market would accept bids (ask) specifying higher (lower) prices only. A bid (ask) consists of a price-quantity pair. The current bids and asks as well as a queue of below market bids was shown to all traders who might accept the market ask or bid at all times before the end of the trading period. In the event of a trader proposing or accepting a bid (ask) implying negative profit, she was warned by the program and given an opportunity to alter her message. On each buyer's (seller's) computer screen there was a record sheet updating her profit across trading periods as well as her permit demand (supply).

The one-sided auctions differed from the double auction in that the bid (offer) auction only allowed buyers (the seller) to announce bids (asks). Each auction alternative allowed for multiple-unit trading. Hence, traders had the option to accept parts of a market bid or ask.

The experimental subjects were 2nd - 5th year economics students at the University of Oslo, none of whom had any previous experience with laboratory experiments. All subjects volunteered to participate following classroom announcements.

[14] The software in question - ESLDA 1.43 - was downloaded from The Experimental Science Laboratory at the University of Arizona, Tucson at http://www.econlab.arizona.edu.

[15] Confer the appendix for an example of the experimental instructions.

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$, min = 24 US$). The payoffs were tax-free and paid privately in cash immediately after the conclusion of each session.

3. Experimental results

The results are reported in three subsections. The first focuses on the cost-effectiveness; the degree to which permit prices reflect the true marginal abatement cost in the market as well as the volume and efficiency of permit trading. The second subsection discusses the equity aspect of tradable permits with reference to the seller's trade gains, whereas the third contains a Borda ranking of the evaluated auctions.

The six laboratory sessions consisted of 15 trading periods each (confer Table IV). Hence, two observations per trading period for each auction type was recorded for each performance measure. In order to minimize the impact of subject effects, the observational unit chosen for analysis below is the mean value of these two observations. By implication, the reported experimental results are based on data samples that consist of 45 observations, 15 for each of the three auction types.

3.1. Cost-effectiveness

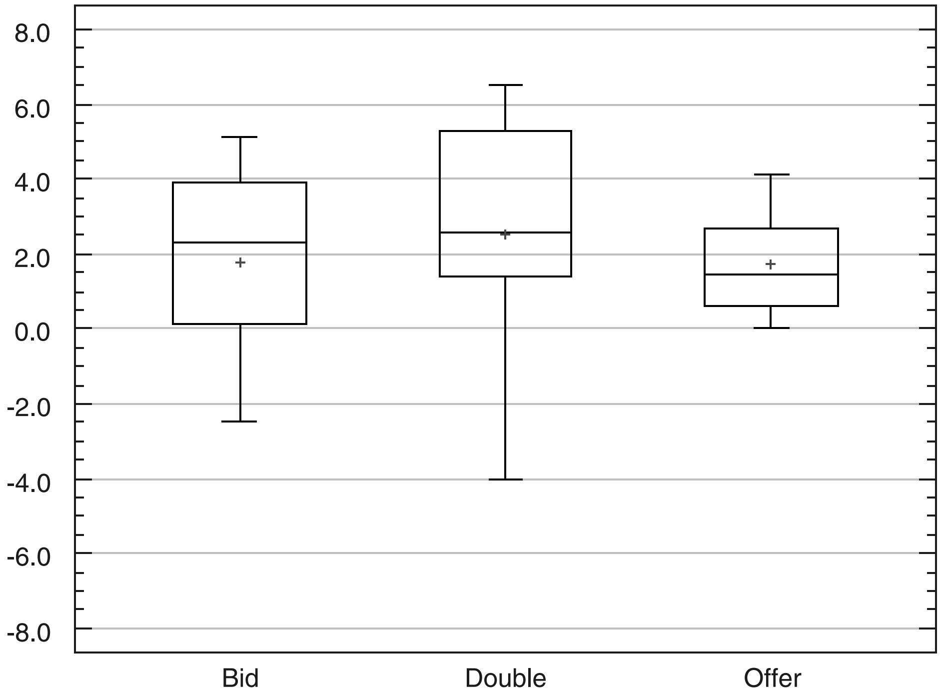
3.1.1. Accuracy of permit prices

Pooling across the six laboratory sessions, the median deviation of mean prices from the competitive level is 1.93 experimental dollars. This observed deviation is considerably below the single-price monopoly prediction of 8 dollars.

The box-and-whisker plot depicted in Figure 2 shows the distribution of mean permit prices relative to equilibrium prices across the three auction types.

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.

***Figure 2.* (Mean price - competitive price) deviations**



The median price mark-up in the bid, double, and offer auction is 2.38, 2.73, and 1.31 experimental dollars, respectively[16]. However, a non-parametric Friedman rank sum test fails to reject the null hypothesis of equal medians (p-value = 0.627) (Hollander and Wolfe 1999).

3.1.2. Permit price volatility

Table V presents summary statistics of the coefficient of variation of permit prices within each trading period, stratified according to auction institution[17].

Uniform prices imply coefficient of variations equal to zero. Perfect price discrimination would imply a coefficient of variation of 19.5. The experimental results do not confine to either benchmark.

An eyeballing of the results indicate that the prices on average exhibit roughly similar fluctuation patterns across the three trading institutions. This impression is strengthened by the failure to reject the null hypothesis of equal medians (Friedman rank sum test: P-value = 0.549).

[16] In each trading period the equilibrium price tunnel is two experimental dollars. Thus, mean deviations equal to one experimental dollar is consistent with cost-effectiveness.

Table V. **Summary statistics: Coefficient of variation‡**

	Bid auction	*Double auction*	*Offer auction*
Mean	9.67	8.89	10.77
Median	8.61	8.60	9.76
Standard deviation	4.94	2.74	5.81
Maximum	19.00	13.51	24.24
Minimum	2.58	4.83	4.67
No. observations	15	15	15

‡ Expressed in percentages.

Result 1:

Permit prices do not accurately reflect the cost-effective level, but correspond better to cost-effectiveness than the price patterns implied by the single-price monopoly and perfect price discrimination benchmarks. Neither price mark-up nor price volatility differs significantly across the evaluated auction alternatives.

3.1.3. Trading volume

The grand median trading volume is 11.5 units. Thus, trading on average approximately yields the cost-effective volume. Quantity withholding as predicted by standard monopoly theory is not observed.

Table VI contains summary statistics according to auction type. A visual impression is that the offer auction on average performs marginally better than the alternative auctions. Correspondingly, the null hypothesis of equal medians is only weakly rejected (Friedman rank sum test: P-value = 0.076).

[17] The coefficient of variation equals the ratio of the standard deviation divided by the mean, multiplied by 100.

***Table VI.* Summary statistics: Trading volume**

	Bid auction	*Double auction*	*Offer auction*
Mean	11.5	11.6	11.9
Median	11.5	11.5	12
Standard deviation	0.57	0.68	0.94
Maximum	12	13	13
Minimum	10	11	8
No. observations	15	15	15

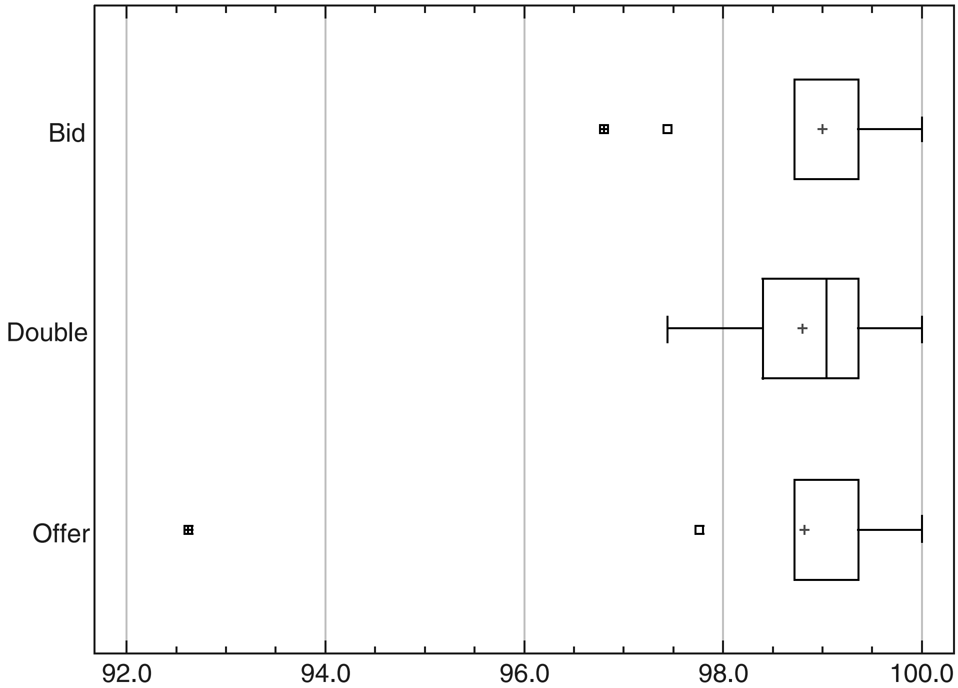
3.1.4. Trading efficiency

In line with trading volumes close to the cost-effective level, the observed efficiencies lie in the vicinity of 100%. The grand median is 99.4% as compared to 92% as predicted by the single-price standard monopoly outcome.

Figure 3 provides a horizontal box-and-whisker plot of efficiencies in the evaluated auction types. The median level under the bid and offer auction coincides with the grand median, whereas the median efficiency under the double auction is slightly lower at 99%.

Also included are outside points that are defined as points which lie more than 1.5 times the interquartile range left of the box and are shown as small squares. Far outside points are points which lie more than 3 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 2 outside points and 2 far outside points.

***Figure 3*. Efficiency**



Again no significant difference between the auctions can be detected. The null hypothesis is of equal medians is retained (Friedman rank sum test: P-value = 0.167).

Result 2:

Both trading quantities and efficiency levels correspond closely to the cost-effectiveness benchmark. No significant differences between the auction types can be ascertained.

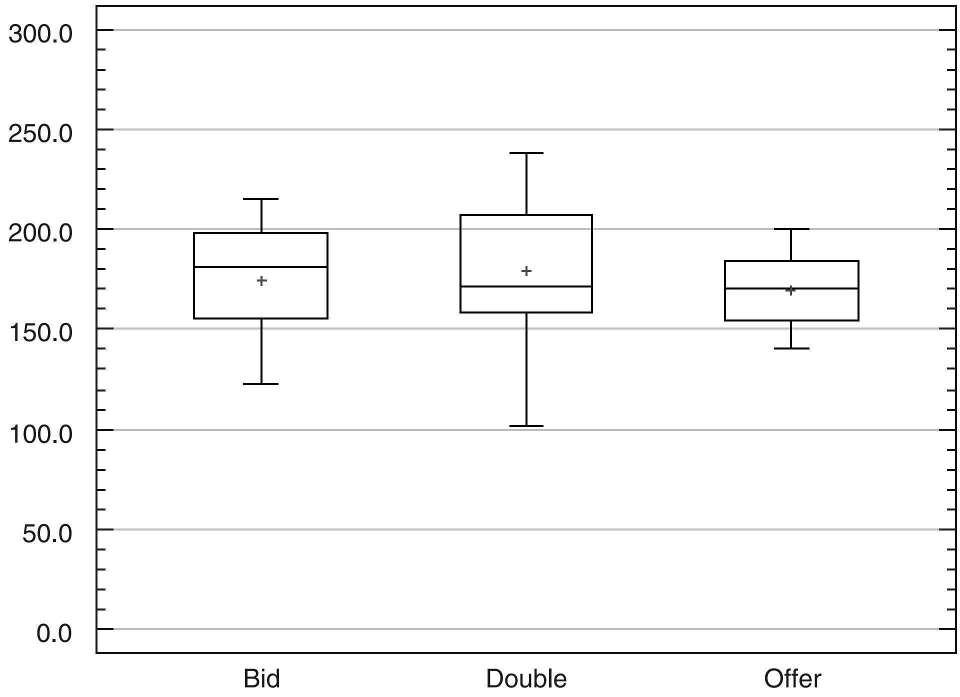
3.2. Equity: Seller's trade gains

Pooling across the laboratory sessions, the median seller's trade gains are 175 experimental dollars. This represents an 11.88% increase on the level implied by cost-effectiveness and uniform equilibrium permit prices. However, this outcome falls considerably short of both the price discriminatory outcome (312 dollars) and the conventional monopoly prediction (216 dollars).

A more detailed analysis by auction type is facilitated by Figure 4. The dispersion of realized trade gains is approximately similar, as are the mean profits accrued by the seller.

The observed median trade gains in the bid, double, and offer auction are 181, 171, and 170 experimental dollars, respectively. Nevertheless, these differences are not statistically significant. The null hypothesis of equal medians is easily retained (p-value = 0.627).

Figure 4. **Seller's trade gains**



Result 3:

The seller is able to extract supra-competitive profits. However, the level of these profits is markedly below either market power benchmark.

3.3. Borda ranking of sequential auctions

This particular ranking procedure attributes equal weight to each performance measure reported in the two preceding subsections. Hence, cost-effectiveness is implicitly given preference vis-à-vis the equity dimension of emission permits.

In accordance with the Borda rank procedure, the auction types are ranked ordinally from best (1) to worst (3) for each of the considered performance measures. The observed median in each case is chosen as the basis for the ranking of auctions. A summarization of these rankings yields the conclusive Borda rank. Table VII presents the outcome of this exercise.

***Table VII.* Borda ranking of auctions**

Evaluation criteria	*Bid auction*	*Double auction*	*Offer auction*
A. Cost-effectiveness			
1. Accuracy of prices	2	3	1
2. Volatility of prices	2	1	3
3. Trading volume	2.5	2.5	1
4. Trading efficiency	1.5	3	1.5
B. Equity	3	2	1
Borda rank (sum)	2 (11)	3 (11.5)	1 (6.5)

As can be seen in Table VII, the one-sided offer auction weakly outperforms the alternative auctions in three of the four cost-effectiveness categories as well as in terms of equity.

Result 4:

The Borda ranking of the evaluated auctions implies the preference ordering $\{$offer auction $\succ$ bid auction $\succ$ double auction$\}$. Thus, in terms of cost-effectiveness and equity, the performance of the sequential auctions improves as the number of market participants decreases.

4. Concluding discussion

The reported experiment investigated the interaction between imperfect competition and sequential auctions for tradable permits. The main results can be summarized as follows.

First, permit trading yields an approximately cost-effective allocation of emissions despite monopolization of the permit market and independent of sequential auction type. Hence, inefficiencies implied by the standard monopoly benchmark are not observed. Noticeably, the restrictions of information flows and ditto potential increase in transaction costs implied by the one-sided auction alternatives do not hamper cost-effectiveness.

Second, on average the seller manages to transform her permit allotment into supra-competitive profits. Again no significant differences between the implemented auction types can be detected. Hence, market power in emission permit markets might be interpreted as primarily an equity issue in as much as specific gratis initial allocations can be converted into supra-competitive profits[18]. Prima facie, the flexibility of the control authorities may be reduced since the set of politically feasible gratis initial allocations decreases. However, a conceivable remedy could be provided by appropriate competition legislation[19].

Third, mean permit prices in general exceed the competitive level. The observation of both cost-effective trading outcomes and supra-competitive profits is due to price discrimination. Equivalently, permit trading are not conducted at uniform prices. Thus, permit prices do not accurately reflect the true market marginal abatement cost, the dynamic implication of which might be a failure of the market for tradable permit to induce the "correct" level of innovation in abatement technology.

Fourth, disregarding the lack of statistically significant differences between the auctions, a Borda ranking of the sequential auctions results in an unequivocal preference for the one-sided offer auction. Conditional upon this specific ranking rule, trading under offer auction rules exhibits greater correspondence with cost-effectiveness and lower supra-competitive profits than the bid and the double auctions. Equivalently, the reported Borda ranking favors the trading institution in which the monopolist acts as a price setter.

The listed results are inferred from on a series of simplified small-scale tests, and the implications for real-life settings ought to be treated as merely tentative. In particular, the ability of the monopolist to price discriminate within each trading period is essential in generating both supra-competitive profits and cost-effective emissions allocations. This phenomenon may seem odd since rational and increasingly experienced buyers ought to anticipate declining prices and withhold demand until the monopolist concedes to trading at lower prices.

However, in the experiment playing such a waiting game runs the risk of being excluded from trading altogether. Also, counterspeculating against the monopolist is made complicated by the buyers' lack of precise information about the market supply curve. Nevertheless, the implemented design in which demand and supply schedules are constantly shifting may overstate the uncertainty faced by real-life traders on permit markets in the field.

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[18] As far as the double auction is concerned, this is consistent with the findings of Muller et al. (1999).

[19] Firms may also be subject to profit regulation that may have implications for their behavior on markets for emissions permits (confer Cronshaw ands Brown Kruse 1996).

This paper has tried to evaluate effects of market power within the confines of exogenously imposed trading institutions. A useful extension of the conducted experiments could be to consider the endogenous development of trading institutions in response to market-based environmental policies (also see Kirchsteiger et al. 1998).

By means of illustration, the 1990 legislation that set up the tradable SO_2 permit program only contained provision for the annual Environmental Protection Agency auction at which 2.8 per cent of the total annual permit allotment is mandatorily offered for sale. In practice, the vast majority of permit trading has instead involved private bilateral trades or been facilitated by brokers who provide price information and match trading partners (Joskow et al. 1998 and Stavins 1998). Thus, an issue that could be explored experimentally is what kind of trading institutions and implied information flows traders themselves would choose to generate, and the extent to which the institutional outcomes vary with different initial permit allocations. These avenues are left for further research.

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The instructions for the seller in session a are reproduced below (confer Table IV). This session tested the offer and the double auction. The buyers' instructions equaled the seller's except for a reversal of trader roles.
Instructions for the residual sessions b - f were similar to the provided example apart from the description of appropriate trading rules in subsection A.3.

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. *As a rule 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 programme 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.

A.2. Your trading role

In this experiment you are going to be a seller of a fictitious good on a computerised 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

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.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.

<u>In your case the conversion factor between experimental dollars and Norwegian kroner equals 0.1[20]</u>. I.e., 100 experimental dollars equals 10 Norwegian kroner.

[20] The buyers' conversion rate was 0.3.