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An Experimental Analysis of Auctioning Emissions Allowances under a Loose Cap

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Abstract

The direct sale of emissions allowances by auction is an emerging characteristic of cap-and-trade programs. This study is motivated by the observation that all of the major implementations of cap-and-trade regulations for the control of air pollution have started with a generous allocation of allowances relative to recent emissions history, a situation we refer to as a “loose cap.” Typically more stringent reductions are achieved in subsequent years of a program. We use an experimental setting to investigate the effects of a loose cap environment on a variety of auction types. We find all auction formats studied are efficient in allocating emissions allowances, but auction revenues tend to be lower relative to competitive benchmarks when the cap is loose. Regardless of whether the cap is tight or loose, the different auction formats tend to yield comparable revenues toward the end of a series of auctions. However, aggressive bidding behavior in initial discriminatory auctions yields higher revenues than in other auction formats, a difference that disappears as bidders learn to adjust their bids closer to the cutoff that separates winning and losing bids.

Key Words: auction, carbon dioxide, greenhouse gases, allowance trading, Regional Greenhouse Gas Initiative, RGGI, cap and trade

JEL Classification Numbers: C92, D44

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Contents

Introduction.....	1
Background and Literature	2
Procedures	6
Results	10
Conclusion	16
References.....	18

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Introduction

The emerging trend toward the sale of emissions allowances as a major method, or even the primary method, for allocating allowances into the economy has focused attention on the implications of various methods for selling allowances. This is especially true given the considerable economic value of the new environmental assets. While there have been some experiments with other forms of sale, economic theory, the weight of recent experience, and current policy proposals lead us to expect that auctions will emerge as an important mechanism for selling allowances. It is widely accepted that the performance of different types of auction mechanisms will vary with the institutional context. Taken together, these factors argue strongly for the importance of investigating the performance of different auction designs in the context of an allowance trading program.

This study is motivated by the observation that all of the major implementations of cap-and-trade regulations for the control of air pollution have started with a generous allocation of allowances relative to recent emissions history. At least at the outset, the supply of allowances has been plentiful relative to the number of allowances needed for compliance. In some cases the supply has remained plentiful while, in others, the supply has become progressively tighter. We refer to cases where the price of an emissions allowance is relatively low as a situation with “loose caps.” This might be relevant in absolute terms, if the emissions constraint does not bind at least for a short period of time, but more generally a loose cap is a relative concept. We investigate the performance of alternative types of auctions when the cap is loose and the expected auction price is low.

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The relative slackness of an emissions cap could have implications for the preferred design of an allowance auction. Vernon Smith (1967) found that, in an experimental setting where bidders in a sealed bid auction shared a common, but imperfectly known, value for multiple units of a good, a loose cap produced a divergence in the performance of different auction types. Specifically, Smith found that uniform price auctions generated more revenue than discriminatory price auctions when excess demand was low, but uniform and discriminatory auctions generated comparable levels of revenue when excess demand was high.

In this paper, we investigate the effects of a loose cap environment on a variety of auction types. We compare single-round, sealed-bid auctions, both discriminatory and uniform price, with the multi-round ascending price English clock auction. In single-round, sealed-bid auctions, bidders submit a demand schedule for blocks of allowances so that bids have both price and quantity dimensions. In multi-round auctions, bidders submit quantities at a given price. If demand exceeds supply, the price is raised (like the advancing of a clock) until demand is equal to supply. We investigate the performance of the English clock auction both with and without excess demand information provided to bidders between rounds.

We find that whether the cap is tight or slack, all auction formats studied are nearly 100 percent efficient in allocating emissions allowances, with no systematic differences among them, e.g. allowances are distributed initially in the auction to those who value them most. As we would expect in the less competitive environment of a loose cap, the amount of revenue raised in the auction appears to be less, relative to a competitive (Walrasian) prediction determined by the supply and demand for permits, than revenue under a tight cap for all auction types. In terms of revenue generation, differences between auction formats are relatively minor. However, one notable effect of the auction design is that aggressive bidding in discriminatory auctions yields higher revenue early in a series of auctions, a pattern that tends to diminish later as bidders learn more about the likely level of the highest rejected bid.

Background and Literature

Several cap and trade programs for controlling air emissions have been characterized by loose caps, particularly during their early years of operation. (Ellerman, Joskow, Schmalensee, Bailey, & Monteiro, 2000) More generally, research by Harrington et al (2008) suggests that environmental regulations often end up being less costly than was anticipated at the time of their adoption and that overestimation of baseline emission levels and failure to take account of the emissions reducing effects of technological change are important factors that contribute to that overestimation.

Probably the most famous case of a loose cap is Phase I of the EU Emissions Trading Scheme (EU ETS). This program was implemented prior to the availability of an accurate inventory of CO₂ emissions in the EU. Once it became clear that the number of allowances allocated was more than needed for compliance, the price of EU ETS allowances crashed. The fall was exacerbated by the limited lifespan of Phase I allowances, which were not bankable into Phase II. One auction of CO₂ allowances under Phase I closed at a price of 0.7 Euros per ton of CO₂, a fraction of the price just weeks earlier. (Ellerman & Buchner, 2007)

The first incentive-based program to be implemented anywhere in the world on a large scale was the phase-down of lead in gasoline in the United States in the mid-1980s. The regulations permitted trading and banking of lead permits through inter-refinery averaging of the lead content of a gallon of gasoline. The standard started at 1.1 grams of lead per gallon in 1982 and was lowered to 0.5 in 1985 and finally reduced to 0.1 in 1986 (Kerr & Newell, 2003).

In California the REgional Clean Air Incentives Market (RECLAIM) program to cap emissions of NO_x in the Los Angeles Basin began in 1994. Under this program regulated facilities were free to pick their baseline emissions level from a time period of strong economic activity and as a result the aggregate emissions cap was not binding during the early years of the program (Burtraw, Evans, Krupnick, Palmer, & Toth, 2005). The Emissions Reduction Market System (ERMS) for Volatile Organic Materials in Chicago has been persistently slack with emissions falling far below the cap between 2001 and 2005 (Evans & Kruger, 2007). A number of factors have contributed to the slackness of the ERM program including inflated baseline emissions, closure of regulated facilities and interactions with regulations directed at other air pollutants.

The U.S. sulfur dioxide emissions trading program initiated in 1995 was specifically designed to be relatively slack at first with a significant tightening of the cap in a second phase. Changes in technology, fuel markets and regulations of the railroads contributed to a decline in compliance cost by the first year of implementation that was not anticipated when the program was enacted in 1990 (Burtraw, 2000; Carlson, Burtraw, Cropper, & Palmer, 2000). Only after trading started in 1993 in advance of implementation did it become clear just how slack the initial cap was. An annual revenue neutral auction that was first held in advance of the compliance period played an important role in the discovery of compliance costs and the associated allowance price that ultimately obtained in the market. Low prices, thin trading, and large amounts of allowance banking characterized the early market for SO₂ allowances. (Ellerman et al., 2000)

In January of 2009, ten northeastern states from Maryland to Maine launched the Regional Greenhouse Gas Initiative (RGGI), the second mandatory emissions cap-and-trade program for greenhouse gas emissions in the world and the first in the United States. For the years 2009 through 2014, the RGGI program caps total annual CO₂ emissions from electricity generators in the region at a level approximately 4 percent above the average annual CO₂ emission levels in the years 2000-2004. Beginning in 2015, the cap declines about 2.5 percent per year for four years until it is 10 percent below the initial cap by 2019. In addition to allowing full trading of allowances, the program provides flexibility by allowing for 3-year compliance periods, with the first period extending from 2009 through 2011, full allowance banking between compliance periods, and limited use of emissions offsets.

The RGGI cap on carbon emissions was set with the idea that it would be “loose” in the early years of the program, so as not to stifle economic growth or cause shortages in the electricity market. However, as the first CO₂ cap-and-trade program in the U.S., the RGGI program is subject to much uncertainty. One of the many sources of uncertainty is the stringency of the annual CO₂ emissions cap compared to actual emissions levels in the absence of a cap. Several recent analyses (Environment Northeast, 2008; New Carbon Finance, 2007; Point Carbon Research, 2007) have compared the trend in CO₂ emissions levels and projected emissions levels from electricity generators in the region to the level of the emissions cap. The evidence suggests that, at the outset of the program, projected annual emissions could fall short of the initial annual RGGI emissions cap of 188 million tons.

The recent predictions suggesting that the RGGI caps might not be binding in the initial years of the program are largely based on the growth in natural gas fired generation in the region,¹ resulting both from greater use of natural gas in dual-fueled boilers that can burn both oil and natural gas and importantly the increase in new, highly efficient, natural gas fired capacity in the region. Consequently, the relative costs of different fossil fuels helps determine the demand for emission allowances through their effect on the dispatch of different types of generators in the electricity sector. For example, in 2004, a spike in natural gas prices lead to greater use of coal to produce electricity, which contributed along with the introduction of the Clean Air Interstate Rule to a marked increase in SO₂ allowance prices (Burtraw et al., 2005). Two years later, total emissions of SO₂ from regulated generators fell by over 800,000 tons

¹ Weather has also been mentioned as a contributing factor. It is not yet known whether this is a transitory or longer-term phenomenon.

relative to emissions in 2005. Nearly 30 percent of that reduction (or approximately 3 percent of the total annual supply of allowances) was attributable to the substitution of natural gas (which emits no SO₂) for oil (which does) at dual-fueled generating units in response to increases in the relative price of fuel oil (U.S. Environmental Protection Agency, 2007). An increase in demand for CO₂ emissions allowances of similar magnitude could result if a major nuclear plant in the region were to unexpectedly go off line for a period of time.

Another factor that will influence demand for emission allowances is the level of overall demand for energy. If a cap and trade program is coupled with programs to enhance energy efficiency, as envisioned in the CO₂ programs in RGGI and in California (California Air Resources Board, 2008), the level of demand for allowances will depend importantly on the effectiveness of those energy efficiency programs and policies. In RGGI, the memorandum of understanding among the ten participating states specifies that at least 25 percent of the value of emissions allowances must be directed toward strategic energy investments such as renewables and energy efficiency, and most of the states plan to use at least this portion of the RGGI allowance auction revenue to fund energy efficiency programs. Simulation modeling suggests that increasing the share of emission allowance revenue dedicated to funding efficiency programs could reduce RGGI allowance prices by as much as 9 percent relative to a baseline with only 25 percent of RGGI revenue dedicated to energy efficiency (Ruth et al., 2008).

In the case of RGGI, there are factors that will help to mitigate the type of allowance price collapse that happened in the European Union allowance market at the end of the first commitment period. First, there is a reserve price in the RGGI allowance auctions of \$1.86 per ton, which means that the RGGI states will sell no allowances in the auction at a price below \$1.86. Second, and unlike Phase I of the EUETS, the RGGI program allows full banking of allowances and the possibility of purchasing allowances at a low price today and saving them for use when economic growth leads to greater electricity demand. In fact, in the first three RGGI auctions, all of which occurred during a serious recession, allowance prices closed well above the reserve price of \$1.86, at \$3.07, \$3.38 and \$3.51 respectively.²

The relevance of this slack demand to auction design arises from a developing expectation that, in the future, most cap-and-trade programs, and, in particular, those for

² The March auction also included a later vintage of allowance which can not be used prior to 2012. These allowances only sold for \$3.05 reflecting their lower “convenience value”.

controlling CO₂ emissions, will provide for the auction of a significant share of allowances. Unlike what has occurred in previous emission cap-and-trade programs, the states participating in the RGGI program, collectively, are planning to auction roughly 90 percent of the emissions allowances created by the program.

The RGGI states decided to expand the role for auctions, in part because they recognized that giving allowances away for free would not prevent electricity producers in the region from folding the value of emissions allowances into their bids in the power market. The region has almost entirely moved away from cost-of-service pricing to market based pricing in electricity markets, which means that the opportunity costs of emission allowances would be passed on in electricity prices even if allowances were received for free by the regulated firms.

In contrast, most prior emissions trading programs, including the SO₂ and NO_x trading programs in the United States and the first two phases of the European Union's Emissions Trading Scheme, began by granting the emission allowances to current emitters for free. Recent regulatory and legislative proposals indicate that the RGGI cap-and-trade program presages a trend of increasing reliance on auctions for allowance allocation. For example, current proposals in the EU provide for selling a substantial majority of the allowances used by electricity generators in the third phase of its program beginning in 2013. At the time of this writing all major proposals for a U.S. federal greenhouse gas cap and trade program envision a significant role for auctions, although some prominent proposals provide, at least initially, for an even split between auctions and free allocation.

As allowance auctions become more prevalent, their performance under different market settings takes on increasing importance. Given the possibility of low excess demand especially at the outset of allowance markets, the choice of auction design should include consideration of the impact of low excess demand on auction performance.

Procedures

In the RGGI program, emissions allowances are distinguished by the first date at which they can be used for compliance, and they can be used at any time after that. Allowances with the same vintage are identical, and therefore, auctions for emissions permits are multi-unit auctions. In the experiment, the term "permit" is analogous to allowances in RGGI, each bidder is assigned several units of production capacity and each unit of production from a particular type of capacity unit requires some number of emission permits, which varies among participants reflecting a distribution of technologies. Bidders' values for permits are determined by the profit

margins on their production capacity and by the number of allowances needed to cover the production activity.

The auction formats that we consider are distinguished in two dimensions: by whether or not there are multiple rounds of bidding and whether or not all bidders purchase permits at the same “uniform” price. In the single round auctions, bidders submit sealed bids for blocks of permits, and it is possible to make different bids for each block. These bids are then ranked from high to low as a pseudo demand function, and then the vertical supply of permits being auctioned determines which bids are accepted. In a “discriminatory auction,” successful bidders pay their own bid prices, whereas in a single-round “uniform price auction,” all pay the same market-clearing price, which is set at the highest rejected bid. In both formats, bids are required to exceed a pre-announced reserve price. The third format we considered is a multi-round “clock auction” in which bidders state how many blocks they wish to purchase at an announced price, and in each round the price is raised sequentially, as if by hands of a clock. The clock price begins at the reserve price and stops rising when aggregate bidder demand is less than or equal to the auction supply. In each round bidders can reduce their quantity as the price rises, or they leave demand unchanged, but they cannot increase the quantity of their bid according to the auction “activity rules” that force bidders to participate actively from the beginning. To maintain comparability with the other auction formats, prices with the clock are incremented by the same fixed increment that corresponded to possible bid increments in the single-round formats. The experiments implemented two versions of the clock, one in which bidders were not told the aggregate demand quantity after each round, and one in which they were provided with this information.³

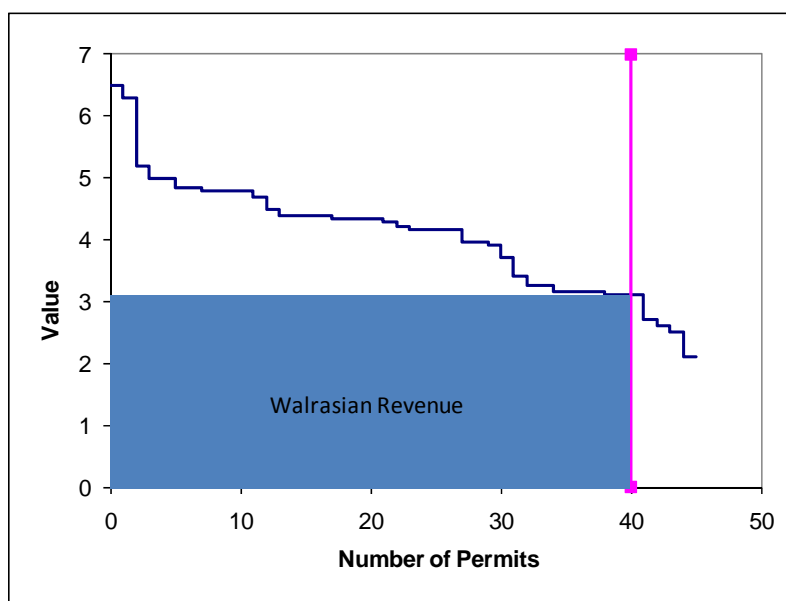
In (Burtraw et al., Forthcoming), we report an experiment with these auction formats under treatment conditions that were designed to facilitate tacit or explicit collusion, e.g. the presence of a chat room or the existence of a secondary market where trades can be arranged to adjust for failure to obtain allowances in a collusive phase. In all of the auctions reported in that paper, however, the cap on emissions was tight in the sense that the available supply of permits in each auction was only about two-thirds of what would be demanded at a price of zero at low prices. In this paper, we report two series of auctions: a baseline series where supply is two-

³ The clock auction implemented in the recent Virginia NO_x auction (Porter, Rassenti, Shobe, Smith, & Winn, 2009) did not provide excess demand information, and the auction administrators felt this decision may have prevented the clock from stopping before it did (Burtraw et al., 2008).

thirds of the quantity that would be demanded at a zero price and a loose cap series with a cap that represents about ninety percent of the quantity that would be demanded at a zero price.

In a loose cap environment, most bids will end up being accepted, and the resulting reduction in competition can serve as a useful “stress test” of auction formats. In a uniform price auction, there may even be a role for the exercise of unilateral market power if the cap is so loose that a single bidder can profit from bidding lower on allowances for marginally profitable capacity units in the hopes of lowering the clearing price on a large number of other, more profitable units. This strategy is referred to in the literature as “demand reduction.” In a clock auction with low excess demand to begin with, a small amount of demand reduction by one or more bidders will stop the clock at low prices. Similarly, there is “less risk” to bidding low on marginal units in a multi-unit discriminatory auction with a loose cap since a higher proportion of bids will be accepted, and the resulting bid reductions may cause revenue to be lower than in uniform-price auctions. This revenue comparison might be reversed if there is demand withholding in uniform price or clock auctions.

The experimental design implemented an asymmetry motivated by the difference between high emitters (e.g., those using coal) and low emitters (using natural gas). Each laboratory auction involved 6 bidders, with 3 “high users” requiring 2 permits per unit of production capacity used, and 3 “low users” who were required to remit 1 permit per unit of production capacity used. All bidders were given 5 units of capacity, regardless of whether they were low or high users, reflecting the approximate equal proportions of electricity production by each type of producer. Thus low users would demand 15 permits ($= 3 \times 5 \times 1$) and high users would demand 30 permits ($= 3 \times 5 \times 2$), for a total demand of 45 permits at a price of zero. For the loose cap treatment, 40 permits were sold in each auction and for the tight cap treatment, 30 permits were sold in each auction. Each unit of capacity could be used to produce a unit of a product that sold for a known price. Since permits could not be banked in this experiment, their values were determined by the difference between the product price and the production cost, divided by the number of permits required. Bidders received randomly determined production costs associated with each unit of capacity; these costs were draws from uniform distributions: [2, 6] for high users, and [5, 10] for low users, with new draws made for each successive auction. The permit values resulting from a given set of cost draws can be arraying from high to low like a demand curve, as shown in Figure 1, where the auction supply is represented as a vertical line at the supply of 40 permits (loose cap).

Figure 1. Permit Values and Walrasian Equilibrium with a Loose Cap

In Figure 1, the intersection of the value array and the auction supply determines a Walrasian price, which will vary from one auction to the next depending on the actual cost draws. Laboratory sessions involved 6 bidders who participated in a series of 8 auctions over the course of an hour (including the reading of instructions). Both loose and tight cap treatments involved uniform, discriminatory and clock auction formats. In addition, the loose cap treatment included a clock auction with full information about excess demand at the end of each round of bidding. Each combination of auction format and cap (loose or tight) involved 6 experimental sessions, each with 6 bidders. The random cost draws were balanced across treatments, by using a given random number “seed” for the first session of each auction type, a second random number seed for the second session of each auction type, etc. There were 252 subjects who participated in the study. All were students at the University of Virginia, and were paid their earnings in cash at the end of each session. Participants received a \$6 initial payment, and earnings in the auctions were in a range from \$15 to \$45 after being converted (at a rate of 30 cents per experiment dollar). The auctions were run using a web-based program that is publicly available on the Auctions Menu of the Veconlab site (<http://veconlab.econ.virginia.edu/admin.php>).

For each auction, we determined the maximum economic surplus that could be achieved given the fixed product price, the individual cost draws, and the number of permits being

auctioned. This surplus is the area below the value array and to the left of the auction supply. In an actual auction, variations in bidding behavior may cause some permits to be purchased by bidders with low values, and the actual efficiency is determined by dividing the value of the resulting allocation by the maximum possible value. A second measure of auction performance is the amount of revenue that it raises. If all bidders bid their full values in a discriminatory (pay as bid) auction, the seller would receive the maximum revenue amount, which is the area below demand and to the left of the auction quantity, i.e. the entire economic surplus. We will use a more realistic benchmark for revenue: the amount of money that would be raised if all permits sold at the market-clearing “Walrasian” price determined by the intersection of the supply and demand curves as depicted in Figure 1 for the case of a loose cap.

Results

Figure 2 shows the average prices for each of the 8 auctions with a tight cap. Each solid line corresponds to a different auction format and the dashed line shows the Walrasian price predictions. All prices represent averages across the 6 sessions. All these prices are close to the Walrasian prediction and there is no obvious trend in price levels. The small price differences do not result in significant differences in auction revenues as determined by a Wilcoxon matched pairs test using revenue averages for each session.⁴ To summarize, differences in auction formats do not have much impact on revenues in the competitive, tight cap environment.

⁴ Using data from the final four auctions, the p-values for pair wise comparisons between auction formats are all greater than 0.10.

Figure 2. Average Price Paid Per Permit: Tight Cap

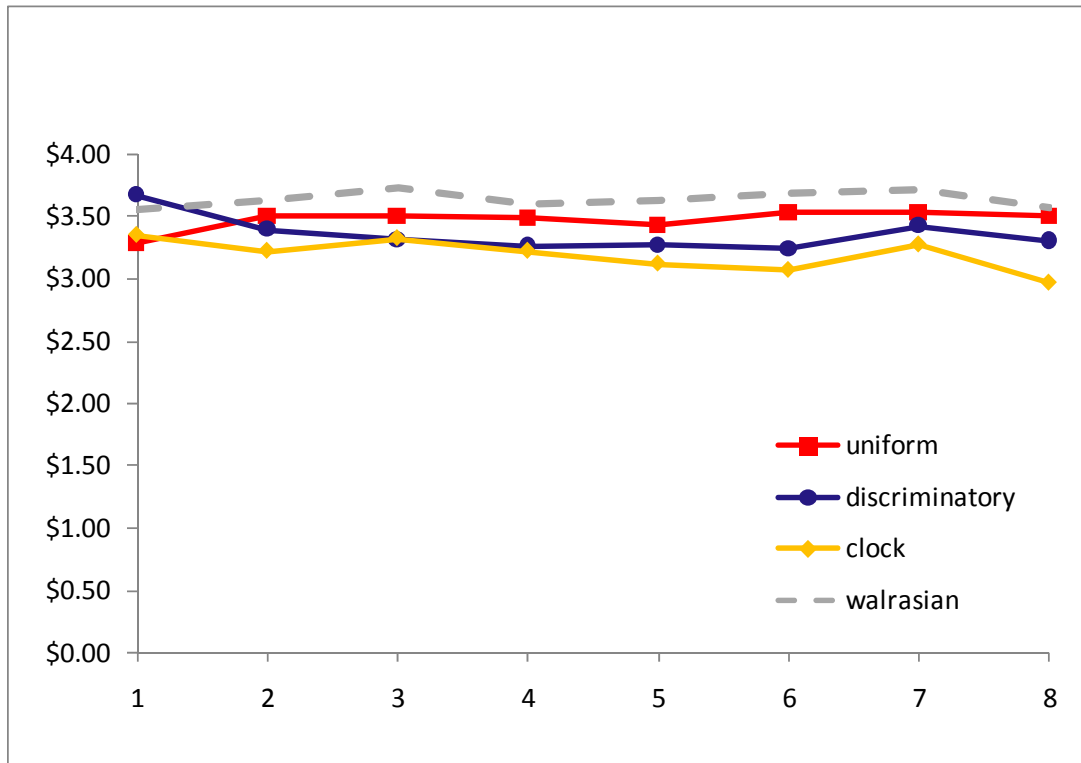
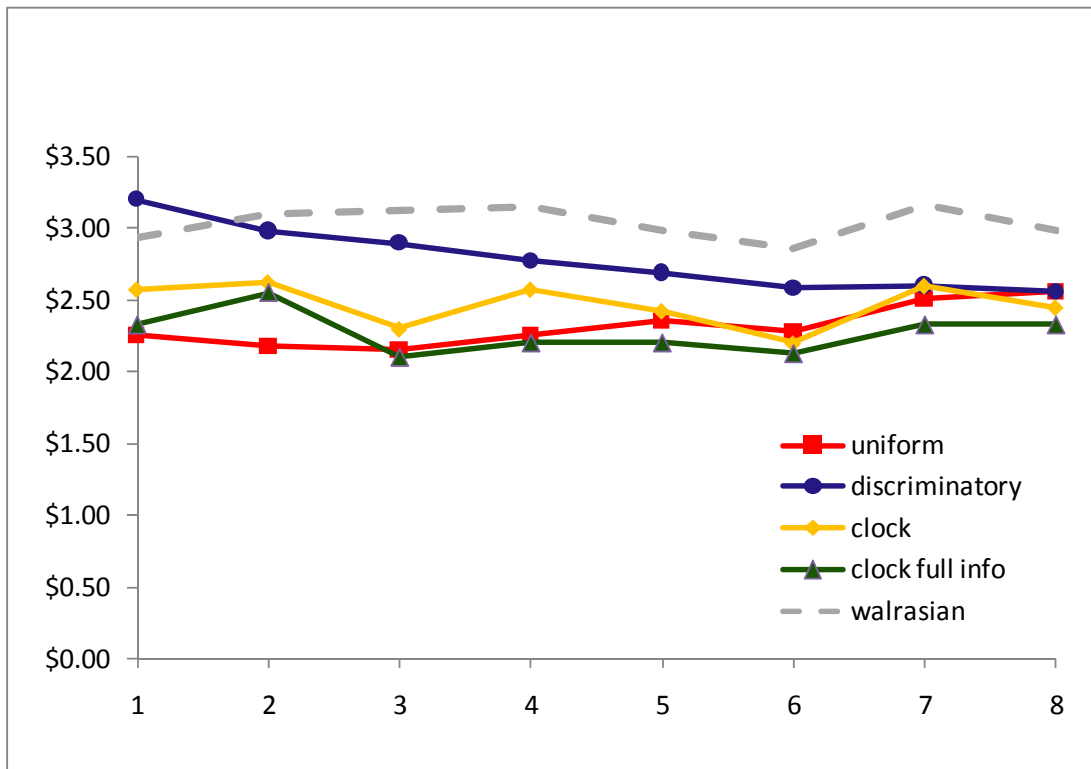


Figure 3 shows the average prices for each of the auction formats in the loose cap environment. This dynamic representation reveals an interesting pattern in which the discriminatory auction yields higher average prices especially in early auctions, but this difference appears to taper off by the end of the series. Using data from the first four auctions in each session, the discriminatory format raises significantly more revenue than the other three formats.⁵ In the last four auctions, the only significant difference is that the discriminatory auction raises more revenue than the clock auction with full information ($W=0$, $p=.031$). There is no difference between the revenues raised under the two types of clock auctions in either case ($W=6$, $p=.438$, for the first four auctions for the first four auctions and $W=5$, $p=.313$ for the

⁵ In the first four auctions, the signed rank test statistic comparing discriminatory to each of the other auction formats considered yielded a test statistic of 0 and a p-value of .031 in each case..

second four auctions).

Figure 3. Average Price Paid Per Permit: Loose Cap



Some interesting properties of the sealed bid auctions are revealed by an analysis of individual bid data and the way that bid patterns evolve over time. Figure 4 shows the bid data for the six uniform price sessions. Bid values are on the vertical axis and permit values are on the horizontal axis. Individual bids are shown for the first four auctions (left) and the last four auctions (right). Larger data points represent higher frequencies of that bid/value combination. If bidders are bidding their true values for permits, the data would fall along the 45 degree line through the origin. In both panels, there is a clear density of bids along the 45 degree line, showing that in uniform price auctions, many bidders bid their true values. Also notable is the instance of many bids above the 45 degree line particularly in the mid-value range, where bids are less likely to be marginal. There are few differences between the early and late bid distributions, indicating that bidding behavior is fairly consistent throughout the experimental sessions. In the final half, however, there is a slight increase in the density of bids at value, and a slight decline in bids at the reserve price for these uniform price auctions.

Figure 4. Uniform Auction Individual Bids

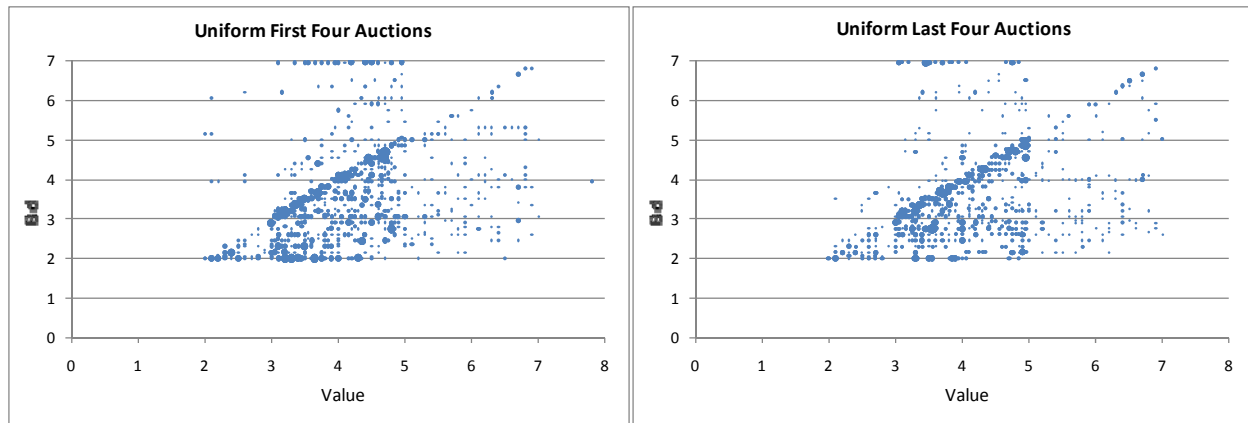


Figure 5. Discriminatory Auction Individual Bids

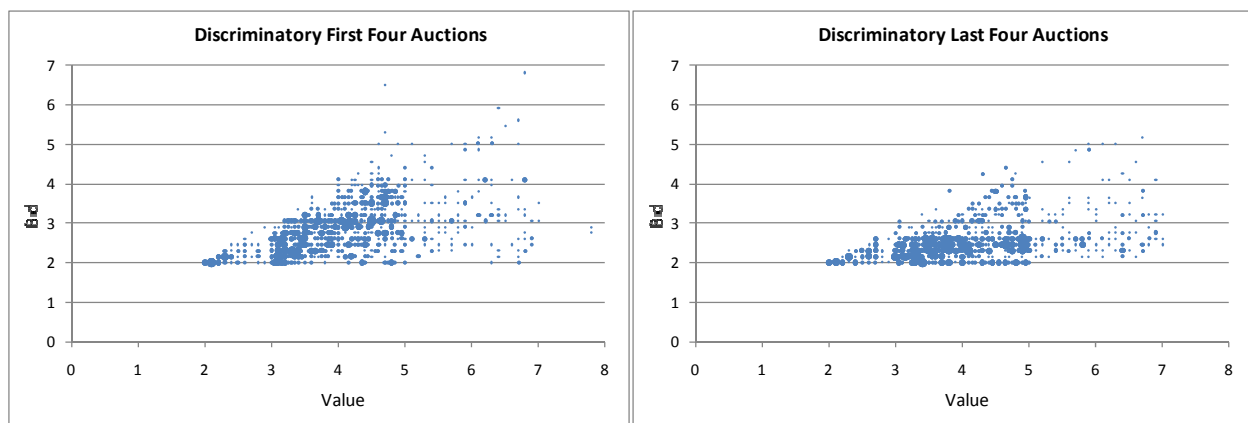


Figure 5 shows the bid data for the six discriminatory sessions for both the first four auctions (left) and the last four auctions (right). It is clear from comparing these figures with the comparable panels in figure (4) that bidders implement different strategies in the two different auction formats. In the discriminatory auctions, there are far fewer bids on the 45 degree line, and the bids are more uniformly distributed between \$2 and \$3, the typical clearing price. In discriminatory, pay as bid auctions, bidders attempt to bid just above the market clearing price for their higher valued units in order to maximize the amount of surplus that they capture. The differences in bidding strategy between the two auction formats may account for the dynamic trend that we see in the loose cap data where the discriminatory auction has higher average prices than the other auction types initially, but over time prices drop with successive auction rounds. It

may take several auctions for bidders to “discover” the clearing price and bring down the average price paid per permit. This can be seen by comparing the bid scatter graph for the first 4 auctions with that of the final 4 auctions, as shown in Figure 5. In the early auctions, bids are more widely distributed between the reserve price and the bidders’ values, but in the later sessions as bidders learn more about the likely cut-off price the bids tend to be more clustered in the \$2 to \$3 range.

Figure 6. Auction Revenue as a Proportion of Walrasian Revenue

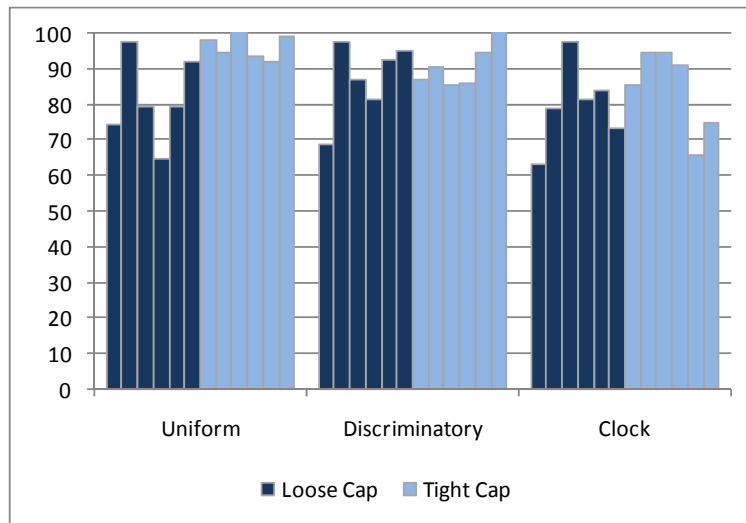


Figure 7. Efficiency

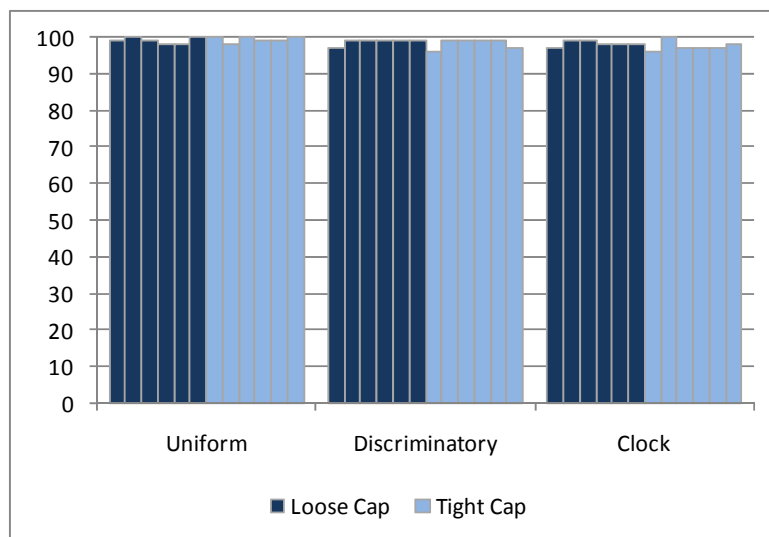


Figure 6 depicts the proportion of the Walrasian revenue that was raised in the final four auctions of each session, with sessions grouped by auction format and tight cap versus loose cap environment. Similarly, the bars in Figure 7 show the efficiency proportions for the final four auctions in each session in both the loose cap and tight cap settings. Each bar represents a session, where the first session listed in each group was done with the first random number seed, etc. There are no clear differences among treatments or auction formats in terms of efficiency, with all values close to 100 percent. In contrast, revenue percentages all appear well-below the Walrasian benchmark of 1, which was the expected result given the non-competitive nature of the experimental setting.⁶ For the pooled data across auction types, the two-sample Wilcoxon rank sum test ($W = 265$ and $p = .031$) allows us to reject, with better than 95% confidence, the null hypothesis that revenues are the same under a loose cap as under a tight cap. As expected, a tight cap results in more revenues than a loose cap.

This effect is not consistent across auction types. Using the Wilcoxon rank sum test for differences in the proportion of Walrasian revenue raised between the tight and loose cap within each auction format, differences arise. Each session was an observation where the proportion of Walrasian revenue averaged across the last 4 auctions served as the measure for comparison. We are unable to reject the null hypothesis of no difference in the proportion of Walrasian revenue raised between the tight and loose cap environment for the discriminatory ($W=38$, $p=.937$) and clock ($W=34$, $p=.485$) auctions. However, we found that the uniform price auction raised a larger proportion of Walrasian revenue in the tight cap environment relative to the loose cap environment ($W=24$, $p=.015$).

Vernon Smith (1967) found that seller revenues were higher in a uniform price auction than in discriminatory auctions in settings with moderate numbers of rejected bids, and that this difference is not apparent with high numbers of rejected bids. While these were multi-unit auctions, they are not directly comparable to our results, since bidders were only allowed to submit two bids; whereas our design allowed bidders to submit any number of bids for blocks of allowances. Moreover, in Smith's experiments, about a third (8 of 26) of the bids would be

⁶ In a series of experiments that we ran under more competitive conditions with 12 bidders and a tighter cap (equal to 70 percent of demand for permits at a zero price), we found revenues to be very close to Walrasian levels for uniform, discriminatory and clock auction formats with no systematic differences across auction types (Holt, Shobe, Burtraw, Palmer, & Goeree, 2007).

rejected even in the treatment with the fewest number of rejected bids, a considerably more competitive environment than the “loose cap” treatment tested in our experiments. As we have already argued, our less competitive set-up is more consistent with what has been observed in the early stages of emission trading regimes ‘in the wild.’ Furthermore, the Smith experiment was done in an environment that was motivated by the Treasury bill auctions, in which the prize values to bidders were identical for all units and were randomly determined, i.e. a random common value. The experiments reported in this paper implement a private value setting to emphasize the private nature of information about pollution control costs.

Conclusion

The initial allocation of emission allowances in a cap and trade program is one of the most contentious issues surrounding this form of environmental regulation. Increasingly, policy makers are turning to the sale of emissions allowances as the desired approach for distributing some or all of the allowances created by a cap and trade program and to auctions as the best approach for structuring that initial sale. Given the substantial value of emissions allowances associated with future cap and trade programs, particularly those designed to reduce emissions of greenhouse gases, finding the most efficient auction method and a way to capture the full market value of that newly created public asset is of keen interest to government officials. In addition, federal legislation to establish cap and trade programs for CO₂ in the U.S. and the current proposal for phase III of the EU ETS envision using a portion of the revenue from an allowance auction to promote carbon free technologies and energy efficiency in an effort to ease the transition to a world with lower CO₂ emissions. In order to be able to fund these efforts to the greatest extent possible, policy makers are keenly interested in having an auction design that will lessen opportunities for collusion and allow them to sell allowances at their full market value.

Past research suggests that the amount of revenue raised in different auction formats could depend on the amount of excess demand in the allowance market and given the prominence of relatively loose caps in the early years of past and existing cap and trade programs, it is important to test the efficacy of different auction types. We use laboratory experiments to test the performance of four auction types in the presence of a loose cap including uniform single round, discriminatory single round, clock and clock with excess demand information.

We find that, with a loose cap, all of the auction formats investigated yield a nearly 100% efficient allocation of permits. As expected, the amount of revenue raised in the auction appears to be less than revenue raised with a tight cap for all auction types. Given a loose cap, auction

type does affect revenues. Discriminatory auctions yielding higher revenues than sealed bid uniform price or the clock auction designs. However, the differences among the different auction types erode over time during a particular auction session. The convergence of results is consistent with learning and price discovery affecting the bids of participants in discriminatory auctions. Bidders in discriminatory price auctions appear to be more successful in later rounds at pegging their bids to the expected market price. This suggests that the advantage of the discriminatory price auction would likely not persist in a regime of regular greenhouse gas auctions.

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