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On fundamental performance of a marketable permits system in a trader setting: Double auction *vs*. uniform price auction

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Abstract

The marketable permits systems have been widely suggested as a potential solution for environmental problems. A critical feature in the market is that an agent can be both sellers and buyers of permits, so-called "trader settings." Although properties of the marketable permits in non-trader settings are well-documented, little is known in a trader setting, particularly about how different auction mechanisms perform and how much each of them achieves efficiency. To answer the questions, we have designed and implemented two different auction mechanisms of trader settings for marketable permits in controlled laboratory experiments: (i) Double auction (DA), and (ii) Uniform price auction (UPA). To the best of our knowledge, this research is the first which designs and implements UPA for marketable permits in a trader setting, and makes a direct comparison with the performance of DA on the same ground. We obtain the following novel results: (1) UPA is more efficient than DA in a trader setting, which is in sharp contrast with the established result in non-trader settings, (2) UPA generates more stable price dynamics and (3) UPA induces subjects to reveal more truthfully about abatement costs for emissions through their trading behaviors. With these results, we conclude that UPA is more likely to work better than DA in a trader setting.

Key Words: Marketable permits, economic experiments, double auction, uniform price auction, and trader settings

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1 Introduction

There have been long debates on how effectively a marketable permits system (MPS) can be applied for pollution control or general environmental problems. Economists have long sought to address the pros and cons of the system (Hahn (1989); Tietenberg (2006); Hahn and Stavins (2010); Goeree et al. (2010)). With respect to the advantage of marketable permits system, economists appear to reach consensus mainly on the following three points: (i) efficiency or least cost property, (ii) incentive to innovate and (iii) information requirements for efficiency (Field and Field (2006); Kolstad (2010)).[1]

Previous studies have examined which trading rules and what institutions in the MPS work best mainly in the controlled laboratory experiments.[2] In the literature, there are two important factors of experimental design: (i) the choice of auction mechanisms, and (ii) trader or non-trader settings. With respect to the first factor, it is concerned with how the price determination mechanism is organized in the permit market. In this paper, of particular interest is the performance of double auction (DA) and uniform price auction (UPA) in the MPS. The DA mechanism is well-known to perform very well under general settings and extensively applied in the marketable permits experiments (Cason (2010) and Van Boeing and Wilcox (1996)). It is a real-time trading institution in which agents can submit bids to buy and offers to sell for a unit of permits, and can even accept the best bid and offer made by other agents for that unit in any time during a trading period of several minutes.[3] Therefore, it is known that DA gives flexibility to agents for trading.

On the other hand, the UPA is known to be simpler than DA in the sense that all of

[1]More specifically, it is generally argued that (i) the MPS achieves efficiency in the sense that pollution reduction takes place in the least cost manner, and (ii) it provides firms stronger incentives to innovate abatement technology because those innovative firms are likely to gain more from trading permits, compared to less innovative firms. The most importantly, (iii) the aforementioned events can be supported even when the government does not know any information of firms' abatement technologies. In the MPS, what the government needs to do is to determine the total number of permits distributed to an industry, the initial allocation for each firm, and to let the firms trade permits under the assumption that trading rules of marketable permits function well. Therefore, the regulatory burden may be less than the other types of pollution control such as environmental tax.

[2]Muller and Mestelman (1998); Cason (2010) for an extensive literature review.

[3]Davis and Holt (1992) for the details about DA.

the permit trades are made with a uniform price.[4] First, a buyer is asked to submit "bids to buy" with which he is willing to purchase each unit of additional permits, and a seller is asked to submit "offers to sell" with which he is willing to sell each unit of permits he has. Typically, subjects exclusively play a role of either buyers or sellers. After all the agents submit bids to buy and offers to sell, a central authority collects and ranks all of the bids to buy from high to low (that is a demand curve), and all of the offers to sell from low to high (that is a supply curve), and determines the intersection of demand and supply curves. More concretely, the intersection occurs at the last unit in which the bid to buy exceeds the offers to sell, and the uniform price is the average between the two.

With respect to the second factor of trader or non-trader, the difference is whether each agent in a permit market can be both a seller and a buyer during trading periods or he can only be either one. If he can be both, we call the environment "trader setting," otherwise "non-trader setting (Ledyard and Szakaly-Moore (1994))." Reflecting the application of MPS, a trader setting is known to be closer to the reality. However, there are many experimental works which employ non-trader settings because it simplifies the experimental procedures and reduces the decision complexity of agents.

A majority of previous works have used DA for experimental study of MPS. In particular, the works by Plott (1983); Kilkenny (2000) and Cason et al. (2003) have used that institution under non-trader settings. They report that the average efficiency observed in the experiments is around 98% and it promises greater flexibility and relief from administrative burdens compared to other schemes, though instability in the permit's prices is observed. These MPS results of DA under non-trader settings are consistent with high efficiency achieved under DA in the general auction studies such as Williams (1980) and Plott and Gray (1990).

Another group of works such as Ledyard and Szakaly-Moore (1994); Godby et al. (1997); Muller et al. (2002) and Cason and Gangadharan (2006) has used DA under trader settings.

[4]UPA is also known as a call market and see Davis and Holt (1992) for the further reference.

The result in these experiments shows that observed efficiencies can exhibit higher variation and be lower on the average, compared to the DA experiments under non-trader settings. The efficiency range is between 60% and 98%. Furthermore, these works report that observed prices of permits could be unstable. In summary, DA under trader settings are more likely to generate lower efficiencies and less stable price dynamics than that under non-trader settings. Some economists argue that agents are given more opportunities of speculative trades for permits under trader settings and this may be the reason for the above results (See, e.g., Ledyard and Szakaly-Moore (1994)).

Although DA experiments are established to exhibit high performance with respect to efficiency, Cason and Plott (1996) and Cason and Gangadharan (2005) have conducted an experiment with UPA under non-trader settings as a possible alternative. It confirms that UPA is very efficient in MPS, and induces true revelation of abatement cost schedules for pollution through observed bids to buy and offers to sell in the experiments. It is also found that price dynamics is stable due to the fact that UPA is relatively simple and does not give opportunities of arbitrage trades to agents in the permit market.

In summary, past literature on MPS mostly employs DA and establishes that the institution achieves high efficiency of pollution reduction, although efficiencies and prices in DA under trader settings could be lower and less stable, respectively, than those under non-trader settings (Muller and Mestelman (1998) and Cason (2010)). In the literature, none of the previous works compare the performance of DA and UPA under trader settings in the same ground, although some authors claim a promising property of UPA as well as the importance of this comparison between the two auction mechanisms (Smith et al. (1982) and Muller and Mestelman (1998)). This is critical in exploring the possible application of MPS to the real world because players of the MPS participate as a trader in reality, and other auction mechanisms might work better than DA in such a setting, which is in contrast with the established result under non-trader settings.[5]

[5]Smith et al. (1982) have established as a general auction study that DA slightly works better than UPA in a non-trader setting of various environments.

We have designed and implemented UPA experiments under trader settings. To directly compare the two experiments, DA experiments were carried out, employing the same environment and control except the auction rules. Our novelty lies in the design of UPA experiments under trader settings in which each subject is asked to submit "bids to buy" for each additional unit he may purchase as well as "offers to sell" for each unit of permits he has, 'at once' in each trading period. More concretely, each subject is required to determine both "bids to buy" and "offers to sell," and submit all of them to the central authority at the same time. In this way, the UPA can be considered a trader setting because each subject does not know whether he is going to be a buyer or seller in advance and could be both, depending on the bidding and offering strategy as well as the announced uniform price. To the best of our knowledge, this research is the first which designs and implements UPA for marketable permits in a trader setting, and makes a direct comparison with the performance of DA in the same ground.

Our experiments yield the following novel results: (1) UPA is more efficient than DA in a trader setting, which is in sharp contrast with the established result in non-trader settings, (2) UPA generates more stable price dynamics and (3) UPA induces subjects to reveal more truthfully about abatement costs for emissions. With these results, we conclude that UPA is more likely to work better than DA in a trader setting. Our results appear to be inconsistent with earlier experimental MPS studies that consistently use DA. This is because many previous works have not considered the UPA even for the comparison except Smith et al. (1982) so that the existence of UPA called less attention in the MPS studies. Surprisingly, however, our results confirm that UPA appears to be better than DA under trader settings since DA generates noisy and speculative trades among subjects, which lead to the efficiency loss and unstable price dynamics compared to the UPA.

Given these results, we emphasize some positive perspectives on UPA as an alternative to DA for the real world application of MPS, and claim that economists need to pay more attention to the possibility of UPA due to the aforementioned properties. Now we should recall an initial motivation and purpose of MPS suggested by Crocker (1966); Dales (1968) and Montgomery (1972). The MPS can provide the flexibility of trading pollution rights. But more importantly, it needs to contribute to the pollution reduction in the least cost manner (efficiently). Therefore, UPA should call more attention for examination and application.

This paper is organized as follows. In the next section, we elaborate on the basic experimental designs. The section is followed by reporting experimental results. The final section offers some discussions and conclusions.

2 Experimental design

2.1 Experimental procedure

The economic experiment was carried out in the computerized experimental laboratory of Yokohama National University and International University of Japan during fall semester in 2010, using Z-tree programs (See Fischbacher (2007) for further information of Z-tree programs). It comprises twelve sessions each involving 8 subjects for a total of 96 subjects and 10 decision-making periods for each session. The subjects were volunteers from both undergraduate and graduate students in various fields except economics, participated in one session only and made an average of $30 based on cumulative earnings. One session took about one and half hour, and it consists of two parts: In the first part, practice rounds were implemented for subjects to double-check their understanding on experiments. In the second part, real rounds were started. The experimental earnings for subjects are the sum of earnings from real rounds.

Subjects participated in 10 experimental periods which is unknown to them. At the beginning of each session, eight subjects were asked to read experimental instructions of marketable permits system and listen to some oral presentation made by an experimenter. For this, we consistently used neutral terminologies in describing the experimental procedures such as the rules of trading. For instance, emission permits were referred to as “coupons”

Units of abatement	T1 (firms 1–2)	T2 (firms 3–4)	T3 (firms 5–6)	T4 (firms 7–8)
1	53	67	27	35
2	61	70	35	38
3	70	74	44	42
4	80	79	53	47
5	91	86	63	**54**
6	103	95	**73**	**63**
7	116	106	**84**	**74**
8	130	**119**	**98**	**88**
9	**145**	**134**	**113**	**105**
10	**161**	**151**	**129**	**125**
Permit endowment	2	3	5	6

Table 1: Assigned marginal abatement costs and permit endowments

and marginal abatement costs were simply "production costs," following the wordings used in Cason and Gangadharan (2006).

Each subject was randomly assigned to a schedule of marginal abatement costs (MACs) for 10 units of pollution and an initial permit endowment, whose list is shown in table 1. There are four types of MACs and initial endowment of permits indicated by $\{T1, T2, T3, T4\}$, and two subjects are allocated to each type. Therefore, thirty two permits are given and distributed to subjects as a fixed supply in the permit market and the corresponding demand for permits is derived from the avoided abatement costs. Given this cost structures assigned to subjects, a pair of aggregate supply (total permits supplied) and demand for pollution (derived from avoided marginal abatement costs) is displayed in figure 1 where an equilibrium price ranges between 88 and 91. The corresponding aggregate demand and supply for permits are given in figure 2. Figure 2 shows that the volume of trades must be at least twelve for social efficiency.

2.2 Treatments

Two treatments are prepared: (i) double-auction (DA) and (ii) uniform price auction (UPA). We conducted six sessions for each treatment with the cost structures introduced in table 1. Regarding DA, we strictly follow the basic design and procedure in Ledyard and

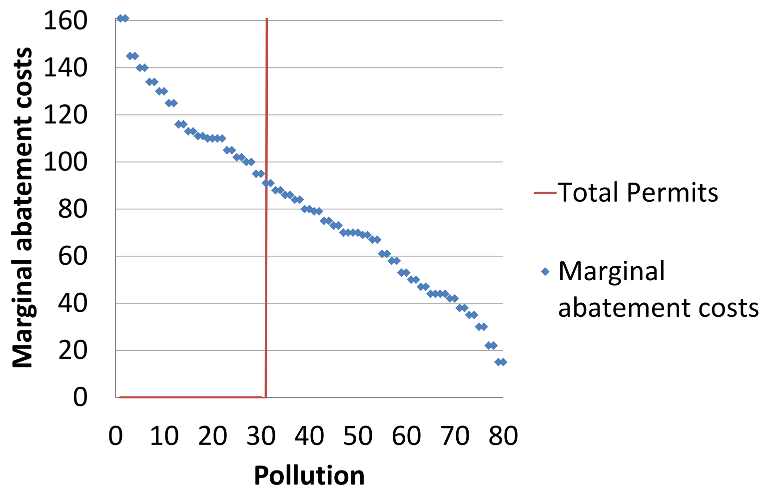


Figure 1: Aggregate demand and supply for pollution

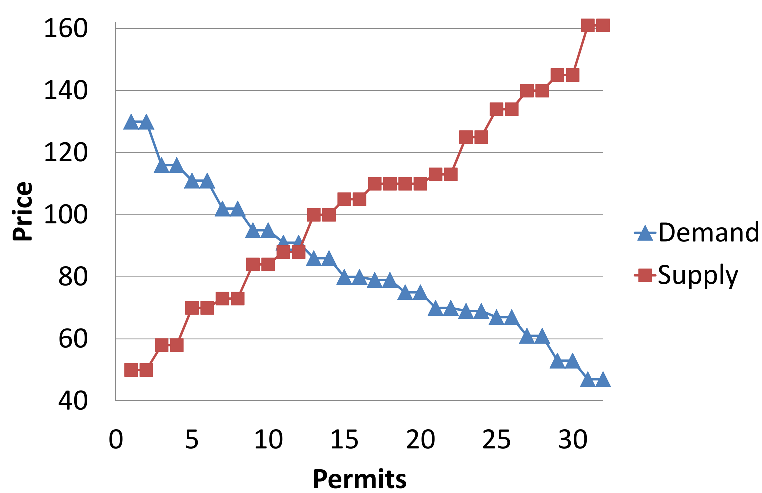


Figure 2: Aggregate demand and supply for pollution permits in the market

Szakaly-Moore (1994) and Cason and Gangadharan (2006) where trader settings are employed throughout their experiments. However, we do not incorporate several additional factors they considered such as market power, imperfect enforcement, uncertainty and banking. This is due to the fact that our focus is on the most fundamental properties of efficiency, price dynamics and cost revelation under the most primitive set-up of DA, and on the comparison with that of UPA.

The basic design and procedure of implementing UPA follow Cason and Plott (1996) except for trader settings. Recall that this study employs trader settings, while Cason and Plott (1996) did non-trader settings. This is one of the novelties in this research. Each participant in UPA under trader settings is asked to submit a bid to buy with which he will be willing to purchase each additional unit of permits and an offer to sell with which he will be willing to sell each unit of permits he has. In other words, they are asked to submit both bids to buy and offers to sell at the same time in a single experimental period, and each subject can be a buyer or a seller depending on the uniform price announced by the central authority. With the uniform price, each subject trades permits, and a final payoff in that period is automatically calculated in the terminal. When the subject has some permits, he does not need to incur the cost for the units of production covered by the permits, otherwise they incur.

Table 2 is an illustrating example for a terminal display of the computer facing each subject. This example corresponds to the case of T1 firm. As shown in table 2, when a subject is assigned to T1 firm, the induced cost schedule for abatement and two permits of the initial endowment are given to that subject, which should be consistent with the information provided in table 1. Then, he is asked to consider how he makes bids to buy for additional units of permits and offers to sell for the permits he has. As mentioned earlier, because our experiment employs a trader setting, we ask each participant to submit both of bids to buy and offers to sell at the same time, and thus this subject of T1 firm is required to submit eight distinct bids to buy for each of additional permits which will cover 8th, 7th,

Initial coupons =	2

Unit	1	2	3	4	5	6	7	8	*9*	*10*
Cost	53	61	70	80	91	103	116	130	145	161
Bids to buy	35	55	63	72	84	92	98	111		
Offers to sell									150	155

# of coupons you traded =	3
Fixed Revenue =	1000
Total production cost =	−355
Sale from selling =	0
Amount spent for buying =	−267

Your market transaction	
a uniform price =	***89***
# of coupons purchased =	***3***
# of coupons sold =	***0***

After coupons are traded

Production Cost	53	61	70	80	91	0	0	0	0	0

Experimental earning =	***378***
Total earning =	***674***

Table 2: An example for a terminal display of the computer facing each subject

. . ., 1st unit of production costs, as well as two distinct offers to sell each of which currently covers the cost of the 10th and 9th unit production. Every subject is required to do the same procedure. For instance, another subject of type T4 is asked to submit four distinct bids to buy and six distinct offers to sell (See T4 type schedule of cost and initial endowments in table 1).

Note that each participant neither knows the abatement cost schedules and initial endowments of other players, nor whether he is going to be a buyer or a seller in our UPA experiment. The experimenter collects all of the information regarding forty eight bids to buy and thirty two offers to sell submitted by eight participants for each period in a session, and calculate a uniform price by ranking bids to buy from high to low and offers to sell from low to high by identifying the intersection of the demand and supply. More specifically, the uniform price is the average of the bid to buy and the offer to sell at the last unit of trades in which the former exceeds the latter.

Table 2 illustrates how the payoff of each subject is calculated in a period for the case where a uniform price is announced as 89. In this case, this subject purchases additional three permits which covers the production costs for 8th, 7th and 6th units because the bids to buy for those units (111, 98, 92) exceed the uniform price of 89 and he purchased three permits. Finally, this subject's payoff is determined by the summation of total production costs, net payment for permit trades and fixed revenue.[6] Finally, notice that this subject has incurred the production costs from 1st to 5th unit production, and could successfully avoid incurring the costs for 6th, 7th,..., 10th units of production because they were covered by holding five units of permits from trading.

Finally, note that the permits traded in a single period do not carry over those in the next period under both DA and UPA treatments, following the previous studies. In other words, although a subject purchased two additional permits and got some payoff according to it in a single period, in the next period everything will start with the initial situation of endowment and payoff before trading. In that sense, we could say that a subject is simply asked to experience the same type of decision environment repeatedly.

3 Experimental result

In this section, we present the experimental results by comparing the data obtained from two treatments of DA and UPA under trader settings. Our focus in this comparison is on (i) efficiency achieved, (ii) price dynamics and (iii) value and cost revelation in the two treatments, and then we seek to conclude which works better, DA or UPA in the same environment.

3.1 Efficiency: DA vs. UPA

In this subsection, we compare the efficiency achieved in two different treatments of DA and UPA under the same environment. Figure 3 exhibits the average efficiency achieved over 6 sessions in each period per treatment. Visual observation on this figure suggests that a series of average efficiencies achieved over periods in UPA is strictly higher than that in DA and our efficiency results for DA are quite consistent with the previous researches which also employ a trader setting (See, e.g., Ledyard and Szakaly-Moore (1994)).[7]

[6] A fixed revenue is included in the payoff calculation for the adjustment purpose.

[7] There has been no research that employs UPA under trader settings for marketable permits experiments.

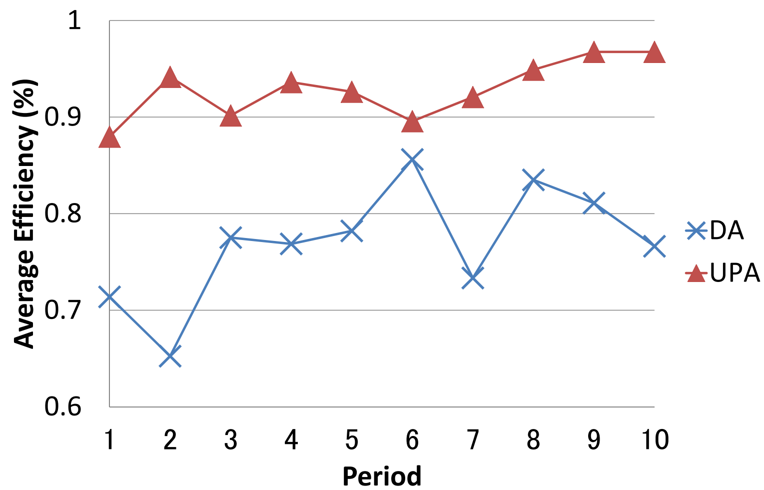


Figure 3: Average efficiency achieved over 6 sessions in each period

Whereas DA is well-known to have high efficient property especially in a non-trader setting where each subject is assigned as either a buyer or seller, a well-established result for DA under a trader setting is provided by Ledyard and Szakaly-Moore (1994), and it shows a similar trend with ours in terms of efficiency. More specifically, Ledyard and Szakaly-Moore (1994) reports that the average efficiency achieved in DA sessions under a trader setting is between 60% and 80% and the range is somewhat similar to ours.

Next, we observe each individual session's data more closely and run a statistical test to conclude the difference between DA and UPA with respect to efficiency. Figure 4 shows all individual observations of efficiency over 10 periods. Because 6 sessions were conducted for each treatment of DA and UPA, we have 6 observations per treatment in each period. This figure gives another confirmation that UPA tends to achieve higher efficiency than DA. Furthermore, two boxplots in figure 5 are drawn by pooling the observations on efficiency over periods, which suggest that they appear to be statistically different each other and the efficiencies under UPA are higher than those under DA.

To statistically check whether observations on two treatments differ or not, we run a Mann-Whitney test by pooling observations across periods per treatment, i.e., DA vs. UPA. The null hypothesis is that the probability distribution of observations on efficiency obtained

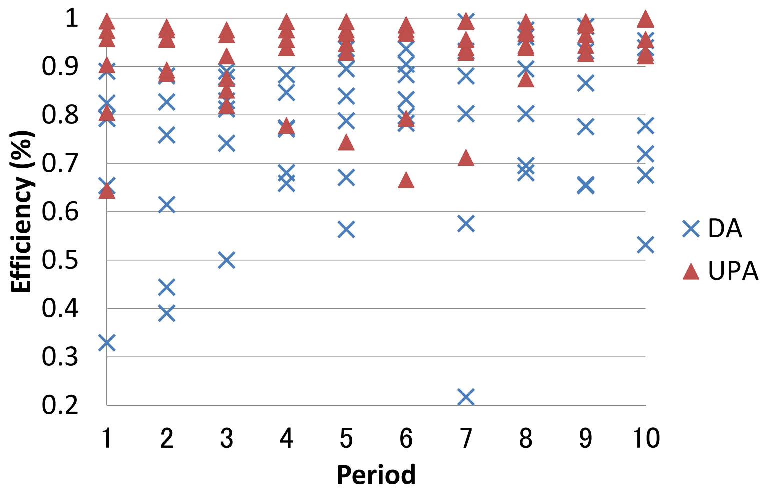


Figure 4: Each session's data of efficiency in each period

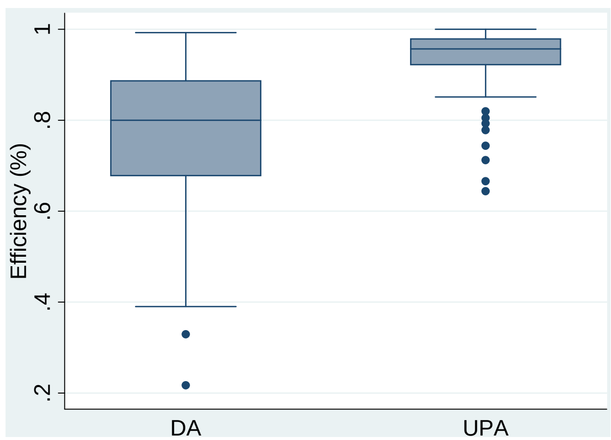


Figure 5: Boxplots of efficiency data for each treatment

in DA is the same as that in UPA. Table 3 shows the result that the null hypothesis is rejected even with 1% significance, and thus we confirm that the efficiency in UPA tends to be higher than that in DA.

In summary, we have obtained a series of visual observations and statistical results that efficiency in UPA is likely to be higher than that in DA under trader settings. We believe that this result can be attributed to many factors. One of the phenomena we have observed in the experiment as a potential reason for this is that many subjects in DA treatment repeatedly buy and sell a coupon in a single period just for arbitrage as a "trader," while

Treatment	Obs	Rank sum	Expected
DA	60	2392	3630
UPA	60	4868	3630
combined	120	7260	7260

Unadjusted variance	36300.0
Adjustment for ties	-20.92
Adjusted variance	36279.08

Ho : efficiency(DA) = efficiency(UPA)
$z = -6.50, Prob > |z| = 0.0000$

Table 3: Mann-Whitney test for comparison of two treatments on efficiency

this opportunity of resell and redemption is simply unavailable under UPA. This type of additional activities available in DA appears to generate a noise for the market performance, and we see that there are many of such trades leading to the loss of efficiency in DA. While we will address more details of this issue in the next and conclusion sections, a feature of real time trading in DA especially under a trader setting may be a cause for the difference with UPA. Later we will introduce a hypothesis to characterize situations or conditions that can lead to such worse performance in DA.

3.1.1 Price dynamics and volume of trades: DA vs. UPA

We now discuss the observed price dynamics per treatment, and focus on how observed trading prices per treatment are close to the theoretical equilibrium price across periods. Figure 6 shows the plot of observed trading prices per treatment in each period.[8] It suggests that prices under DA are likely to be more widely spread, whereas prices under UPA are more concentrated in the range between 80 and 90. Reflecting what we have observed in figure 6, average prices under UPA in each period are lower than those under DA, as shown in figure 7.

Here note that our experimental setup yields the theoretical equilibrium prices of $88-92$.

[8] An observed trading price for DA in each period is the average taken over the prices of all the trades made during 3 minutes in that experimental period.

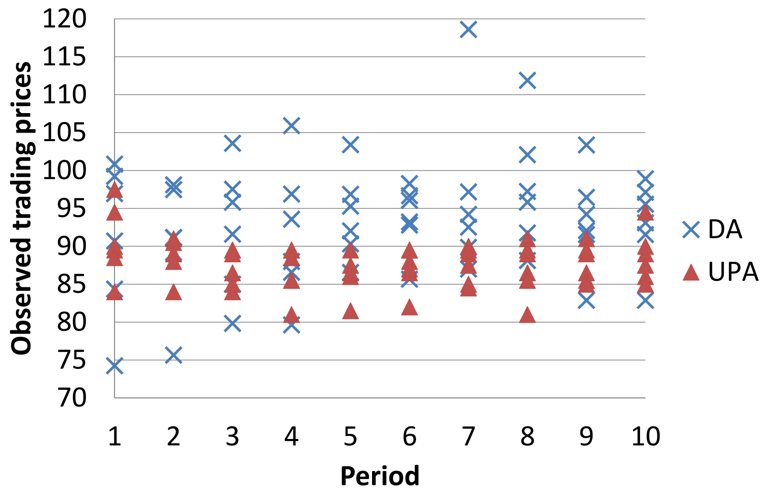


Figure 6: Each session's observed trading prices in each period

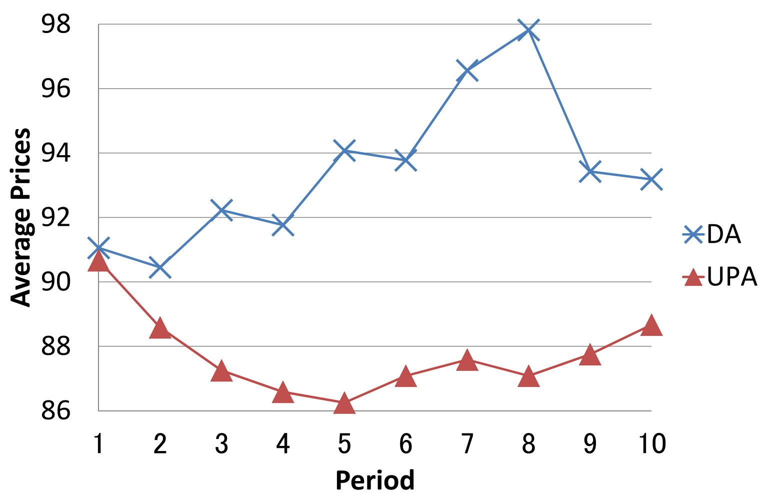


Figure 7: Average prices in each period per treatment

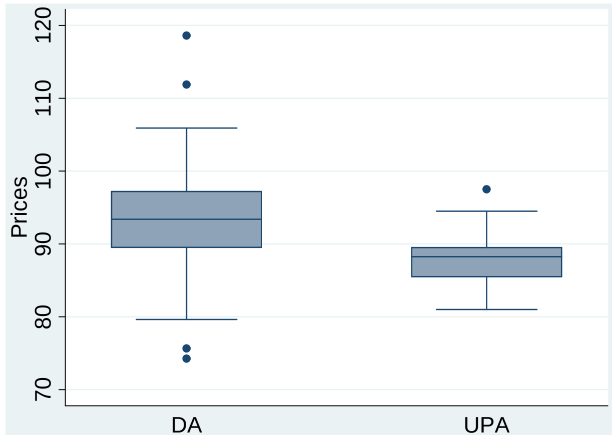


Figure 8: Boxplots of trading prices pooling observed data over periods per treatment

If the two trading rules of DA and UPA are effective, the observed prices in the experiments should be sufficiently close to that theoretical value. Of course, we admit that even if observed prices are close to the theoretical value, it does not guarantee that the mechanism achieves high efficiency. However, the trading mechanism could be considered more desirable if it gives rise to more stable trading price dynamics around the theoretical equilibrium level.

With this in mind, we further seek to characterize the observed prices over periods per treatment. Figure 8 shows the boxplots, which are drawn by pooling the observed prices over the periods per treatment. It also suggests that the distributions of observed prices under two treatments of DA and UPA appear to be different. More specifically, the distribution in DA exhibits the higher average price and wider variation than those in UPA. To confirm the differences more rigorously, we run a Mann-Whitney test with the null hypothesis that probability distributions of prices under the two treatment are identical.

Table 4 provides the evidence that the null hypothesis is rejected even at 1% significance level and it implies that the probability distribution of observed prices under DA is different from that under UPA. To characterize the difference further, we also run a squared rank test for variance by posing a null hypothesis that the variance of observed trading prices under DA is higher than that under UPA (See Conover (1999) for the squared rank test of variances). The result suggests that the null hypothesis is not rejected at any significance

Treatment	Obs	Rank sum	Expected
DA	60	4659.5	3630
UPA	60	2600.5	3630
combined	120	7260	7260

Unadjusted variance	36300.0
Adjustment for ties	-46.26
Adjusted variance	36253.74

Ho : Price(DA) = Price(UPA)

$z = 5.407, Prob > |z| = 0.0000$

Table 4: Mann-Whitney test for comparison of two treatments on observed trading prices

and thus the variance under DA is likely to be higher. In summary, we conclude that price dynamics under UPA is different from, and more stable around the theoretical equilibrium price than that under DA, based on the hypothesis tests of a Mann-Whitney for probability distribution and a squared rank test for variance.

Next, we look at the volume of trades that has occurred in a period per treatment. Summary statistics of the volume of trades in a period are shown in table 5 by pooling the observed data per treatment. Following our intuitions, the volume of trade in DA is larger than that in UPA. Furthermore, the variation in DA is much bigger than that in UPA and the range of data does not even overlap each other (See table 5 and check the minimum and maximum in volume of trades for each of DA and UPA).

As mentioned earlier, the volume of trade must be 12 or more than 12 to achieve economic efficiency. Considering this fact, the volume of trades is slightly short in UPA because the average is 9.65. However, because the standard deviation is quite small (1.117), we can say that the observed volume of trades concentrates around 10 in UPA. On the other hand, DA results show a minimum of 28 and a maximum of 111 in volume of trades and this implies that the number of trades can highly be different depending on how trades evolve within a period. The average is 46.3, and the standard deviation is 14.53. Thus, the volume of trade more highly fluctuates in DA, compared to that in UPA.

Finally, we provide figure 9 that gives another look for the data in the volume of trades.

Variable	Mean	Std. Dev.	Min.	Max.
DA	46.3	14.534	28	111
UPA	9.65	1.117	7	12

Table 5: Statistics for the volume of trades in a period per treatment ($N = 60$)

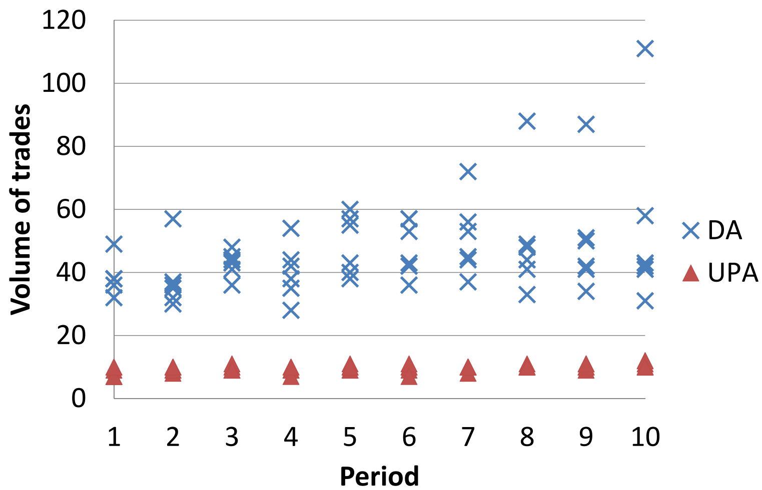
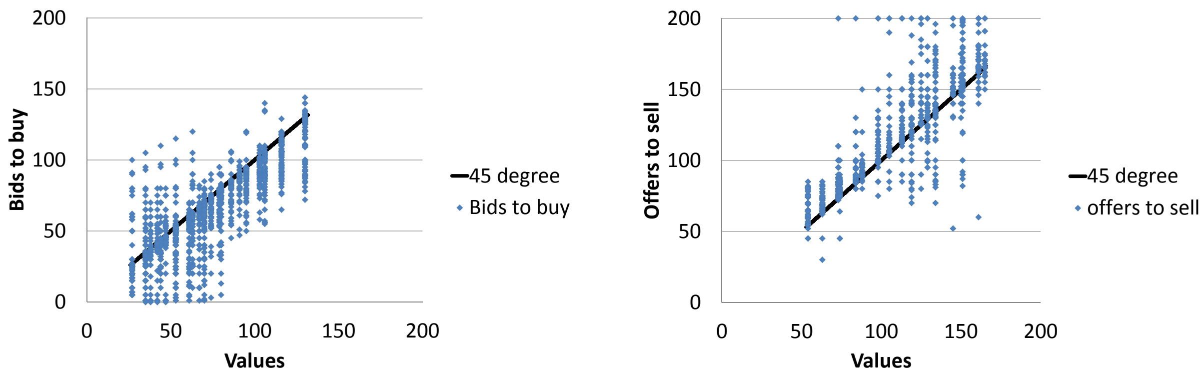


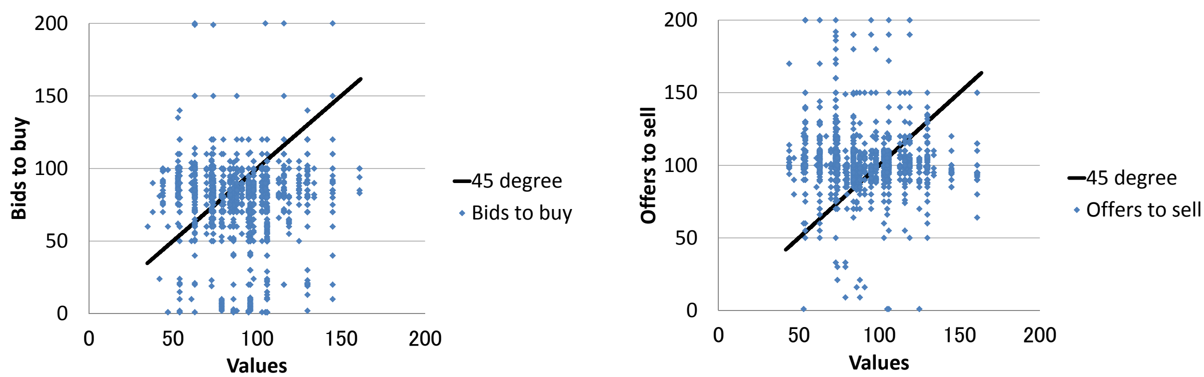
Figure 9: Each session's observed volume of trades in each period

It shows the observed volume of trades for each session per treatment over periods. As you can see, the volume of trade in DA is much higher and more widely spread out than that in UPA. These trends are quite consistent with the summary statistics in table 5. In general, the volume of trades in UPA is confined to the range between 7 and 12, which generates the high efficiency in the performance. However, the volume of trades in DA can be very excessive, which sometimes becomes more than 50 and we have identified that the excessive trades are mostly driven by speculative trades. These speculative trades that appear in DA highly reduce the efficiency achieved in that period and this is one of the most significant factors in our experiment that DA does not perform very well. As mentioned earlier, we will discuss why and how this type of speculative trades occurs in discussion and conclusion section.



(a) Bids to buy over values in UPA (b) Offers to sell over values in UPA

Figure 10: Bids to buy and offers to sell over values (MACs) in UPA



(a) Bids to buy over values in DA (b) Offers to sell over values in DA

Figure 11: Bids to buy and offers to sell over values (MAC) in DA

3.2 Cost and value revelation: DA vs. UPA

In this subsection, we report how bids to buy and offers to sell closely follow the true costs and values induced in the experiments. In general, if the market mechanisms work in the way that people misrepresent or do not follow their true valuation, the trading prices tend to diverge from the equilibrium prices, and it is less likely to have efficient (or Pareto optimal) results. Therefore, we seek to identify which mechanism of DA or UPA induces more truthful revelation on costs and values for emissions through bids to buy and offers to sell.

Figures 10, 11 and 12 show how much bids to buy and offers to sell observed in each auction mechanism reflect the true value of marginal abatement costs (MACs) for emissions. First, we focus on the data in UPA, which corresponds to figure 10 consisting of two subfigures 10(a) and 10(b). Subfigures 10(a) and 10(b) show bids to buy and offers to sell over the values, respectively. The distinction between two subfigures is obvious from visual observation. Bids to buy tend to be lower than 45 degree line, whereas the opposite trend holds for offers to sell.

This feature in the observed data can be attributed to the fact that bids to buy must be lower than or equal to the value of MAC to avoid unnecessary loss from a trade, and offers to sell must be larger than or equal to that value in UPA for the same reason. If subjects are rational and understand the mechanism of UPA from the beginning of experiments, there should not be any bid to buy above 45 degree line and any offer to sell below that line. However, observed data suggests that there are some irrational behaviors. This is mainly due to the fact that subjects misunderstand or make mistakes, whereas other research, which employs UPA, shows the same degree of irrationality.

To confirm the general trends observed in UPA, we run the OLS for each of bids to buy and offers to sell. Tables 6 and 7 exhibit regression results of bids to buy and offers to sell, respectively. Note that demand and value are said to be revealed more truthfully when the regression is closer to the 45 degree line. Consistent with figures 10(a) and 10(b), the regression results show that both bids to buy and offers to sell are positively correlated with the true values of MACs. Bids to buy regression shows that an intercept is statistically significant and strictly positive as shown in table 6. On the one hand, offers to sell regression shown in table 7 is closer to the 45 degree line compared to bids to buy regression because the intercept is not statistically significant and the slope estimate is statistically significant with the estimate of 1.130. In general, we conclude that subjects in UPA experiments have at least partially revealed their cost and values through bids to buy and offers to sell, based on these regressions.

Table 6: OLS regression of "bids to buy" for UPA

Variable	Coefficient	(Std. Err.)
Value	0.883**	(0.010)
Intercept	1.537*	(0.715)

Table 7: OLS regression of "offers to sell" for UPA

Variable	Coefficient	(Std. Err.)
Value	1.130**	(0.037)
Intercept	-1.851	(4.194)

Next, we analyze the DA in similar manner. Figure 11, consisting of two subfigures, exhibits the scatter plot of observed revelation over the true cost and values through bids to buy and offers to sell. Subfigures 11(a) and 11(b) shows the revelation results for bids to buy and offers to sell, respectively. These two subfigures reveal that both of observed bids to buy and offers to sell appeared not to be correlated with the true value and cost of MACs, which is obviously different from the UPA results shown in figure 10. To statistically confirm this visual observation over DA results, we run the regressions.

Tables 8 and 9 show the regression results for bids to buy and offers to sell under DA, respectively. These results reveal that a slope estimate is very different from unity and in fact, the estimates are negative in both regression (See slope estimates in tables 8 and 9). Although both slope estimates are statistically significant, the results are far from true revelation of values due to the negative values of the estimates. In fact, the estimated regression lines are quite flat so that these regressions illustrate how far bids to buy and offers to sell are from 45 degree line.

Table 8: OLS regression of "bids to buy" for DA

Variable	Coefficient	(Std. Err.)
Value	-0.118*	(0.052)
Intercept	92.579**	(4.938)

Finally, we look at the aggregate data of pooling observed bids to buy and offers to sell per treatment and run the regressions with the aggregate data. Figure 12 exhibits the scatter

Table 9: OLS regression of "offers to sell" for DA

Variable	Coefficient	(Std. Err.)
Value	-0.110**	(0.030)
Intercept	113.589**	(2.787)

plot of the aggregate data where subfigures 12(a) and 12(b) correspond to UPA and DA, respectively. These two subfigures again reveal the general tendency that bids to buy and offers to sell in UPA are more positively correlated with the values of MACs, while those in DA are not. In the same way, we run the regression for confirmation of this trend. Tables 10 and 11 exhibit the regression results for UPA and DA, respectively. These regression results confirm the visual observation we made so far for UPA and DA, that is, bids to buy and offers to sell in UPA more closely follow 45 degree line than those in DA because table 10 shows a slope estimate of 1.144 with statistical significance, but table 11 does a slope estimate of -0.130. These regression results are, in general, in line with figures 12(a) and 12(b).

Table 10: OLS regression for UPA

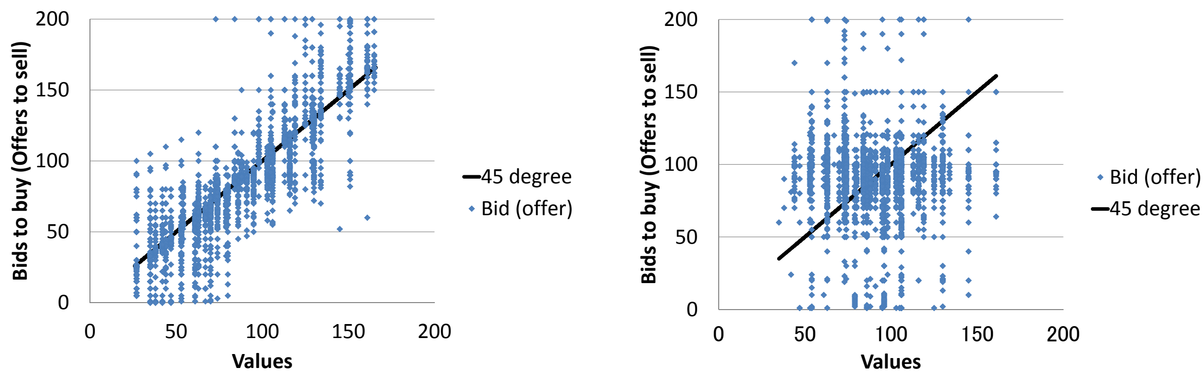
Variable	Coefficient	(Std. Err.)
Value	1.144**	(0.015)
Intercept	-11.291**	(1.366)

Table 11: OLS regression for DA

Variable	Coefficient	(Std. Err.)
Value	-0.130**	(0.030)
Intercept	105.361**	(2.796)

4 Discussion and conclusion

In this paper, we have addressed the issue of market performances in the MPS by comparing two auction mechanisms of DA and UPA under trader settings. Although there have been numerous works which examine the MPS in the controlled laboratory experiments, none



(a) Pooled data of aggregating bids to buy and offers to sell over values in UPA

(b) Pooled data of aggregating bids to buy and offers to sell over values in DA

Figure 12: Aggregate bids to buy and offers to sell over values (MAC) in each auction mechanism of UPA and DA

of them have compared the two mechanisms in the same ground of trader settings. Some authors have clearly mentioned that UPA might be a good alternative that enables us to achieve high efficiency and stable price dynamics instead of DA and our research sought to fill this open question.

Our experimental results have shown the following novel results: (1) UPA is more efficient than DA in a trader setting, which is in sharp contrast with the established result in non-trader settings, (2) UPA generates more stable price dynamics and (3) UPA induces subjects to reveal more truthfully about abatement costs for emissions through bids to buy and offers to sell. With these results, we conclude that UPA is more likely to work better than DA in a trader setting. Our results seem to be inconsistent with a general trend that many experimental MPS studies consistently use DA only for their analysis of markets. This is because the works may assume that DA is the best and have not considered UPA even for the comparison except Smith et al. (1982). Put differently, environmental economists pay less attention to UPA in both trader and non-trader settings except . Surprisingly, however, our results confirm that UPA is more effective than DA under trader settings since DA generates noisy and speculative trades among subjects, which lead to the efficiency loss and unstable price dynamics compared to the UPA.

We conjecture some reason for this result. Participants in DA under trader settings are given many opportunities of re-selling and redemption for permits, that is, more opportunities of speculative trades, which can be independent of efficiency aspects of the MPS. As mentioned in some of previous works, DA under trader settings sometimes generates instability of both permit prices as well as excessive volume of trades, and it leads to the loss of efficiency. Now, a following question naturally arises: what situation leads to such bad performance of DA under trader settings?

In this experiment, we have employed the marginal abatement cost schedules parametrized by Cason and Gangadharan (2006), and it yields a situation that a slope of aggregate demand for pollution in a market is relatively flat around the neighborhood of theoretical equilibrium price and volume, compared to those experiments which exhibit high efficiency even in DA under trader settings (A neighborhood of the intersection between demand and supply in figure 1).[9] Ledyard and Szakaly-Moore (1994), which shows a similar result with ours in terms of efficiency, have also employed the cost schedules in which the slope of aggregate demand for pollution is relatively flat around the neighborhood of the intersection between demand and supply for permits.

This observation leads us to think one hypothesis. That is, when the slope of aggregate demand for pollution is relatively flat in the neighborhood of the intersection between demand and supply, it is more likely that multiple subjects have similar valuations for permits around the equilibrium prices. In such a case, they are more motivated to conduct arbitrage trades for permits because they are exposed to more opportunities to earn more or even a little more by repeatedly buying and selling the unit when prices get closer to the equilibrium. Sometimes, we have also observed that such speculative trades of permits yield instability of prices and excessive volume of trades. This line of story is consistent with the results

[9]For instance, Godby et al. (1997); Muller et al. (2002) show that DA under trader settings can perform very well exhibiting efficiencies of at least 90%. However, we have identified that a slope of aggregate demand around the intersection is quite steep. Therefore, an incentive for speculative trades could be very low once trading prices settle down.

established in the financial market studies (See, e.g., Shiller (1981)).

We also conjecture that this type of speculative trade is unlikely to occur in a situation where aggregate demand is relatively steep around the intersection between demand and supply for pollution. This is because each player's valuation is highly heterogeneous from the beginning and there would be no much opportunities for arbitrage. On the other hand, UPA does not give such opportunities of speculative trades to participants due to its nature and what participants can do is to submit bids to buy and offers to sell before the price announcement. This difference under two auction mechanisms could be consdiered a hypothesis as well as an argument to support our result.

Recall that this research is the first which designs and implements UPA for marketable permits in a trader setting, and makes a direct comparison with the performance of DA under a trader setting in the same ground. Our results clearly suggest some positive perspective of UPA as an alternative to DA for the real world application of MPS. At the same time, this work raises a new open question that the market performance of DA under trader settings may be highly dependent upon the steepness of the slope in aggregate demand. Future studies need to explore this open question related to DA, and also pay more attention to the possibility of UPA due to the results we have confirmed. Although this research is still limited in the sense that our results are established in a simple environment of trader settings, it can be extended to several different environments such as inclusion of uncertainty, banking and market power for comparing UPA and DA performances.

Finally, we should recall an initial motivation and purpose of MPS suggested by Crocker (1966); Dales (1968) and Montgomery (1972). The MPS can provide the flexibility of trading pollution rights. However, more importantly, it needs to contribute to the pollution reduction in the least cost manner or efficiently. Therefore, UPA should call more attention for further examination and application as a possible alternative.

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