Auction Design for Selling CO_2 Emission Allowances under the Regional Greenhouse Gas Initiative

Phase 1 Research Report (Draft)

May 25, 2007

Investigators:

Dallas Burtraw
Jacob Goeree
Charlie Holt
Karen Palmer
Bill Shobe

Auction Design for Selling CO_2 Emission Allowances under the Regional Greenhouse Gas Initiative

Phase 1 Research Report (Draft)

May 25, 2007

Contents

Executive Summary

The purpose of this research project is to assist with the design of auctions for the sale of carbon dioxide (CO_2) allowances in the Regional Greenhouse Gas Initiative (RGGI). Considerable experience in the sale of assets by governments has lead to the conclusion that careful attention to auction design can be critical to their success in achieving the goals specified for the auction. Usually the goal specified in the sale is to maximize some combination of efficiency and revenues. In RGGI other factors important to the success of an auction include transparency, ease of administration, competitiveness, the ability of the auction to elicit bids that reflect actual valuations by bidders, and restricting bidder opportunities for acting strategically. Auctions for RGGI CO_2 allowances will be taking place with the expectation that there will be an active secondary market for these assets and that a significant amount will be traded outside of the auctions themselves.

The long experience with auctions and the substantial value of items sold at auction has led to the development of a large body of academic literature on the subject. By reviewing case-study methods and statistical examinations of the actual outcomes of real-world auctions we can find empirical evidence of how well the theory fits the actual results. In addition, increasingly auction theory is being tested and refined in the economics laboratory. Experiments have been found to offer a virtue not only in testing strategic relationships and the likely market equilibria that might obtain, but also because the formalized experimental setting requires a detailed specification of the institution that will embody the auction format. Thinking through all of the details associated with that institution helps planners to anticipate potential problems. This research project relies on both the existing scholarly literature and experiments tailored to represent the RGGI context to develop recommendations for the design of auctions in RGGI.

The first phase of this project is primarily concerned with providing policymakers in New York and other RGGI states with information sufficient for them to choose an auction type from among the wide variety of alternatives. The results of this effort are included in this interim report. The second phase of this study will use the auction form chosen by policymakers based on Phase 1 to conduct a series of experiments designed to help in crafting the detailed specifications needed to implement an auction of the type chosen.

Several recommendations are offered at this interim stage. The most important of these is the recommendation for an auction format from among the types of formats that have been studied that can be the focus for Phase 2. For this purpose we recommend that RGGI may wish to consider a mixed auction program. The first time that a given vintage (preferably defined according to the 3-year compliance period) is auctioned, an English clock with a shootout round. The English clock will facilitate price discovery, and the shootout helps prevent collusion or manipulation of the market. Subsequent auctions of that vintage would be sealed-bid price auctions, but we do not yet offer a definitive recommendation about whether these should be discriminatory or uniform price auctions. This interim report also provides a summary of the experiments that have been conducted to date and an annotated bibliography that will be updated over the course of the project.

1. General Introduction

The purpose of this research project is to assist with the design of auctions for the sale of carbon dioxide (CO_2) allowances in the Regional Greenhouse Gas Initiative (RGGI). The analysis provided in this study will be equally applicable to either a larger, region-wide auction or a set of smaller auctions at the individual states across the region.[1]

Considerable experience in the sale of assets by governments has lead to the conclusion that careful attention to auction design can be critical to their success in achieving the goals specified for the auction. Sales have included a diverse array of rights such as timber harvests, resource extraction, electromagnetic spectrum, securities, and, as in this case, emission allowances. Usually the goal specified in the sale is to maximize some combination of efficiency and revenues. Roughly speaking, efficiency is measured by whether the auction results in the rights being owned by those who value them the most. While it is often the case that an auction with a high level of efficiency will also be good at raising revenues, and vice versa, this is not always true. Where evidence suggests a divergence, then an explicit tradeoff between these goals will be required.

Factors particularly important to the success of an auction also include the auction's competitiveness, the ability of the auction to elicit bids that reflect actual valuations by bidders, and restricting bidder opportunities for acting strategically in a way that defeats the efficiency or revenue raising function of the auction. In addition, there may be other, secondary characteristics that are of importance to policy makers or that may have an impact on the market into which the goods are sold, if not the efficiency of the auction itself. These factors may include price volatility, effects on related markets, transparency, administrative costs, and perceived political risk in auction outcomes.

Auctions for RGGI CO_2 allowances will be taking place with the expectation that there will be an active secondary market for these assets and that a significant amount of allowances will be traded outside of the auctions themselves. Concerns about the role of an auction in CO_2 allowance trading can be roughly divided into three categories, those concerns that arise due to the existence of trading itself, concerns that arise due to the auction institution chosen, and some concerns that involve the interaction of the auction with an existing market. In this report, we will primarily be addressing the latter two concerns and will try to point out cases where expressions of concern about the auction may be about issues that arise not from the auction but from the tradability of allowances themselves. These particular issues would arise whether the allowances were distributed for free (grandfathered), auctioned, or allocated in some other way.

---

[1] The RGGI Model Rule specifies that each state must allocate at least 25% of its budgeted allowances to a consumer benefit or strategic energy purpose account. These allowances are to be sold or otherwise distributed to promote energy efficiency, to directly mitigate electricity ratepayer impacts, or to promote lower-carbon-emitting energy technologies. Some RGGI states, including New York, have stated that they intend to auction 100% of their budgeted allowances. Many, but not all, RGGI states have expressed interest in conducting their auctions jointly.

The long experience with auctions and the substantial value of items sold at auction has led to the development of a large body of academic literature on the subject. This literature has three branches: theoretical, empirical, and experimental. The theoretical literature by focusing on the abstract strategic form of auctions allows us to make predictions about how various types of bidders will respond to particular auction forms in particular situations. These theoretical predictions are put to the test in two ways.

First, there is substantial and growing experience with real-world auctions and an increasing value of goods that are sold by auction in both the public and private sectors. By reviewing case-studies and statistical examinations of the actual outcomes of real-world auctions we can find empirical evidence of how well the theory fits the actual results.

Second, increasingly auction theory is being tested and refined in the economics laboratory. An economics laboratory generally comprises a group of human subjects at a set of computers that are linked together with specialized software that allows the subjects to be presented with a set of carefully designed decision tasks where the incentives, choices, information, and other characteristics are carefully controlled. By allowing one factor to vary while holding all other factors constant in the laboratory, experimentalists can test theoretical predictions about how that "treatment variable" affects outcomes. Due to their availability and suitability, college students are frequently used as experimental subjects in economics laboratories. Generally the experiment is structured so that these student subjects earn a payment based on the outcome of their choices.

Economics experiments are increasingly used for analyzing public policy. They have become an established tool for examining economic theories and institutions. Auctions, in particular, because of their compact institutional form are well-suited to experimental investigation. Experiments have proven valuable not only in testing strategic relationships and the likely market outcomes that might obtain, but also because the formalized experimental setting requires a detailed specification of the institution that will embody the auction format. Thinking through all of the details associated with that institution helps planners to anticipate potential problems.

Given the number of institutional design issues needing to be addressed, it would be impractical to carry out a detailed analytical study and experimental exploration of design issues for a large number of auction types. As a result, this research project has been divided into two phases: (1) the first phase focuses on the choice of an auction type, and (2) the second phase focuses on the detailed institutional design based on the auction type chosen in phase 1.

The first phase is primarily concerned with providing policymakers in New York and other RGGI states with information sufficient for them to choose an auction type from among the wide variety of alternatives. This phase includes the preparation of an annotated bibliography of key papers on auctions generally, emission auctions in

particular, and other, related auction topics including among other things auctions used for obtaining electricity supplies, often referred to as independent system operator (ISO) auctions. Phase 1 also includes a round of experiments to investigate the performance of a number of auction forms considered to be likely candidates for use in a CO_2 allowance auction. The Phase 1 experiments measured the efficiency and revenues from the tested auction types taking into account asymmetries in the cost of compliance and also taking into account the likely presence of a secondary (spot) market for allowances. Based on results from the academic literature, experience with previous auctions of allowances, and the laboratory experiments, this report on Phase 1 of the research provides recommendations concerning which auction forms are likely to provide the best fit for the auction of RGGI allowances.

Phase 2 of this study will use the auction form chosen by policymakers based on Phase 1 results to conduct a series of experiments designed to help in crafting the detailed specifications needed to implement an auction of the type chosen. Phase 2 will examine the likely impact of:

- Secondary markets
- Banking and reserve prices
- The presence of varying allowance distribution mechanisms
- Market power and collusion
- Participation by "non-compliance entities"
- Revealing bid information after the auction

The Phase 2 report will include sufficient detail to use as a basis for purchasing the brokerage services needed to implement an allowance auction.

In the next section, we provide an introduction to several key auction formats and we report on the experiments from Phase 1 that were carried out between early March and early May of 2007 primarily at the economics experiment lab at the University of Virginia. Next we will provide some annotated references to the academic literature on auctions and, in particular, on auctions of emissions and of electricity supply. Finally, we will use the accumulated evidence from our experiments, from prior emission auctions, and from the academic literature to recommend auction forms to carry forward into Phase 2 of the research.

2. Experimental Methods

A key part of this research is the use of experimental methods to test alternative auction formats as well as to test a specific format that would be developed in detail. The experimental methods proceed in two phases. Here we introduce several key auction formats and the research design that is used to compare these formats in the laboratory setting.

2.1. Introduction

RGGI CO_2 allowances permit the release of a ton of CO_2 into the atmosphere and are identical except for their vintage, which determines the first year in which the allowances may be used. Once an allowance vintage year has been reached, the allowance may be used in that year or banked for use in any future year. Since many allowances will be sold in any single auction, this study is limited to auction forms appropriate to the sale of multiple units of an identical commodity. Multi-unit auctions can usefully be categorized in two dimensions, the number of rounds, one or more than one, and how the price is set for the buyers, a single price or a 'discriminatory price' that differs among buyers and depends on the amount of their bid. These different auction forms have different properties and may be used in combination to improve overall outcome.

For Phase 1, we conducted experiments with 5 alternative auction formats, including three mentioned in the statement of work, that have been used previously in the field: discriminatory sealed-bid (used for SO_2 allowances under title IV), uniform price sealed-bid (used in Ireland for auctioning ETS CO_2 allowances last year), and an English clock (ascending bid) auction (used for the Virginia NO_x auction of allowances to comply with the NO_x SIP Call). These auction formats are described in section 2.2, along with two others that were tested: a Dutch (declining price) auction with discriminatory pricing ("buy now"), and an English clock followed by a final sealed-bid "shootout," which we called the "shot clock." Section 2.3 describes the general industry structure that was used for these Phase I auction experiments. Section 2.4 provides a comparison of the performance measures used to evaluate these auctions, including economic efficiency and revenue, and it provides the results from the first phase of experiments.

2.2 Auction Formats

We have considered and tested several alternative auction formats. The first three, taken from the Statement of Work, are: discriminatory sealed-bid, uniform price sealed-bid, and clock. In addition, we implemented a shot clock (an English clock followed by a final "shootout sealed-bid phase") that is designed to deter collusion, and a Dutch (multi-round, declining price, discriminatory price) auction. These formats are described in the paragraphs that follow, along with a couple of other ideas that we considered but are not pursuing at this juncture.

All of these auction formats are multi-unit auctions for a fixed number (Q) of allowances. Each bidder is assigned a production capacity, each unit of which requires some number of allowances in order to proceed with production. Bidders' values for allowances are determined by the profit margins on their production capacity and by the numbers of

allowances needed to cover the production activity. Each bidder is given an "activity constraint" that restricts the number of allowances on which they can bid. In practice, this activity maximum can be infinity, i.e. no limit, or it could be determined by financial pre-qualifications. In the initial round of experiments, where banking is not allowed, bidders only bid on allowances that they need to support their production activity. Hence, these activity limits are not binding except in the clock auctions where, as a feature of that format, a bidder is not allowed to increase the number of units requested as the price rises in subsequent rounds. Also, in the shot clock format, the activity constraint that the bidder ends up with in the penultimate round constrains the number of allowances that they can bid for in the final round shootout.

Discriminatory: This is a single-round, sealed-bid auction in which the bidders can submit multiple bids at different prices, and the highest bids for the Q allowances obtain allowances at their own bid prices. The auction is "discriminatory" because the price paid varies among bidders, in relation to their bid price. Ties at the cutoff price are decided at random. This is a very simple auction to conduct and understand. In auctions for single prize "units," the presence of bidder risk aversion may cause revenues to be higher in this auction than in a uniform price auction (where all bidders pay the same price), but in multi-unit auctions the amount of revenue collected can be greater than or less than revenues from a uniform price format auction. In multi-unit auctions, revenue comparisons between the discriminatory and uniform price formats tend to depend on the nature of the distributions of the bidders' values (willingness to pay) for the items being auctioned. One perspective on this might be that experimental results would be unreliable unless great care is taken to precisely match conditions in the experiment with the empirical situation in RGGI. We suggest that a more accurate perspective is that the actual distribution of bidders' values is not fully knowable and that an attempt to represent it precisely implies false precision. In the experiments we represent an accurate by stylized distribution of bidders' values, and we observe whether important variations in revenue are achieved when that distribution is varied.

Uniform Price: This is also a single-round, sealed-bid auction in which bidders can submit multiple bids at different prices, but the price paid by all bidders with the highest bids for the Q available units is equal to the highest rejected bid. This is the type of auction that was used for CO_2 allowances in Ireland last year; it is also transparent and easy to conduct. In auctions for a single unit, the bids will tend to reveal bidders' values (with some noise[2]), which tends to produce an efficient allocation to the bidder with the highest value. This result does not necessarily carry over to a multi-unit case, where bidders may attempt to manipulate the clearing price by bidding low on "marginal" units in the hopes of bringing down the market-clearing price. Uniform price auctions may also involve some embarrassment for the seller if some bidders with very high bids obtain units at low prices. This may leave the seller open to criticism that buyers obtained goods at prices substantially below what they were willing to pay.

[2] The word 'noise' in this context means that there is some randomness in our observations of values.

English Clock: This is a multi-round auction in which the auctioneer posts a sequence of increasing prices, usually at regular time intervals, and the bidders state the quantity they are willing to buy at the given price. The "provisional" price starts at a price low enough so that the quantity demanded at that price is greater than the amount the auctioneer has to sell. The price is raised, as if by the hand of a clock, in response to the excess demand (e.g. the total quantity bid, Q*, that is greater than the available number of allowances Q). So, at each stage, the provisional price is announced and bidders state how many units they desire. The auction stops when the demand falls below the amount offered for sale: $Q^* <= Q$. There is an issue of how to deal with the possibility of unsold units if $Q^* < Q$ in the final round. We follow the procedure used in the Virginia NO_x auction of rolling back the price by one bid increment and selling all Q units at the lower price if to do so would increase revenue. In case of a rollback, all who expressed a willingness to buy at the higher price are included, and the remaining $Q - Q^*$ units are allocated on the basis of the chronological order in which the bids were submitted in the penultimate round, which provides bidders with an incentive to bid early in each round.

In order to force bidders to bid actively, each bidder's activity limit (quantity bid) falls to the number of units requested in a round and cannot be raised in subsequent rounds, so activity has a "lose it or use it" feature that prevents bidders from hiding their interest in early rounds. Another issue that arises in a multi-unit auction is what information to provide bidders after each round. The experience with the Virginia NO_x auction and in other settings that we have reviewed suggests that it is best not to reveal the total number of allowances requested in each round so that bidders will not be able to determine whether unilateral demand reductions on their part will stop the clock. Providing less information will tend to discourage collusion among bidders. Multi-round auctions have the advantage of giving bidders a chance to think carefully as the prices develop, and delays can be minimized by providing an incentive to bid early. Also, since, at each stage, each remaining bidder knows that there are other bidders who value the items at least as much as they do, then from that bidder's point of view, the probability that he is greatly over-valuing the items is reduced. This reduces the incentive to hedge bids to avoid the 'winner's curse'.

Shot Clock: This is also a multi-round clock-driven auction with the same activity constraints described above. The clock price rises in successive rounds, and it stops when the total number of units requested falls to a "cutoff" level that is a specified fraction higher than the number of units being auctioned: $(1+x)Q$, where $x > 0$. For example, if a 10% cutoff trigger were used in an auction of 1,000 items, the cutoff could be triggered when the quantity bid drops below 1,100 items. When the clock stops, all bidders may submit a final set of sealed bids in the form of quantities and prices subject to two constraints: any additional bids must be greater or equal to the final clock price, and the number of allowances bid for may not exceed a bidder's activity. For any units without a bid in the shootout round, the final clock price applies. Allowances are awarded to those making the Q highest bids, and bidders pay their own bid prices, so this is a hybrid between an English clock and a discriminatory, sealed-bid auction. It is sometimes called an "Anglo-Dutch auction," since the ascending price phase is like an English auction, and the final shootout has a discriminatory flavor, as does the multi-

round Dutch auction to be described next. Incentives for collusion and strategic manipulation may be reduced by not revealing the numbers of allowances requested after each round, and not revealing the exact level of the cutoff. The presence of the final shootout stage reduces the effectiveness of collusion and strategic manipulation.

Dutch: This multi-round auction starts with a high provisional price, which falls by pre-determined increments. In each round, the bidder can "lock in" some purchases at the current provisional price (analogous to a "buy now" provision in an online auction at eBay), and/or the bidder can wait for the price to fall. The auction stops when the number of allowances locked in is greater than or equal to Q, with ties in the final round decided by the time at which a bid was entered, again providing an incentive for bidders to act early in each round. Again, the multi-round nature of a Dutch auction may provide bidders with time to think about bids as the auction progresses.

Other Auction Types: We ran tests on a multi-round discriminatory auction with increasing prices, which was loosely patterned after the Federal Communications Commission (FCC) "simultaneous, multi-round auction." In each round, bidders submit bids, and the Q highest bids are announced as provisional winners. These winning bids need not be raised in the following round, but provisionally rejected bids must either be raised or withdrawn (thereby reducing a bidder's activity). In tests, this format required more than five times as many rounds of bidding to reach convergence as a simple clock auction, since bid increases for a small number of rejected bids tended to rotate across bidders, thereby slowing the overall degree of price increases. An alternative, not tested thus far, would be to have a fixed number of stages (say 2-3) and to have bids in the initial stage(s) determine eligibility and lower limits for bids submitted in a final stage. This format is similar to the shot clock in that early round bidding determines eligibility and may provide some price discovery information, but we decided to use the shot clock instead for the purpose o investigating performance of this type of hybrid approach. If the shot clock format is pursued in the second phase of research, one design alternative would be to simplify it in the manner described here.

2.3. Market Structure and Laboratory Procedures

The auction experiments conducted to date were evaluated in a stylized setting that was intended to capture key aspects of the market for allowances, while keeping the setup simple enough to be relatively transparent for subjects.

Each experimental session involved 12 participants, recruited from the undergraduate population at the University of Virginia. Participants were given a financial reward just for showing up, in addition to earnings from purchasing the auctioned "permits"[3] at prices below their values in the experiment. Each participant was given the role of a firm with multiple "units" of capacity that could be used to produce a product that sold at a known price. The use of each capacity unit required that the person obtain permits.

[3] The word "permits" was used in the experimental sessions to abstract somewhat from the specific context of pollution trading.

To represent the technological characteristics of the market in the laboratory experiments we draw on information that the emission rate (tons CO_2 per MWh) for gas-fired generation is about 0.428 times that for coal-fired generation. Currently electricity generation from coal and gas-fired generation are roughly equal in the ten state RGGI region. For the laboratory experiments it is important to have a correct stylized representation of the underlying technology but it is not important to achieve precision. To move forward we assume that coal-fired generation requires 2 emission allowances for every 1 allowance required by gas-fired generation and that capacity for generation exists in equal proportions.

To keep the experiment from becoming too complicated, we used relatively small numbers of permits; with 60 permits being sold in each auction. Thus each permit in the experiment corresponds to a block of "allowances" in the market. We introduced an asymmetric cost of compliance by requiring some subjects to obtain more permits to operate capacity than others. In particular, half of the subjects were "low users," who needed *one* permit for each capacity unit, and half were "high users" who were required to obtain *two* permits to operate each of their capacity units. You can think of low users as using natural gas, and the high users as using coal; the equal numbers of low and high users was intended to roughly mimic the relative proportion of coal and gas generators in the region. With a fixed and certain output price used in the Phase I experiments, there is no motive for non-emitters (nuclear, hydro) to acquire permits. However we plan to include subjects with non-emitter roles in the setup in Phase II.

Production costs for each unit were randomly generated for each new auction, in order to ensure that comparisons among auctions were not driven by particular configurations of units' costs. Banking of permits was not allowed in these sessions, so each auction is a separate strategic situation, and costs were regenerated each time. (In contrast, the costs for each unit will remain fixed except for the possibility of uncertainty in fuel prices from auction to auction in the phase two sessions where banking, non-compliance penalties, and other dynamic considerations are introduced.)

The difference between the known price of the product and the randomly generated cost is the profit margin, and permit values are determined by taking this profit margin and dividing by the required number of permits to operate a unit of capacity. For example, with a cost of 6 and a price of 12, the margin is 6, and the permit value would be 6 for a low user who requires one permit to operate the capacity unit, whereas the value of each permit would be 3 = 6/2 for a high user who is required to have two permits to operate. The costs of operating capacity for low users were set to be roughly twice as high as the costs for high users, to reflect the higher costs associated with natural gas generation. This cost difference also served to approximately equalize earnings across subjects with different roles. The costs for low users were randomly drawn from the interval [5, 10], with all values in this interval being equally likely, and the costs for high users were drawn from the interval [2, 6].

With a fixed output price, a "wide" distribution of costs determines a wide range of permit values. Since costs are drawn from the range [5, 10] for low users, with all draws in this range being equally likely, then a product price of 12 will result in a range of permit values between 2 (= 12-10) and 7 (= 12-5). The values for high users are obtained by dividing profit margins by the required number of permits (2) per capacity unit, so a cost distribution from the range [2, 6] results in values between 3 = (12 – 6)/2 and 5 = (12 – 2)/2. Note that a narrow range of costs would determine a narrow range of values and a relatively flat ("elastic") demand for permits, whereas a wide range of costs would determine a wide range of values and a more inelastic demand. We narrow ranges of values in some sessions to induce a more elastic demand for permits. In the narrow-range treatment, the cost distributions of [2, 6] and [5, 10] for high and low users were reduced to [3, 4] and [7, 8]. The narrow range of values creates a more competitive situation, with low earnings, so participant earnings were doubled for the narrow range treatment by doubling the conversion rate between lab earnings and cash earnings paid at the end of the experiment. The parameters used are shown in Table 1.

Table 1. Experiment Parameters

	Wide Cost Range	Narrow Cost Range
Low User Cost Distribution	[5, 10]	[7, 8]
High User Cost Distribution	[2, 6]	[3, 4]
Product Price	12	12

We ran 15 sessions with these wide cost distributions, 3 sessions for each of the five auction types described above, using a total of 180 subjects (= 15x12). In the second set of sessions with the narrow cost ranges, we focused primarily on the three auction types listed in the statement of work. In particular, we ran three sessions using each of the three main auction types (uniform & discriminatory sealed-bid, and clock) and one session each for the other two auction types (shot clock, Dutch), for a total of 11 sessions and 132 subjects. The participants for this second set of sessions were recruited from those who had participated in the first set of sessions.

Finally, we ran four sessions with a spot market following each auction (wide cost range).[4] The spot market is structured so that participants can submit limit orders that specify a maximum quantity of permits and a maximum purchase price or a minimum sales price, e.g. sell up to 6 permits for at least $4. Buy orders were arrayed from high to low, sell orders were arrayed from low to high, and the price determined by the intersection of these arrays was the price at which transactions were executed. Then after the spot market cleared, subjects decided how many permits to use in production and whether to bank permits or incur a deficit. It was announced that any deficit in permits was penalized at a rate of $9 (about three times the predicted price, which is defined below) after the spot market that followed auctions 3, 6, 9, etc. That is, the experiment

[4] In addition, we ran another 12 pilot sessions for testing purposes (some done with fewer than 8 auctions or 12 participants) to refine the instructions and procedures. Subjects earnings were in the $30-$40 range, and in total, we have spent about $11,500 on subject payments thus far.

characterized a compliance or true-up period that occurred after every three auctions. In fact, there were only 8 auction/spot-market pairs, but this was not announced in advance, so subjects behaved as though the experiment would continue beyond number 8.

2.4. Performance Measures and Results

The two numerical performance measures to be considered are revenue and efficiency. "Efficiency" as used here means the maximum possible total surplus of value over cost. So, when a bidder wins an allowance at auction, the surplus generated from that purchase is the value that allowance has to the bidder minus the amount paid. Efficiency can be reduced if the "wrong" (high-cost) emitters operate their capacity units while some low-cost emitters do not, or if some permits go unsold and total production of the final product is reduced.

In a competitive market, there will be a price that causes the quantity demanded to be just equal to the quantity supplied; this price-quantity pair is known as a "Walrasian equilibrium." In a Walrasian equilibrium, the surplus is maximized because traders keep trading until the goods are owned by those who value them the most. It is called an equilibrium because there is not incentive for anyone to trade once this point is reached. The "Walrasian revenue prediction" is the amount of revenue that this sale would raise, price times quantity. At a Walrasian equilibrium, most traders value the good traded at something more than the price paid; they earn a 'surplus' on each of these units.

The efficiency measure used in the experiments is the actual surplus achieved as a percentage of the maximum possible surplus obtained by maximizing surplus subject to the constraint that 60 permits are used, which is essentially the "area under the demand curve" for allowances. Surplus will be maximized if allowances are allocated to those who value them the most so this measure tells us how far we are from that objective. Auction revenue is expressed as a percentage of the maximum surplus, which would also be the revenue if bidders bid their full values for each permit in a discriminatory auction. This is an unrealistic revenue goal, since bids in a discriminatory auction will generally be below value, and therefore, the results graphs also show the competitive or "Walrasian" revenue benchmark that would result if bidders were to bid their true values in a uniform price auction.[5]

Figures 1-5 show the revenue and efficiency results for each trial in a representative session conducted with each auction format; in each case using the wide cost range. In each figure, the Walrasian revenue prediction is shown by the light gray line; these lines are the same for all figures since the same sequence of random cost draws was used in each of these sessions so that comparisons across auction formats would not be affected by the random variations in the costs used. As we analyze this data, the main focus will be on the final 4 auctions of each session since they are less sensitive to "learning

[5] The Lagrange multipliers for this constrained optimization problem determine the predicted permit prices, which vary from one auction to another due to randomness in the cost realizations.

effects,"[6] but it is interesting to look at performance measures in the initial auction. In particular, more aggressive bidding in the first auction causes revenues to be higher, and efficiencies lower than in later auctions. This is particularly apparent in the declining price Dutch auction where subjects seemed prone to press the "buy now" button, even though the instructions contained warnings about possible losses and all bid screens were followed by a "confirm or rechoose" screen with warnings in cases where bids could result in losses. Some screen shots of instructions for a typical clock auction session are provided in Appendix F.

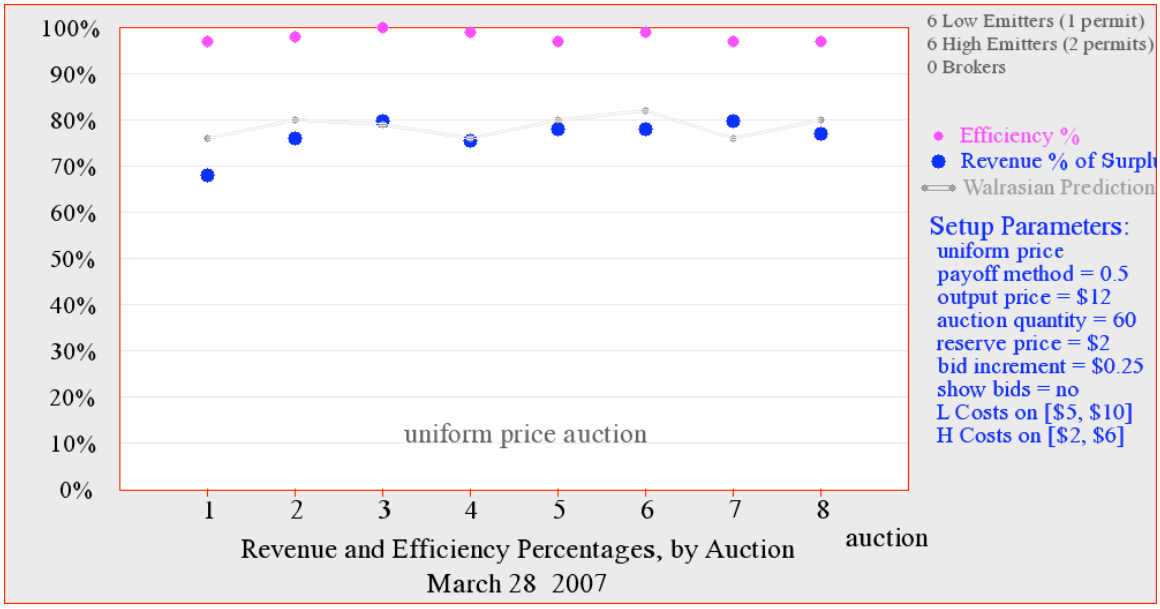


Figure 1. Revenues (blue) and Efficiencies (magenta) for a Uniform Price Auction
Key: Walrasian revenue predictions are shown as the gray line.

[6] Learning effects result from subjects improving their understanding of the given auction procedures and setup as they gain experience.

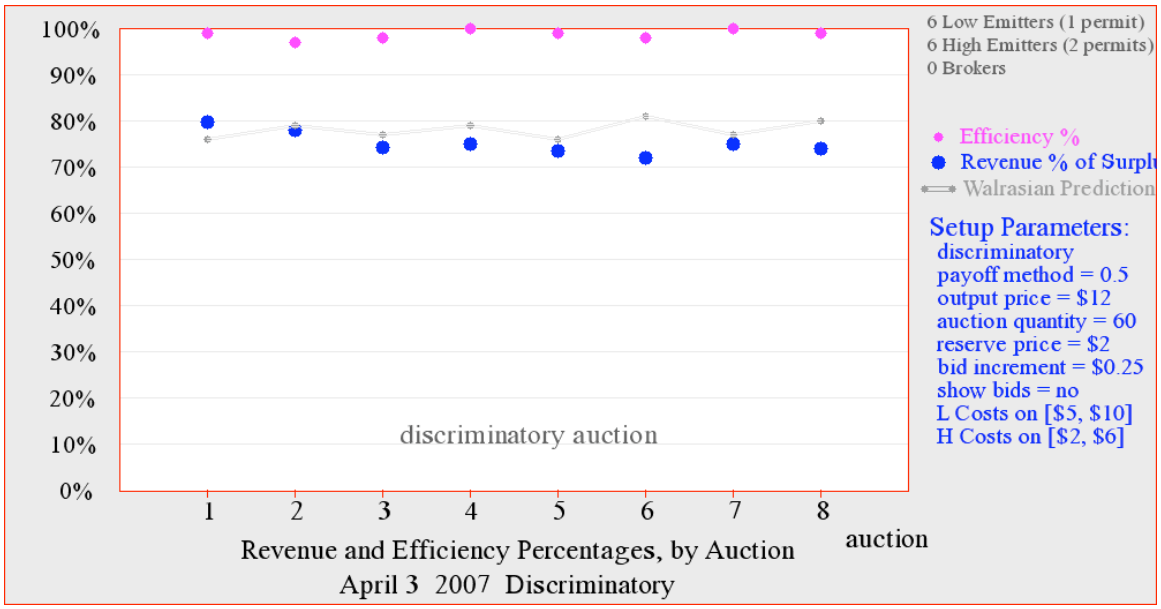


Figure 2. Revenues (blue) and Efficiencies (magenta) for a Discriminatory Auction
Key: Walrasian revenue predictions are shown as the gray line.

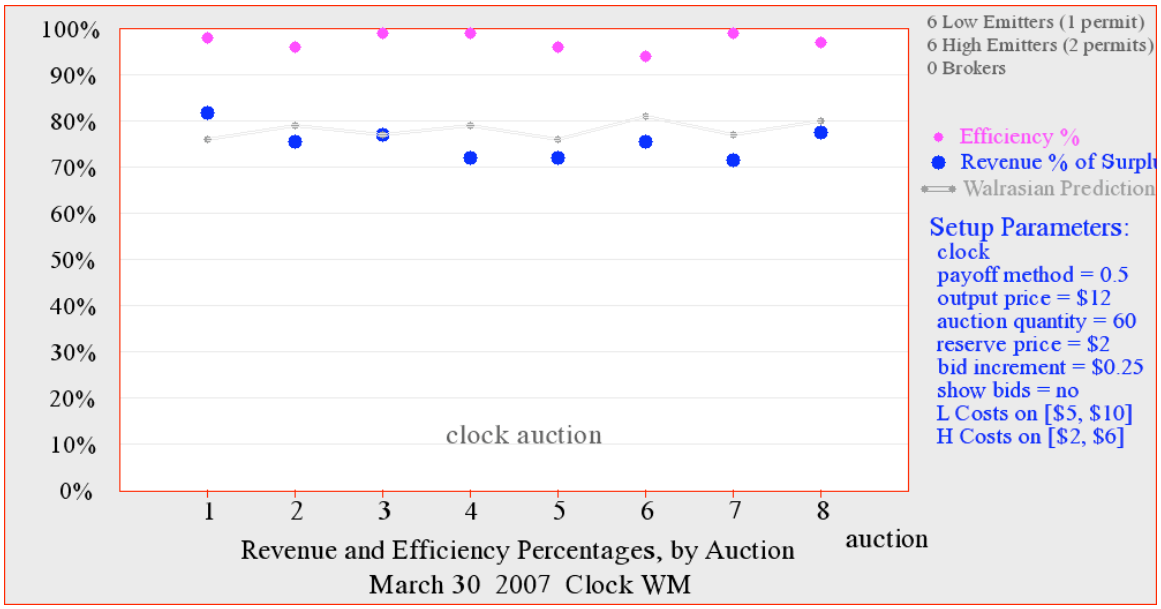


Figure 3. Revenues (blue) and Efficiencies (magenta) for a Clock Auction
Key: Walrasian revenue predictions are shown as the gray line.

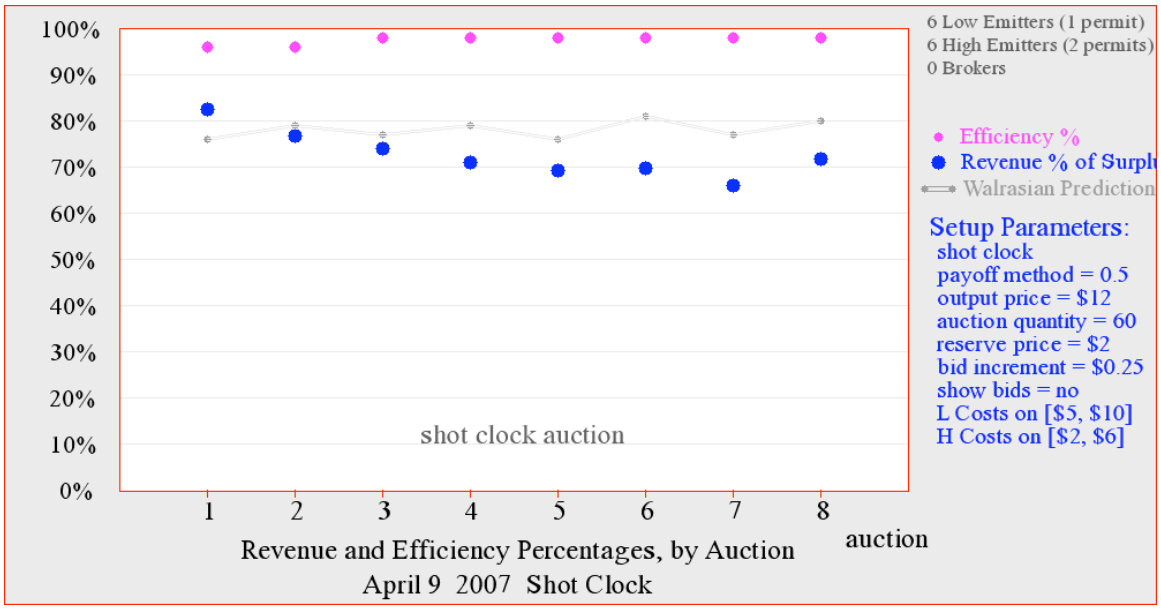


Figure 4. Revenues (blue) and Efficiencies (magenta) for a Shot Clock Auction
Key: Walrasian revenue predictions are shown as the gray line.

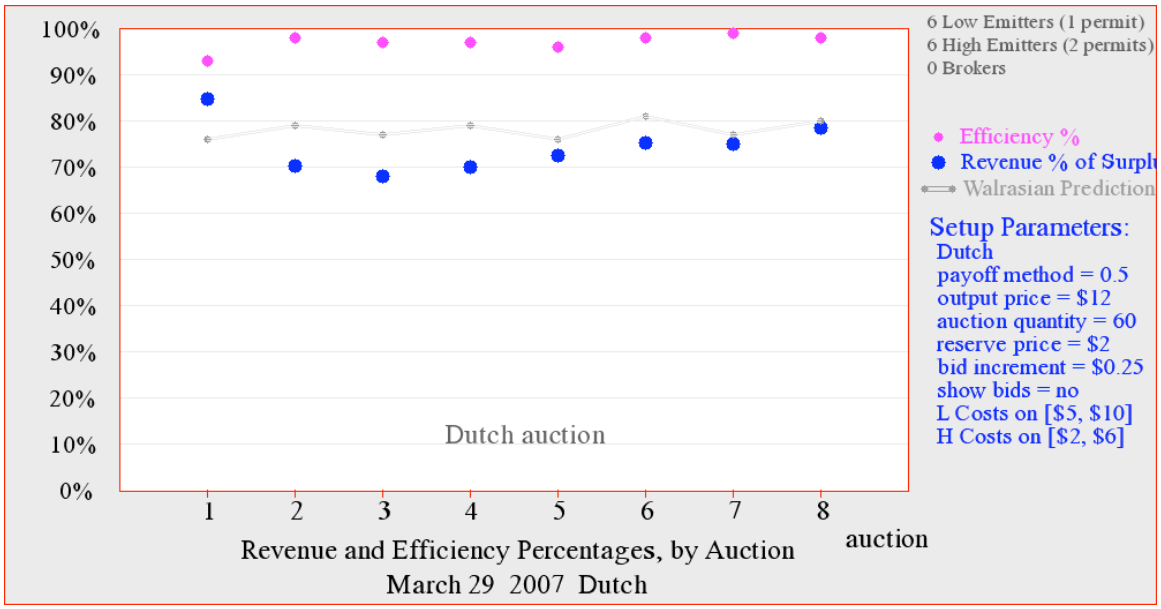


Figure 5. Revenues (blue) and Efficiencies (magenta) for a Dutch Auction
Key: Walrasian revenue predictions are shown as the gray line.

Tables of revenues and efficiencies for all auctions in all sessions are provided in the Appendices A-D, but it is instructive to look at summary averages for the final 4 auctions

of each session. Table 2 shows the revenue and efficiency percentages for the 15 sessions done with the wide cost range, with averages for the last 4 auctions of each session to account for learning effects. The main result is that all auction formats are reasonably efficient, and the revenues for the two single-round, sealed-bid formats (discriminatory and uniform price) are at least as high as those for the multi-round formats.

Table 2. Summary Performance Measures for Wide Cost Range Sessions
(Averages for the final 4 auctions in each session)

	Revenue Percentages		Efficiency Percentages	
	Session	Overall	Session	Overall
Uniform Price	78, 78, 74	77	98, 98, 98	98
Discriminatory	75, 74, 79	76	98, 99, 99	99
Clock	67, 74, 71	71	95, 97, 97	96
Shot Clock	73, 75, 69	72	98, 99, 98	98
Dutch	75, 77, 74	75	98, 99, 99	99

Previous work had suggested that auctions with a uniform price property (single-period uniform and English clock) might perform better with a narrow cost range. This pattern is suggested by the results in Table 3, but there is some overlap and the results are not definitive. In any case, we do not see the dramatic revenue increase of over 15% reported by Porter et al. (2006) for a treatment with a narrow range of bidder values.

Table 3. Summary Performance Measures for Narrow Cost Range Sessions
(Averages for the final 4 auctions in each session)

	Revenue Percentages		Efficiency Percentages	
	Session	Overall	Session	Overall
Uniform Price	92, 92, 93	92	99, 99, 99	99
Discriminatory	87, 92, 93	87	98, 99, 99	99
Clock	91, 90, 93	91	100, 98, 100	100
Shot Clock	87	87	94	94
Dutch	92	92	99	99

We also ran four 12-person sessions with spot markets after each auction. Banking was allowed and permit deficits were penalized at a rate of $9 after the spot market following every third auction. As before, there were only 8 auctions, but subjects were not told the number of auctions in advance, so many of them carried inventories after auction 6. The non-compliance penalty was so severe that all participants managed to avoid penalty fees, by carrying an inventory of permits, making purchases in the spot market, or curtailing permit use. The results of these sessions are shown in Table 4, where the efficiencies and revenues are shown for all 8 auctions in sequence. As was the case without spot markets, there is no clear ranking of one auction format over the other, and differences are largely

driven by the success or failure of inventory management and speculation efforts. In all sessions, banking of permits may reduce production in early periods and expand it past the optimum in later periods, resulting in efficiencies of more than 100%. The added complexity caused by permit banking makes auction comparisons more difficult, but it will be useful in assessing the effects of market power, reserve prices, "loose caps," spot market trading by non-emitters, and other factors to be investigated in Phase 2 of this research.

Table 4. Sessions with Banking and Spot Markets After Each Auction (Wide Cost Range)

	Revenue Percentages		Efficiency Percentages	
	By Auction	Overall	By Auction	Overall
Uniform Price Sessions	60, 68, 71, 67, 70, 70, 66, 69	68	66, 94, 89, 84, 108, 09, 93, 100	93
	63, 73, 77, 72, 72, 78, 77, 80	74	82, 88, 81, 84, 104, 108, 87, 80	89
Discriminatory Sessions	74, 76, 73, 75, 71, 71, 71, 74	73	90, 89, 92, 90, 91, 108, 107, 104	96
	79, 81, 79, 78, 79, 78, 79, 81	79	81, 93, 106, 84, 105, 101, 95, 99	97

3. Literature on Auctions

A voluminous literature on auctions has grown up over the last three decades. The literature has three main branches. The main stem is analytical work that has approached auctions as a market institution with the potential for strategic behavior on the part of buyers and sellers. Since many different types of goods may be brought to auction, and there may be many different configurations of sellers and buyers, a variety of market structures are possible. The second branch is an empirical literature that stretches from business school case studies to the use of advanced econometrics to test auction theory. The third branch is the experimental literature.

In this section we identify many of the most influential articles in the last thirty years and we provide annotated references to summarize the main results, especially as they may be relevant to the auction of emission allowances. This review is ongoing so several references are as of yet not annotated, and additional references will be added.

After providing a review organized simply by alphabetical order of the first author, we develop an interim summary of the literature with a table providing the main findings. This summary provides the point of departure for an assessment drawing on the published literature about the choice of auction format to be the central case for further experimental research. We use the literature review to complement the experiments that we have already conducted.

3.1 Annotated Bibliography

The annotated bibliography is attached as an appendix.

3.2 Summary and Discussion

Table 5 provides a summary of some of the most important findings in the auction literature. We evaluate these in a qualitative way by indicating cases when an auction type is generally thought to have a positive attribute. Each numbered attribute is explained in turn.

Table 5: Atributes of Auction Formats Identified in Previous Studies:
'Yes' Indicates a Positive Attribute

	Single-Round Auctions		**Multi-Round Auctions**		
	Uniform Price	Discriminatory	English (Ascending) Clock*	Shot Clock**	Dutch (Declining) Clock**
1) Round by round price discovery feedback information	No	No	Yes	Yes	No
2) Avoids bidder *ex post* regret	Yes	No	Yes	No	No
3) Avoids seller *ex post* regret	No	Yes	Yes	Yes	Yes
4) Prevents "demand reduction" price manipulation	No	Yes	No	Yes	Yes
5) Deters collusion among bidders	Yes	Yes	?	Yes	Yes
6) Prevents surprise power play to corner market	Yes	No	Yes	No	No
7) Promotes entry	Yes	Yes	No	Yes	?
8) Revenue maximization	Indeterminate				

* The English (ascending) clock is a uniform price auction.

** The shot clock and Dutch (declining) clock auctions are discriminatory price auctions.

1) Round by round price discovery feedback information. The price discovery attribute (learning by bidders) is based on the notion that bidders may initially have only a very vague conception of what the "going price" will be, so that a multi-round auction, which by its nature includes useful feedback, will provide better information for "price discovery." The English clock and shot clock auctions have this feature because bidders

receive information that the total demand is less than supply as the clock price is incremented. The Dutch clock auction also has multiple rounds, but the bidders make binding "buy now" decisions along the way as the price drops, so there is little chance to learn for these bidders.

2) Avoids bidder *ex post* regret. The *ex post* bidder regret can occur when a bidder pays more than would have been necessary to make a purchase, as in discriminatory, shot clock, and Dutch auctions. This regret is more likely to be a problem when bidders are acquiring inputs (e.g. allowances) used later in competition with other bidders in providing the electricity output. Competing firms may value price uniformity, and the people doing the actual bidding for those firms will of course, want to avoid the appearance of "leaving money on the table" in a public setting where all bids are likely to be announced *ex post*. Delaying the announcement of actual bids until some time has elapsed may reduce the importance of his attribute. Also, in discriminatory price auctions, weaker bidders run greater risk of suffering the winner's curse. A weaker bidder is one who may have a smaller share of the market or less knowledge (greater uncertainty) about market or technological characteristics.

3) Avoids seller *ex post* regret. The converse of the bidder *ex post* regret problem arises when bids reveal that the winners would have been willing to pay a lot more than they ended up paying, as happened in a broadcast license auction in New Zealand. This problem does not arise in the three auctions where winning bidders pay what they bid, nor does it arise in the clock auction that truncates the bidding when demand falls to the number being sold. It does not arise in clock auctions because the bidders never need to state the maximum amount they would be willing to pay for a given unit.

4) Prevents "demand reduction" price manipulation. In auctions with uniform prices (including the English clock), the price paid for all allowances depends on bidding "at the margin," and bidders with multiple units may have an incentive to withhold demand on marginal units in order to reduce the price paid for high-value, infra-marginal units. For example, in a uniform price auction, bidding low on low-value units might end up lowering the highest rejected bid. Similarly, lowering one's purchase request in an English clock auction for units that are marginally profitable at the current clock price might cause the clock to stop and lower purchase costs for high-value infra-marginal units.

5) Deters collusion among bidders. Another potential issue with multi-round auctions is that sellers might be able to infer things about whether others are adhering to collusive agreements. In an English clock auction, for example, suppose that all bidders agree to request shares of allowances that add up exactly to what is being auctioned after the price reaches a low but focal level. Then if the price continues to rise after that point, bidders would know that someone did not restrict their demand. However, efforts to punish the defector in the same auction are limited, since bidders who have already reduced their activity levels cannot raise them again, and continuing to bid after the clock price exceeds the value of a unit is risky unless other's valuations are known. This is a good reason for not revealing the excess demand at each stage in a clock auction. The idea behind the

shot clock is that even if the clock stops as planned by a bidding consortium, each bidder would have a private incentive to bid higher in the final sealed-bid stage.

6) Prevents surprise power play to corner market. One scenario that has come up is the possibility that an aggressive bidder might try to corner the market by obtaining a large share of the allowances in a surprise move. This, of course, could happen in the sealed-bid auctions and in the Dutch auction by bidding to purchase a large block of allowances at a high price. In contrast, bidders in an English clock auction will see the price rise when one bidder is demanding a high share of the allowances, and these bidders can respond by continuing to bid for allowances as long as the clock price does not exceed their valuations. The potential for market cornering behavior is not restricted to auctions. Purchasing allowances on the spot market could accomplish the same end. It is, however, worth assessing whether the existence of auctions makes market manipulation easier. One obvious conclusion would be that smaller, more frequent auctions would automatically be less useful for market cornering efforts than would less frequent, larger auctions. For smaller auctions, a bid to purchase all units at a high price could not allocate enough allowances to cause large price movements given the numerous other opportunities to purchase allowances. The issue of artificially high prices due to hoarding or market cornering efforts is also addressed in the current regulations by rules allowing for offsets at various price triggers.

7) Promotes entry. Sealed bid auctions give entrants a better chance of winning, especially weaker entrants who do not have an incumbent position in the market. In multi-round auctions there is a better chance for a strong incumbent to respond and punish entrants, as noted above, and hence to deter entry. The shot clock preserves the opportunity for a new entrant to bid their value and be somewhat insulated against retaliation. Aggregation of small bidders through brokers or intermediaries is another remedy. In this market, entry into the CO_2 market is not difficult, and sufficient levels of competition may make entry deterrence less of an issue.

8) Revenue maximization. Discriminatory price auctions provide some incentive to bid below one's true willingness to pay and this can lead to a lower equilibrium price and lower revenue from the auction. The incentive stems from the fact that in such an auction the bidder pays whatever price is bid. There is a possibility that one could cast a winning bid at a level below true willingness to pay, so the bidder will factor this into the bid decision. The auction literature suggests that the ability of a given auction form to maximize revenues will depend at least in part on specific characteristics of the market for allowances, in particular, demand elasticity and the relative scarcity of the allowances.

4. Analysis and Discussion

To offer a recommendation for New York and RGGI we draw on information from our own experimental efforts and the broader literature because neither body of information is sufficiently rich to provide unequivocal guidance. The experiments that we have conducted characterize some important aspects of the market structure for RGGI allowances that does not exist in the previous literature. Meanwhile much experience and knowledge conveyed in the previous literature rests on theoretical results and empirical experience that we cannot afford to and need not replicate in the laboratory.

From the experimental effort so far we have learned that the somewhat more exotic auctions that were tried did not outperform the basic auction forms already being used in allowance allocations. A criterion that we consider in making a recommendation is the simplicity of the auction format because a simple format is likely to be more transparent and have lower administrative costs for participants. While more analysis of the data is necessary, the tentative conclusion we reach is that the sealed bid auction with either uniform or discriminatory pricing should be candidates for the final recommendation. Nonetheless, the auction literature offers some justification for the use of more complicated auction formats in order to address special issues such as the desire to help with price discovery and the desire to mitigate collusion or market manipulation. The English clock with and without the final shootout round may be considered candidates for these reasons.

Several criteria should be considered in establishing an auction plan, including factors such as fairness, transparency, ease of administration, avoiding excess price volatility, and the ability to raise revenue. However, the efficiency and revenue raising capacity of an auction are closely related. An auction that is subject to collusion, thus producing lower revenues, is also likely to be inefficient because those firms that value the allowances the most will not obtain them at auction. Instead, some of the allowances will end up in the hands of firms placing lower value on the allowances. This reduced efficiency imposes a real cost on society. So, an interest in maximizing revenues raised by an auction will generally work in favor of more efficient auctions as well.

4.1 SO_2 auction prices and secondary markets

One general question that can be addressed based on previous experience has to do with the performance of auctions for emission allowances in general in the face of a secondary allowance market. Evidence about this is available from the history of the SO_2 emission allowance trading program that was initiated by Title IV of the 1990 Clean Air Act Amendments. Two questions linger from the previous literature: (1) has to do with the influence of a pool of allowances issued through auction on the price of allowances in the spot market, and (2) on whether the allowance auction reflects willingness to pay (marginal cost of abatement) in the same way as does the spot market.

Title IV specifies that 2.8 percent of the allowances issued every year should be allocated through a revenue-neutral auction. The proceeds from the auction are returned to industry in proportion to the underlying allocation of the remainder of the allowances. Figure 6 illustrates the pattern of prices in each auction since 1995, as well as the spot market price approximately one month prior and one month after the auction. In virtually every year the auction price has been nearly coincident with the spot market prices in the surrounding months, or it has been in line with a trend in prices. This evidence suggests that the allowance auction has not disrupted price-setting behavior in the spot market, and furthermore that the auction reflects willingness to pay in a similar manner as does the spot market. Of course, the auction is for a small portion of all allowances, but it is relatively large compared to allowance trading activity in the spot market, because most allowances are allocated directly to the firms that use them.

Largely similar results were achieved with an English clock auction used to sell 5% of 2004 and 2005 vintage NOx allowances under Virginia's SIP Call NOx budget. The auction of 3,710 NOx allowances was held in June of 2004. Even though the amount of allowances sold was more than 30 times greater than the daily number of trades then occurring in the spot market, the clearing prices for the auction were 5% to 7% higher than the spot market prices just before the auction. The increase over the recent spot market price may have involved a small measure of good luck by catching the market before a period of higher prices. The price of NOx allowances did trend somewhat higher for the months after the auction. However, the sale of a large block of allowances reflected the valuation in the spot market and did not cause a price reduction as had been forecast by traders in the days before the auction.

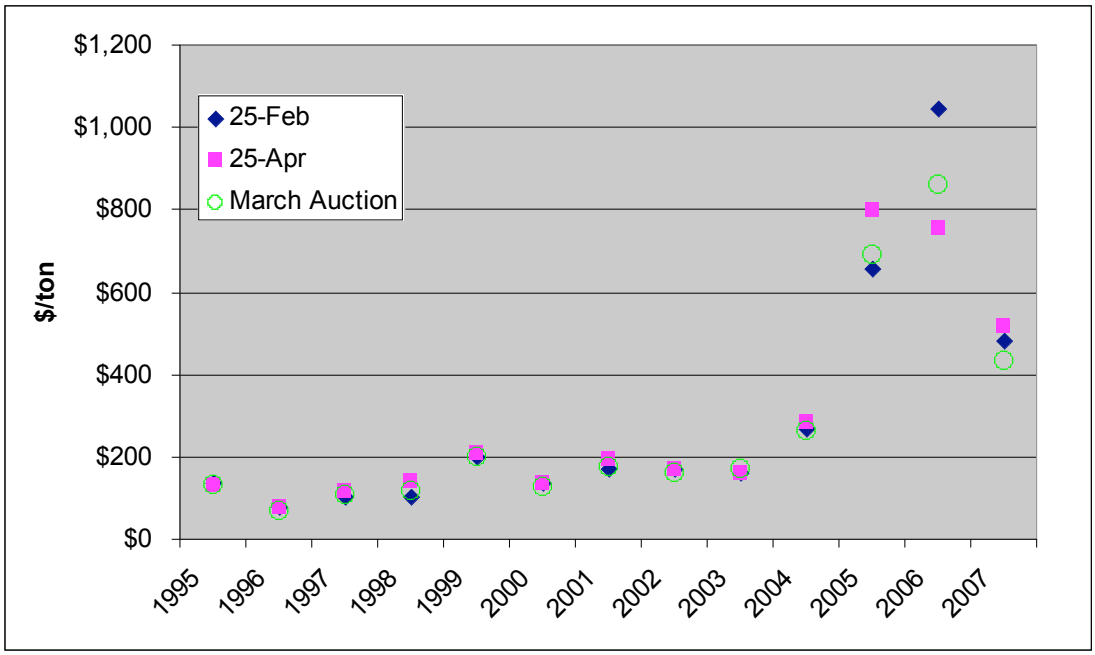


Figure 6: SO_2 Auction and Trading Prices

Notes:

The price for April 2007 was not available at the time of this writing so March data is used. Market data source: Cantor. "SO2 Allowance Price Indications: Historic Monthly Bulletins." http://www.noxmarket.com/Environment/?page=USAComp_MarketData-BulletinsHistoric. Accessed May 7, 2007. Auction data source: Clean Air Markets. "Annual Auction." EPA. http://www.epa.gov/airmarkets/trading/auction.html. Accessed May 7, 2007.

4.2 Reserve prices

The setting of a binding, unannounced reserve price is essential for the proper functioning of any auction. Reserve prices reduce the profitability of collusion. The academic literature and numerous notorious examples of failed auctions point to a credible and efficient reserve price as one of the most important aspects of auction design. This issue is important in the first years of the of the RGGI CO_2 allowance market when the quantity of allowances initially distributed into the market is relatively close to baseline emission levels. If the market is fully developed, then in the first years of the program the ability to bank allowances protects against their value falling to zero. This is because investors and speculators would be willing to buy the allowances during periods of depressed prices and hold the allowances until the initial distribution of allowances declines and prices rise. Hence, in equilibrium, the price in one period should be related to the price in a subsequent period by the opportunity cost of capital. However, at the outset of the program the market may not be in equilibrium as market participants are still learning about how the market will function. If the market is not fully developed in this way, the presence of a reserve price helps to provide stability and provides assurance to those entities that are making efforts to reduce emissions that their emission reductions have financial value.

Efficient reserve prices also could play a role in controlling price volatility. As we note previously and in the literature review, there are compelling reasons for the use of a reserve price. What is unclear from previous experience is what the state(s) may want to do with allowances that are not sold because the reserve price is triggered. If allowances not sold due to a binding reserve price are banked by the state, then these allowances could be held as a contingency bank to be sold in auction during periods when prices spike above some predetermined price ceiling. One obvious measure of price levels are the triggers that allow various types of offsets to be brought into the market. The process of rolling allowances from periods of very low prices to periods of extremely high prices would tend to reduce volatility in allowance prices thereby reducing price risk to generators and their customers. Access to emissions offset markets will also help to limit price volatility in RGGI allowance markets.

4.3 Price discovery

When considering whether to use an allowance for compliance, a firm will compare the value of allowances to the cost of reducing CO_2. If the market price of allowances is less than the cost of reducing a ton of CO_2, then the firm would be better off having someone else reduce emissions by buying and using an allowance (or, equivalently, using one already owned) than reducing the emissions itself. The opposite is true if the price is above the costs of control, then the firm would control a ton rather than use an allowance. Since this is true for all emitters, then a market for allowances should result in the allowance price being equal to the cost of controlling a ton of carbon, and that cost will be approximately the same for all firms. This results in the most cost effective distribution of CO_2 controls across firms.

Since the cost of a given level of control is minimized by having the price of allowances equal the marginal cost of control, it is important that the auction provides accurate price signals. Accurate price discovery in an auction can help establish a market price close to the marginal cost of control. Once the market has reached this equilibrium then the spot market will provide a continuous summary of current opinions about the current value of allowances and hence the current marginal cost of control. This price will adjust daily as expectations change concerning fuel prices, electricity demand, and other factors.

The English clock auction form, with its sequence of price and demand signals, offers bidders an important piece of information not available in sealed bid auctions. The knowledge that at the current price other bidders value the items at least as much as you do, provides some assurance that, at the current price, you have not greatly overestimated the value of the items. A risk averse bidder or a bidder with less information may then bid somewhat more aggressively due to the reduced risk of overvaluing the items. Once an active spot market for the asset exists, this price discovery advantage of the clock auction may not be as important. As already noted, the secondary market provides continuous price discovery signals. As the experience with the SO_2 market has shown, a sealed-bid auction of allowances already traded in a secondary market will closely track the prices in the secondary market.

The SO_2 experience and Virginia's NO_x auction experience as well as the experience with the Irish auction of CO_2 allowances in the EU ETS clearly demonstrate that an auction need not disrupt the spot market price signal even if the number of allowances sold at auction is much greater than the quantities traded in the spot market on a daily or weekly basis. The number of allowances traded on the spot market over a period of days or weeks is not a measure of the "liquidity" of the market. In fact, the opposite is more likely true since a periodic injection of allowances into the market through a sequence of regularly scheduled auctions can lower the perceived risk of illiquid markets, reducing overall price volatility.

Because it is a uniform price auction, the English clock, when used to sell multiple items, gives bidders an incentive to shade their bids a bit. This is because a reduction in the quantity bid below that actually reflecting the bidders value may result in the auction

clearing at a lower price. So, while the bidder may not get as many units as might have been warranted at the clearing price, he will save some money on all of the units that he does win at auction. Discriminatory auctions are not subject to this incentive to shade bids since lowering the bid on one unit does not affect the price paid on other units. The incentive to shade bids in multi-unit, uniform price auctions, known as 'demand reduction', must be weighed against the superior price discovery properties.

4.4 Collusion

When potential bidders collude to coordinate their bidding, it is done with the intent of lowering the price the colluding bidders pay for the goods purchased. As noted earlier, the lost revenue is generally associated with lower efficiency and also with less accurate price discovery since the clearing price will be lower than would occur in a competitive market. In addition, collusion may result in outcomes that will be perceived as unfair by other bidders.

Sealed-bid auctions are generally thought to be more resistant to collusion than are multi-round auctions where repeated signals of value and demand are available to participants. One way to reduce the impact of collusion in multi-round auctions is to limit signals to the minimum information needed for participation in the auction. Another way to improve the performance of multi-round auctions in the presence of possible collusion is to combine them with sealed-bid auctions. Both of these strategies are used in the "shot clock" design tested. The bidders know only the current price, not the size of excess demand, and not the amounts bid by others. The shootout round, provides each colluding party with a opportunity and incentive to renege on collusive agreements and earn extra profits without the other parties to the collusion having a chance to retaliate.

4.5 Fairness, transparency, and administration

Sealed-bid auctions, both discriminatory and uniform, have been used by governments for many years to sell a wide variety of assets. They are well understood by bidders, they are transparent, and are administratively simple. The use of the Internet for bid submission has further reduced the transaction and administrative costs.

Using the English clock for selling government assets is relatively more recent, but increasingly common. Experience with the Virginia NOx auction in particular demonstrates that an English clock auction can be deployed quickly (in a matter of a few weeks) and can provide a high degree of transparency. The cost of actually bidding and administering these auctions may be slightly higher due to the requirement that the sequence of price announcements are made over a period of time. However, this difference is probably not large enough to overcome other advantages that the auction may have in a given context. Two NOx allowance auctions in Virginia each required approximately two hours. Most of the administrative costs were related to managing the

financial assurances, contracting, and ownership transfers. These costs are the same regardless of auction type.

While less widely used, the Dutch clock is similar to the English clock with respect to fairness, transparency, and administrative costs.

The shot clock auction combines the characteristics of the English clock and the sealed-bid, discriminatory price auction. Because it is the combination of two auction types, the shot clock may be seen as the most complicated of the auctions considered. The differences should not be over estimated, however. The implementation of the auction using the Internet makes the differences in administrative costs quite small. The actual auction itself is likely to take somewhat longer, the time difference being measured in hours (at most) rather than days. Combining, as it does, two standard auction types, it is doubtful that the shot clock would be seen as lacking in fairness or transparency once bidders have experience with the auction form. This conclusion is bourn out in our experiments, where the subjects had little difficulty learning to bid in the shot clock format.

4.6 Summary

None of the auction types is best in all areas of performance. The English clock has an edge in price discovery; an edge that we expect will largely disappear once an active spot market develops. The sealed-bid auction is generally thought to perform better in environments where collusion is likely. For perceived fairness, and transparency the sealed-bid auction and the English clock are indistinguishable. The shot clock is somewhat more complicated, but our experimental subjects did not appear to have any trouble using it. The advent of internet bidding has virtually eliminated the differences in administration costs, although there are modest differences in the time it takes to run the different auctions, with sealed-bid being the quickest followed by the English clock and the shot clock.

There is little reason to believe that the different auction forms will differ significantly in their effects on the liquidity of the spot market, the volatility of prices, or the performance of the secondary markets in general.

5. Interim Recommendations

The remainder of this discussion is dedicated to identifying a recommendation for the auction format (Recommendation 1) along with some recommendations for structural elements that may need to be written into the auction regulations.

Recommendation 1

RGGI may wish to consider a mixed auction program. The first time that a given vintage (preferably defined according to the 3-year compliance period) is auctioned, an English clock with a shootout round using discriminatory pricing should be used. Subsequent auctions of that vintage would use a sealed-bid format.

The English clock facilitates price discovery, and the shootout round helps prevent collusion or manipulation of the market. It is also not yet clear whether the sealed-bid auctions should use discriminatory or uniform prices. This choice depends on issues not resolved in Phase 1 analysis or experiments and will be addressed explicitly in Phase 2.

Recommendation 2

The auction literature suggests that allowance vintages should be defined according to enforcement or true-up periods (the three year compliance periods) rather than calendar years. This will reduce transaction costs and improve efficiency without reducing the environmental effectiveness of the cap.

Defining vintages as the larger compliance period reduces transaction costs by eliminating otherwise irrelevant distinctions based on year. The more uniform is the definition of an asset, the less costly it is to trade. Trading costs reduce efficiency by preventing trades that might otherwise make traders better off. We would expect that the allowances for all three years within a compliance period would sell for nearly identical prices, yet they would be quoted as separate assets with separate bid-ask spreads on the spot market and would add unnecessary confusion to price signals. Larger vintages also provide a larger pool of allowances available for trade, making it harder to affect market price by hoarding allowances.

Recommendation 3

Auctions should be held quarterly throughout the vintage period.

Quarterly auctions provide regular liquidity to the market and minimize the importance of demands on firm capital. Smaller, more frequent auctions will be less likely to have a significant effect on the spot market. Using auctions to facilitate hoarding or market-cornering strategies would be less effective with relatively small and frequent auctions than with larger, less frequent ones. Further work on the frequency of auctions will be conducted in light of issues that will be examined in Phase 2.

Recommendation 4

Use credible reserve prices during all auctions. For the reserve prices to be credible, the state must be willing to leave some allowances unsold and be willing to continue to do so until such time as the price rises above the reserve level. To reduce price volatility, the unsold allowances could be banked. Allowances in the bank would be made available during price spikes above a specified price ceiling.

In phase 2 of this project we will rely on further review of the empirical literature as well as experimental methods to provide further guidance on how the reserve price should be determined, as well as what may constitute a price spike.

Recommendation 5

Policymakers should consider selling some fraction of allowances in advance of the beginning of a compliance period.

The selling of future vintages into the current market helps firms reduce risk and creates helpful market signals concerning future allowance costs. This does not imply borrowing allowances from a future compliance period since these "unripe" allowances could not be used for compliance until their compliance period. An active market for future vintages helps with price discovery and investment planning. Our initial recommendation is to sell these future vintages using the format recommended in Recommendation 1. The issue of how many allowances to sell in advance of their vintage will be addressed in Phase 2.

Recommendation 6

Allowance auctions should be open to any party willing and able to meet financial qualification requirements.

The auction literature indicates that participation in the allowance auctions should not be limited to particular firms or individuals. The widest possible participation should be encouraged in order to reduce the potential for collusion and market power in the allowance market. However, because there will be an active secondary market for allowances, it is unlikely that efforts to limit ownership could be effective without eliminating most of the advantages of having tradable allowances. This is something that we will be addressing in some detail in Phase 2.

Recommendation 7

The auction mechanism should require strong financial assurance from bidders and should limit bidders to activity no greater than their assurance. In addition, there should be a significant penalty for default and non-payment on the part of winning bidders.

The auction literature provides strong evidence that careful thought must be given to the bonding mechanism that certifies eligibility in the auction. More detail about this mechanism will be developed in Phase 2.

Appendices A-D: Experimental Results

Appendix A. Revenues as a Percentage of Maximum, Wide Value Range

	Auction								
	1	2	3	4	5	6	7	8	All
Uniform									
1st session	71	74	77	79	76	81	77	80	77
2nd session	68	76	80	75	78	78	80	76	77
3rd session	60	74	71	73	70	75	71	80	72
Discriminatory									
1st session	77	76	76	76	74	76	74	76	75
2nd session	80	78	74	75	73	72	75	74	75
3rd session	89	83	83	82	81	81	78	78	82
Clock									
1st session	65	70	66	71	66	57	65	69	67
2nd session	82	75	77	72	72	75	71	77	75
3rd session	71	74	71	67	67	75	66	74	71
Shot Clock									
1st session	84	75	77	73	71	74	71	74	75
2nd session	81	85	79	79	80	79	71	68	78
3rd session	82	77	74	71	69	70	66	72	73
Dutch									
1st session	85	70	68	70	72	75	75	78	74
2nd session	85	79	77	80	76	77	76	78	79
3rd session	90	77	71	74	71	74	74	77	76

Appendix B. Efficiencies, Wide Value Range

	Auction								
	1	2	3	4	5	6	7	8	All
Uniform									
1st session	94	96	97	98	98	98	99	97	97
2nd session	97	98	100	99	97	99	97	97	98
3rd session	97	98	97	98	96	96	100	99	98
Discriminatory									
1st session	97	96	99	99	98	98	98	98	98
2nd session	99	97	98	100	99	98	100	99	99
3rd session	99	97	99	99	98	99	99	98	99
Clock									
1st session	93	94	98	96	93	95	96	98	95
2nd session	98	96	99	99	96	94	99	97	97
3rd session	95	94	98	97	93	99	97	100	97
Shot Clock									
1st session	95	98	98	98	98	97	98	98	98
2nd session	98	96	99	99	99	100	98	97	98
3rd session	91	96	98	98	98	98	98	98	98
Dutch									
1st session	93	98	97	97	96	98	99	98	97
2nd session	96	98	98	99	99	99	99	99	98
3rd session	97	99	98	99	98	99	100	99	99

Appendix C. Revenues as Percentage of Maximum, Narrow Value Range

	Auction								
	1	2	3	4	5	6	7	8	All
Uniform									
1st session	82	88	92	91	92	91	92	92	90
2nd session	89	91	92	91	92	91	92	92	91
3rd session	89	91	92	91	92	94	92	92	92
Discriminatory									
1st session	83	81	81	82	85	86	88	89	84
2nd session	95	92	92	92	92	91	92	93	92
3rd session	87	85	83	82	82	82	83	84	84
Clock									
1st session	92	91	88	91	92	91	88	92	91
2nd session	85	91	85	94	92	91	80	85	89
3rd session	92	91	92	91	92	94	92	92	92
Shot Clock									
1st session	68	92	73	92	90	91	92	75	84
Dutch									
1st session	92	87	89	91	92	90	91	92	91

Appendix D. Efficiencies, Narrow Value Range

	Auction								
	1	2	3	4	5	6	7	8	All
Uniform									
1st session	99	97	99	99	99	99	99	100	99
2nd session	98	99	99	99	99	99	99	99	99
3rd session	99	99	99	99	99	99	99	99	99
Discriminatory									
1st session	98	99	98	99	97	99	98	99	98
2nd session	99	99	99	99	99	99	99	100	99
3rd session	98	98	99	99	99	99	99	99	99
Clock									
1st session	100	99	99	99	100	99	99	100	99
2nd session	100	99	96	99	99	96	98	99	98
3rd session	100	97	100	100	100	100	100	100	100
Shot Clock									
1st session	71	99	78	99	99	100	99	79	91
Dutch									
1st session	99	99	99	99	99	99	99	99	99

Appendix E: Annotated Bibliography

Athey, S. and P. A. Haile (2002). "Identification of Standard Auction Models." Econometrica **70**(6): 2107-2140.

Athey, S. and P. A. Haile (2006). Empirical Models of Auctions. NBER Working Paper.

This paper offers a survey of empirical models to estimate behavior in auctions and identifies some of the main findings using recently developed techniques. Several other citations are offered and discussed in detail.

Hendricks, Pinkse and Porter (2003) analyzed oil lease auctions, which are a well-known example of a common value problem. The price of the resource is determined by an external market, so it is common to all bidders. This gives rise to the possibility of a winner's curse, because who ever bids high enough to win the auction apparently assumes a higher resource availability than others and hence has reason to doubt their own expectations over the resource availability. Winning bidders tend to be the ones who have over-estimated the resource value. The authors find that subtle inferences are economically important and are incorporated in bidding strategies, and the magnitude of the curse is significant. It appears larger when there is greater anticipated competition, which follows from the assumption of symmetric pure common values.

Haile, Hong and Shum (2003) examine common and private values in first-price auctions. A hypothesis is that as the number of competing bidders increases so will the winner's curse. However, they find this may not be important in the case of timber contracts.

Hale and Tamer (2003) analyze ascending auctions, which they characterize as a dynamic game with a rich strategy space, and the role of reserve prices. They show bidders make an inference based on the reserve price policy. Actual reserve prices in timber auctions are likely to be below optimal levels, but raising them would have only a small effect on expected revenues and on the probability of a sale. Hence, one might conclude that it is more important to have reserve prices than to worry too much about their levels, at least with respect to maximizing revenues.

In another study of timber auctions, Athey, Levin and Seira (2004) look at variation in auction format between ascending and first-price auctions to assess competitiveness and the widely believed notion that ascending

auctions are more susceptible to collusion. The Revenue Equivalence theorem (Vickrey, 1961) implies that if bidders are risk-neutral, have independent and identically distributed values, and bid competitively, the two auction formats yield the same winner, same expected revenue and the same bidder participation. However if these assumptions are relaxed, then auction format becomes relevant. The authors go on to cite Maskin and Riley (2000) who find that first-price auctions lead to inefficient entry and bidding. The effect on revenue is ambiguous. The authors conduct new empirical work to find that bidding behavior in the timber industry is less aggressive in ascending auctions, suggesting collusion. In some cases they cannot reject the hypothesis that the bids in ascending auctions are equal to those predicted for the first-price auction, but in another case they find the ascending auction is less competitive. The setting here is when bidders are face-to-face, which provides some opportunity for signals. They find similar welfare effects for a fixed number of participants. When the number of participants is endogenous, the sealed bid auction increases revenue, suggesting in this case that auction format is important with respect to collusion.

Jofre-Bonet and Pesendorfer (2003) consider the role of capacity constraints that make winning an auction affects valuation in future auctions. A study of highway construction reveals asymmetries in bidding strategies based on point in time, which may depend on their performance in a previous auction. The winner in one auction affects the bids in subsequent auctions, given capacity constraints.

Hortacsu (2002) looks at whether to use discriminatory or uniform price auction formats for treasury bills, drawing on evidence from Turkey. The debate lingers since Friedman (1960) about which format will raise the most revenue. Bidding one's true marginal valuation is not an equilibrium strategy in either auction. In the discriminatory auction "truthful" bidding would lead to zero surplus to any bidder. In a uniform-price auction, bidders also have an incentive to shade bids below marginal valuations, since a bidder's own bid may set the price for all infra-marginal units. Which format yields the most revenue depends on the primitives of the problem (Ausubel and Cramton, 2002). Hortacsu finds that a uniform auction would not enhance revenues in the case he considered empirically.

Athey, S. and J. Levin (2001). "Information and Competition in U.S. Forest Service Timber Auctions." The Journal of Political Economy **109**(2): 375-417.

Ausubel, L. (2004). "An efficient ascending-bid auction for multiple object." American Economic Review **94**(5): 1452-1475.

This paper provides us with an ascending price auction for the allocation of multiple homogeneous objects that displays remarkably good characteristics. As a matter of fact such format inherits many of the advantages of the single unit English Auction. In particular, if values are private sincere bidding is an equilibrium and brings an efficient allocation (in this case as in his static Vickrey counterpart). If values are affiliated, the Ausubel auction remains efficient while the static Vickrey auction is not. This replicates the relationship between English Auction and SPA for the multi-object scenario.

Ausubel, L. and P. Crampton (1998). Demand Reduction and Inefficiency in Multi-unit Auctions.

One of the main contribution of this paper is to point out that the sealed bid uniform price auction used for the allocation of multiple unit is in general inefficient due to a phenomena known as demand reduction. Essentially, a large bidder has a stronger incentive to shade his bid than a small bidder and this may cause him loosing some units for which his value is ex-post higher than the small bidder. The reason is simple to understand and is analogous to the one that leads a monopolist to sell a less than efficient quantity. Recall that in a uniform price auction the bidder pays the market clearing price. Such price with positive probability is determined by one of the prices posted by the large bidder. As the price he pays is the same for all units, it may payoff for him to "risk" to win less units but at a lower price.

Avery, C. (1998). "Strategic Jump Bidding in English Auctions." The Review of Economic Studies **65**(2): 185-210.

This paper uses Milgrom- Weber (1982) affiliated value model to study an open auction where bidders are allowed to raise the price discontinuously (unlike in the standard model). It shows that bidders can exploit such possibility to implement a form of implicit collusion by signaling their type in a first stage to understand who among them is the strongest bidder. Once they have signaled such information they use a less aggressive strategy if they are considered weak and a more aggressive one if they are strong. The use of such asymmetric strategies decreases the sellers revenues.

Back, K. and J. Zender (1993). "Auctions of Divisible Goods: On the Rationale for the Treasury Experiment." The Review of Financial Studies **6**(4): 733-764.

This paper looks at multi unit auctions and compares the performance of the sealed bid uniform price auction with the one of the sealed bid discriminatory auction. The main difference between the two is that in the first format the winning bidders pay the market clearing price, while in the second one they pay their own bid. Notice the analogy with the Second Price Auction and the First Price Auction here. One of the point of the paper is however that the main insights on the single object framework (FPA vs. SPA) cannot directly be replicated in their multi-units counterparts. The paper highlights the pros and cons of these two formats.

Bergemann, D. and S. Morris. (2005). "Robust Mechanism Design." 6. Retrieved Access Date.

Bergemann, D. and J. Valinaki (2006). Information in Mechanism Design.

Binmore, K. and P. Klemperer (2002). "The Biggest Auction Ever: The Sale of the British 3G Telecom Licences." The Economic Journal **112**: C74-C76.

The authors review the British third-generation (3G) mobile-phone license auction that concluded in April 2000. The auction raised $34 billion, equivalent to 2.5% of British GNP. The authors discuss the lessons learned, and the merits of using an auction compared to “beauty contests” for administrative allocation of licenses according to various qualifying criteria.

It is important to note the differences between radio spectrum auctions and allowance auctions. In many ways the radio spectrum auction issues are much more complicated. The path was cleared for auctions in telecommunications by the US Federal Communications Commission (FCC) use of a simultaneous ascending auction design in 1994. That auction raised about $20 billion. The UK continued to use administrative “beauty contests” through the 1990s for its 2G phones. The central virtue of an auction is that it is the method that is expected to allocate resources to those who can use them most valuably. The authors offer several citations (e.g. Milgrom 2000) that the secondary market will not be as efficient. They also indicate that an auction approach will lead to less litigation than an administrative approach, with references to experiences in Spain and Sweden. While there may be good grounds for direct allocation, the regulatory will have to answer “Why subsidize this industry rather than others?”

A major concern of the UK auction was to promote entry since there were

a small number of bidders chasing a small number of licenses. Where entry is important, an ascending price auction is not ideal. The reason is that one powerful bidder can effectively threaten to raise their bid as long as necessary, and thereby defer entry. Sealed bid auctions would be better at promoting entry because they give entrants a better chance of winning against strong incumbents. However, they do not give bidders the opportunity to gather information about the business plans of their rivals, or to update their expectations if in the case of a common (associated) value auction. A potential fix to this is labeled an Anglo-Dutch auction, which resembles the shot-clock approach used in our experiments. This approach encourages entry by closing with a sealed bid, but allows for discovery in the early stages of the auction with an ascending clock. Another way that the UK design attempted to limit collusion was to limit the number of licenses that could be purchased to one.

The authors stress that any reserve price should be a clear commitment not to sell if the bids do not meet the price. If the bidders expect the government would subsequently resell at a lower price then the bidders will behave strategically to push the price down.

The authors also note the significant effect on non-economists of having the opportunity to play in the experiment. “By contrast, mathematical equations have very little persuasive power.”

Several potential mistakes did not surface in the UK, but there are lessons for other auctions. One chief problem was the inadequacy of the deposits that bidders were required to put down. This also has been noted in emission allowance auctions. Plus, the longer the time in clearing the auction (the UK auction ran for several weeks) the more likely that external events may change values and cause bidders to retract previous bids.

Finally the authors emphasize that the UK auction should be copied, but that auctions should never be copied without attention to local circumstances. The really bad mistake is to take an auction design off the shelf. There is no “one size fits all.”

Bohringer, C. and A. Lange (2005). "Economic implications of alternative allocation schemes for emission allowances." Scandinavian Journal of Economics **107**(3): 563-581.

Bulow, J. and J. Roberts (1989). "The Simple Economics of Optimal Auctions." Journal of Political Economy **97**(5): 1060-1090.

This paper makes the Myerson optimal auction "accesible for the crowds". Where the Myerson paper takes the abstract (and powerful) mechanism design point of view as a starting point, these authors show that the final results can be interpreted in the more familair language of a price-discriminating monopolist. In particular, the optimal reserve prices and bidding credits (used by the FCC, for instance) are derived by considering standard monopoly maximization problems.

Cason, T. N. (1995). "An Experimental Investigation of the Seller Incentives in the EPA's Emission Trading Auction." The American Economic Review **85**(4): 905-922.

Cason evaluates the proposed EPA auction method for CAAA SO2 allowances, in which the lowest asking seller receives the highest bid offered as the selling price and the next lowest asker receives the next highest bid and so on until the asking price is greater than the bid. This has the potential to encourage sellers to ask a price that is lower than their cost. He analyzes the inverse version of this auction scheme where buyers face the same incentives as the EPA version using a risk-neutral Nash equilibrium. He then designs experiments where players of different experience levels bid against each other and in some cases against "robot" players that play the risk-neutral Nash equilibrium strategy. The results of the experiment are compared against the theoretical predictions of the Nash equilibrium.

The experimental design is very controlled. Players are randomly assigned to a computer terminal. Inexperienced players only bid against other inexperienced and the same with experienced players. The number of buyers is either 3 or 6. Each player's value is randomly assigned from a uniform distribution and the seller's asking price (which is the actual received price the winner will pay) is also taken randomly from a different uniform distribution. One permit is sold in each round and there are 30 rounds in most of the experiments.

Cason has three hypotheses, which are 1) Winning bids are higher with a greater number of bidders 2) All bids are higher with a greater number of bidders 3) Market trading efficiency is lower with a greater number of bidders. His hypotheses are born out in some, though far from all, of the experimental cases with statistical significance at the 5% level.

Cassady, R. (1967). Auctions and Auctioneering, Berkeley: University of California Press.

This is an old but quite comprehensive study that provides a detailed

description of many auction mechanisms used in practice.

Che, Y.-K. and I. Gale (1998). "Standard Auctions with Financially Constrained Bidders." The Review of Economic Studies **65**(1): 1-21.

Standard models assume that bidders attach some value to the object for sale but that they do not suffer from any financial constraint so that in principle can bid any sum of money. This paper looks at the standard private model but relaxes the assumption that bidders do not suffer from financial constraints; in particular, it assumes that any bidder has a certain budget and that he holds private information regarding it. The main result is that the First Price Auction (FPA) outperforms the Second Price Auction (SPA) both in revenues and efficiency. The intuition why revenue equivalence breaks in such direction is that in the FPA bidders shade their bids in equilibrium so that the added constraints is less likely to bind that in the SPA, where instead bidders would be willing to bid up to their value.

Compte, O. and J. Philippe. (2007). "Auctions and Information Acquisition: Sealed bid or Dynamic Formats." Retrieved Access Date, from http://www.enpc.fr/ceras/jehiel/ascendRand.pdf

This paper highlights a possible virtue of open formats versus sealed formats: the formers by allowing a bidder to observe the strenght of competition during the auction provides better incentive for acquiring better information, which in turn boosts both revenues and efficiency. The setting they look at is the standard one of private value amended to allow for (costly) information acquisition during the auction. Some bidders are assumed to be informed about their exact valuation, while others know only the expected value of it and by paying some cost can find out the exact one. The idea is that in a sealed format a bidder needs to take his information decision prior to the start when little is known about the strenght of the actual competition. Hence, the fact of giving up a sure amount of money so early on makes the incentive to acquire information low. Conversely, in an open format a bidder can postpone such decision and observe how many bidders are left. If the realized level of competition turns out to be low, he will invest.

Cramer, J. and R. P. McLean (1988). "Full Extraction of the Surplus in Bayesian and Dominant Strategy Auctions." Econometrica **56**(6): 1247-1257.

This paper together with the previous (Cramer and McLean (1985)) represents a very important theoretical contribution. It shows that if the private information that bidders receive is not drawn independently of the other bidders information as normally assumed, but rather is correlated,

then the seller can construct a mechanism that extracts all bidders surplus (notice that this implies that the mechanism is also efficient). The result is theoretically very remarkable as it holds very generally even when the correlation is very weak. In such case, however, it requires the use of lotteries involving potentially extremely high payments that in practice no bidder would be willing to accept (or would simply default).

Cramton, P. and S. Kerr (2002). "Tradeable carbon permit auctions: How and why to auction not grandfather." Energy Policy **30**(4): 333-345.

Dasgupta, P. and E. Maskin (2000). "Efficient Auctions." Quaterly Journal of Economics **115**(2): 341-388.

Sometimes the main objective of a seller is not to maximize revenues but rather to achieve an efficient outcome, where by efficient we mean that we would like to allocate the object to the bidder who values it the most. This paper extends the Vickrey-Clark- Groves mechanism to a setting where bidders valuations are interdependent and provides a mechanism that can allocate the object efficiently (under the assumption that bidders private information is unidimensional and some technical conditions necessary for efficiency are satisfied). It represents an important theoretical result. However, such mechanism is not observed in practice as it requires bidders to report to the seller an unrealistic amount of information (essentially, each bidder should state his value contingent on each possible realization of his opponents private information). For a similar mechanism that still achieve efficiency but requires less information to be reported, see Perry and Reny (2002).

Fischer, C., S. Kerr, et al. (1998). "Using emissions trading to regulate US greenhouse gas emissions: An overview of policy design and implementation issues." National Tax Journal **51**(3): 453-464.

Garratt, R. and T. Troge (2006). "Speculation in standard auctions with resale." Econometrica **74**(3): 753-769.

Garratt, R. and T. Troger (2006). "Speculation in Standard Auctions with Resale." Econometrica **74**(3): 753-769.

Guillotreau, P. and R. Jimenez-Toribio (2006). "The Impact of Electronic Clock Auction Systems on Shellfish Prices: Econometric Evidence from a Structural Change Model." Journal of Agricultural Economics **57**(3): 523-546.

Hafalir, I. and V. Krishna "Asymmetric Auctions with Resale." American Economic Review.

Haile, P. A. (2001). "Auctions with Resale Markets: An Application to U.S. Forest Service Timber Sales." The American Economic Review **91**(3): 399-427.

Hendricks, K. and H. J. Paarsch (1995). "A Survey of Recent Empirical Work Concerning Auctions." The Canadian Journal of Economics / Revue canadienne d'Economique **28**(2): 403-426.

Holt, C. (1980). "Competitive Bidding for Contracts under Alternative Auction Procedures." The Journal of Political Economy **88**(3).

This paper is one of the first to study the impact of bidders risk aversion on the auction format performance (the results are stated for a procurement auction but they analogously hold for a standard auction). The main result is that under risk aversion the First Price Auction (FPA) outperforms the open auction. The intuition why the revenue equivalence breaks is simple. If bidders are averse to risk they are willing to give up part of their potential profits to increase their chances of winning. This fact drives the winning price up. Such adjustment, unlike in the open auction, it is possible in the FPA, as there in the risk neutral equilibrium bidders shade their value. For a study of the optimal format under risk aversion see instead Maskin and Riley (1984).

Jehiel, P. and B. Moldovanu (1999). "Resale Markets and the Assignment of Property Rights." Review of Economic Studies **66**(4): 971-991.

Jehiel, P. and B. Moldovanu (2001). "Efficient Design with Interdependent Valuations." Econometrica **69**(5): 1237-1259.

One of the important contributions of this paper is to provide a negative (or impossibility) result. It shows that if the information that bidders receive is multi-dimension, there is no hope (in general) to achieve the efficient

allocation, i.e to allocate to the bidder with the highest valuation. This opens an important problem as there are many circumstances where bidders hold multi-dimensional information, a very natural setting being for instance the one of multi-objects auctions. The conditions that are necessary for efficiency are provided both for the multi-dimensional and the uni-dimensional case.

Joskow, P. L., R. Schmalensee, et al. (1998). "The Market for Sulfur Dioxide Emissions." The American Economic Review **88**(4): 669-685.

The Joskow article argues that the theoretical and experimental findings by Cason are not actually born out in practice in the EPA SO2 allowance auctions. The most plausible explanation is that the EPA auctions compose a small part, only about 2.8%, of the overall SO2 allowance trading market. Hence the participants in the auction, both buyers and sellers, have a real functioning trading market that they can fall back on. As the authors put it, “The development of the outside market significantly tightened the ‘opportunity cost bounds’ on the behavior of auction participants”.

The authors looked at both spot auctions and six and seven-year advance auctions, but the results were similar for both types. The main evidence that they offer in support of the thesis is that as time went and the SO2 trading market got more and more robustly established with reliable prices, deviations from market prices in the auctions diminished. In 1993, the first year allowances were auctioned, several buyers put in low-ball bids as the market price was not yet established. By 1995 the buyers’ bids were much flatter and only went down to 10% below the best available estimate of market price. Additionally, in 1993 the lowest winning bid (the market clearing price) was 20.6% below the average winning bid in the spot auction, but by 1997 it was only 3.4% below. The authors concede that the outcome could be different if the EPA auction were the only way to acquire allowances.

Klemperer, P. (1999). "Auction Theory: A Guide to the Literature." Journal of Economic Surveys **13**(3): 227-286.

Klemperer, P. (2002). "What Really Matters in Auction Design." The Journal of Economic Perspectives **16**: 169-189.

Klemperer analyzes auction format with special attention to telecommunications as an operating example. He argues that the key

concerns about auction design can be learned from elementary economics and strategic behavior. He examines collusion, entry-deterring behavior and predatory behavior. He suggests that most literature focuses on issues that are second-order for practical design, that is a fixed number of noncooperative bidders, and it emphasizes effects such as risk aversion, correlation of information, budget constraints and complementarities. However, these may be more important issues for allowance markets, compared to telecommunications markets, which have fewer bidders and fewer goods (licenses) to be auctioned. He finds that ascending and uniform-price auctions are both very vulnerable to collusion and efforts to deter entry. He nominates a final sealed-bid stage into an otherwise ascending auction to create an Anglo-Dutch auction to address this. This design resembles the “shot clock” auction design we have modeled.

The concern about tacit or explicit collusion has been important in the multiunit (simultaneous) ascending auctions. When there are limited buyers, the ascending clock provides information that helps collusion. This was seen in the German experience with the spectrum auction in 1999. There is also evidence of collusion in US markets, because of repetition in different geographic areas, which provides the ability to retaliate.

A frequently repeated auction, sometimes called a repeated stationary auction, is particularly vulnerable to collusion. Electricity markets are a good example. In the case of allowances, a lesson here might be that absent other good reasons to have frequent auctions, fewer auctions would help deter collusion.

Ascending auctions are especially bad at attracting bidders (Bulow and Klemperer, 1996). There is a strong presumption that the firm that values the item the most will be the ultimate winner, so competitors are not enticed to enter. Other auction forms can have similar problems if there are great asymmetries among bidders and entry costs are large. An example is the UK 1991 sealed-bid auction of television franchises.

The winner’s curse can depress bidding in some ascending auctions, when bidders have close to common values for the item being auctioned and when there is some uncertainty about its actual value. The winner’s curse affects weak firms more than strong ones. Hence the advantaged bidder usually wins, and can pay a low price. This is illustrated by the 1995 auction in Los Angeles for mobile-phone licenses. A strong bidder also has the incentive to establish a reputation for aggressiveness. If this effect is present in an allowance auction, it suggests that smaller firms will defer to the secondary market or to brokers, and the difference in price between the auction and secondary market will earn rents to large firms

that bid in the auction.

Many poor experiences in ascending price auctions were aggravated by the failure to set a proper reserve price. Inadequate reserve prices increase the incentive for predation and may encourage collusion. Not only are serious reserve prices opposed by bidders, but often by politicians who fear the embarrassment of not selling the item.

Similarly, sealed-bid auctions can also be embarrassing. One example was discovered by the BSCH (Spain's biggest bank) when they won an auction for the Sao Paulo bank Banespa at three times the bid of the runner up. So firms may oppose first-price auctions. But the converse second-price auction would be embarrassing for the auctioneer in this case, as occurred in New Zealand, and this could be remedied by a reserve price.

Loopholes and special strategic opportunities can plague auctions. Test-bedding is essential to discover these loopholes. The Turkey auction of telecom licenses sequentially is an example of this. In the US bidders have won spectrum auctions but have defaulted on their commitments after long delays. In these cases the default penalties were small and bidders are bidding for options on prizes rather than the prizes themselves.

Ascending auctions are subject to rule breaking by bidders, because it allows cheat time.

Auction design may be less important when there is a large number of bidders for whom entry is easy. The Treasury auctions are an example. Experiments with different kinds of auctions have leaded inconclusive results.

The author offers solutions, one of which is to make ascending auctions more robust. An ascending auction may succeed in allocating to the bidder who values an item most. It also helps bidders learn about the market by inference of the value to others. To avoid signaling, bidders can be forced to bid round numbers. Keeping secret the numbers of bidders remaining makes collusion harder.

In sealed bid auctions firms are unable to retaliate and collusion is difficult. However the advantaged bidder will probably win, but it must make its single offer in the face of uncertainty about its rival's bids. Weaker bidders hence have some chance. They are more attractive to entrants. Also, the winner's curse is less severe in the case of common values. However, by

giving some chance of victory to weaker bidders, the sealed bid auction is less likely to lead to efficient outcomes. Also, bidders need good private information about value. Hence pay-your-bid discriminatory auctions may discourage bidders. The entry problem is less serious when small bidders can buy from intermediaries, such as brokers, who can aggregate smaller bidders demands and bid in their place as occurs in auctions of Treasury bills.

The Anglo-Dutch (or shot clock in our terminology) is a suggested remedy bringing the best of both auction types. An auction with similar features is the OpenBook auction for corporate bonds. eBay auctions also have this feature, with an ascending price that rushes toward closure so bidders have one last opportunity to bid their best and final offer. This approach will repel collusion, and encourage entry. But it also is more likely to sell to the highest valued buyer as will an ascending auction.

The author notes in closing that most auctions work well, and even cases where there have been problems probably are better outcomes than the administratieve “beauty contest” alternative.

One size does not fit all. Auction formats should be tested.

Kline, J. J. and F. M. Menezes (1999). "A simple analysis of the US emission permits auctions." Economics Letters **65**(2): 183-189.

This paper focuses exclusively on a stylized version of the EPA SO2 auction method and uses it to prove two propositions under complete information. The propositions are: “that there are either inefficient equilibria (where no goods are exchanged) or efficient equilibria (where all possible gains from trades are realized). The efficient equilibria have the property that all trades occur at a uniform price.”

Two examples are also provided where the participants are under incomplete information. The first case results in the sellers shading their bids up when both buyers and sellers are behaving strategically. The other case results in both buyers and sellers shading their bids down. It is an important finding that under some circumstances sellers will inflate their asking price when behaving strategically, which is counterintuitive to what one might expect.

List, J. A. and D. Lucking-Reiley (2000). "Demand reduction in multiunit auctions: Evidence from a sportscard field experiment." American Economic Review **90**(4):

961-972.

Management, E. R. (2005). EU ETS: Planning for Auction or Sale.

This consultancy study was done for the UK to help them decide how to liquidate surplus allowances in their New Entrant Reserve. A draft report was developed that considered four circumstances listed below, based on criteria used to assess the suitability of each method. Stakeholders were invited to respond in writing. The feedback was favorable, but some concerns were identified. A value was placed on continuity. Concern about the EU-wide policy was considered to be secondary. There was a general preference for auctions on the basis of transparency, openness of participation and continuity (in view of future phase disposals). The ascending clock auctions were preferred, particularly among service providers and electricity generating companies. Other themes that were valued included easy and low cost participation, and adequate time for participant preparation.

Four proposals that were considered included:

- Liquid EU ETS market and low surplus volume -> market order
- Liquid EU ETS market and low moderate volume -> sequence of market orders
- Illiquid EU ETS market and low surplus volume -> uniform-price sealed-bid auction
- High surplus volume or illiquid EU ETS market with moderate surplus volume -> ascending clock auction

The consultants concluded with a recommendation of an ascending clock auction as the default method, to be used if either of the following conditions hold one month before the scheduled auction:

1. Volume to dispose is more than 5% of average daily volume.
2. Volume to dispose times the average sale price is more than 2 million pound.

Otherwise a sequence of market orders should be used. A market order is the offer to sell at the current market price. In contrast, a limit order is the offer to sell at a fixed price.

That is, in summary, an ascending auction should be used unless the market is sufficiently liquid and the volume to dispose is small. Except for ‘small’ volumes, auctions are thought to perform better than sales.

Two main considerations were economic efficiency and good value for the taxpayer. Further, the auction should be simple with low transaction cost.

Three factors are important in considering the auction or sale theory:

1. The product is homogeneous and divisible.
2. The product is actively traded in secondary markets.
3. The market for allowances is not concentrated.

Mandell, S. (2005). "The choice of multiple or single auctions in emissions trading." Climate Policy **5**(1): 97-107.

The main issue addressed by this article is the frequency of CO2 permit auctions. One of the auction frequencies considered is the 'single-auction approach', in which a single auction is held at the beginning of a commitment period to sell the entire volume of allowances for that period. The alternative is the 'multiple-auction approach' in which several auctions are used throughout the commitment period to sell the volume of allowances. The primary contribution of this article is to address auction frequency in the context of the 'winner's curse'.

The author makes some arguments for why an auction is preferable to any system of free allowance allocation. Two assumptions underpin the discussion of auction frequency. First, the market for CO2 permits is 'small'. Second, any CO2 allowance auction is run as an ascending clock auction. The author acknowledges that ascending auctions for multi-unit goods may yield inefficient prices when large bidders choose to shade their bids, but this concern vanishes when the number of bidders is 'large' or the secondary market is competitive. To the extent that either of these is true, the bid shading problem is more a question of wealth distribution than efficient allocation.

A literature review reveals two pre-existing ideas on auction frequency. The first is that higher frequency allows firms a shorter planning horizon when bidding into each auction. This benefit of higher frequency auctions is undermined by an efficient secondary market for allowances. The second benefit of high frequency auctions is cash-flow management, but it is undermined by a perfect market for capital.

A perfectly competitive secondary market for CO2 allowances removes the benefits of a multiple-auctions approach to initial allowance allocation. However, the market will not be perfectly competitive if it provides too little price information (e.g. prices are confidential) or it is illiquid.

The 'winner's curse' may arise in an auction for a good in which all bidders will value the good equally, but with uncertainty. Consider the bidders' expectation of the good's value to be i.i.d. with mean at the true value. The

winner of the auction will, upon winning the auction, expect that his valuation of the good must have been too high since all others valued it lowered. Formally, “the bidder’s expected value of the good prior to the bidding process is larger than the expected value conditional on winning.” The bidders’ recognition of the winner’s curse will cause them to adjust their bids downwards. The key is uncertainty. With no uncertainty, the winner’s curve vanishes. As uncertainty grows, so too does the impact of the winner’s curse.

To put the winner’s curse back into the context of CO2 allowance auction frequency, we must reconsider the secondary market for allowances. If it is perfectly competitive, then there is no uncertainty about allowance valuation and the winner’s curse does not exist. To the extent that the secondary market is imperfect, the frequency of allowance auctions can affect the information available to the bidders. Increasing auction frequency improves market information and minimizes the effect of the winner’s curse.

Allowance auction frequency has two other notable impacts. More frequent auctions yield higher overall transaction costs and are more vulnerable to collusion. Higher transactions costs are an obvious result of frequent auctions. Greater vulnerability to collusion results from the opportunity to follow through with threats of punishment more quickly.

High frequency allowance auctions can offset the problems presented by the ‘winner’s curse’, but at the cost of higher transactions costs and greater vulnerability to collusion. Since the winner’s curse only emerges in the presence of an imperfect secondary market for allowances, the viability of frequent auctions only emerges in the same case. The author assumes that secondary markets for CO2 allowances will evolve over time. He therefore asserts that, “A plausible policy recommendation… would then be to use frequent auctions during the early years of the scheme with the intention of decreasing the frequency in future stages…”.

Margolis, M. and J. F. Shogren (2004). "Implementing the efficient auction: initial results from the lab." Economics Letters **84**(1): 141-147.

Vickrey’s second-price auction (for 1 good) is demand revealing and efficient in theory. As such, it is not directly relevant to an allowance auction. A variant to Vickrey’s auction has bidders with affiliated values, i.e. the value to one bidder depends in part on information available only to some other bidder. This auction is neither demand revealing nor efficient. Dasgupta and Maskin (2000) constructed a generalized version of the Vickrey auction, called an efficient auction, in which each bidder

expresses his bid as a function of other bidders' signals. This auction is theoretically efficient even when the bidders have affiliated values. This may have some relevance to allowance auctions as bidders in these markets may have affiliated values.

This paper experimentally assesses the efficient of an efficient auction with inexperienced bidders. The findings is that bids are systematic, but yield a bid curve flatter than the truthful one.

Maskin, E. (2003). Auctions and Efficiency, Cambridge University Press.
This is nice survey regarding the important issue of allocating efficiently an object by means of an auction or some other mechanism. It presents the main results available in the literature (up to his publication) and pinpoints some of the questions that remain to be answered.

Maskin, E. and J. Riley (2000). "Asymmetric Auctions." The Review of Economic Studies **67**(3).
The vast majority of models in auction theory assumes that bidders are perfectly symmetric. This is an interesting theoretical benchmark to begin with, but cannot adequately represent many practical applications, especially if the asymmetries are expected to be strong. The problem with asymmetric models of auctions is that deriving the equilibrium bidding behavior is often too a difficult task. This paper looks at the private value model and separately introduces three different and very specific types of asymmetries regarding the distribution from which the bidders private information is drawn. It shows that the ranking of First Price Auction and open auction depends critically on the asymmetry taken into consideration. It thus provide some policy recommendations to a seller who has some knowledge of the type of asymmetry bidders display (note that Revenue Equivalence does not hold as bidders beliefs are asymmetric).

McAfee, P. and J. McMillan (1987). "Auctions with a stochastic number of bidders." Journal of Economic Theory **43**(1): 1-19.
Most of the models in auction theory assume that the number of bidders participating in the auction is fixed and known by all participants. Such assumption is not realistic in many applications. This is one of the first paper that relaxes it, assuming the number of bidder is stochastic. It shows that if bidder are averse to risk the revenues for the seller are higher when a bidder perceives the number of his opponents as uncertain. It therefore suggests that when possible the seller should conceal the number of participants.

McAfee, R. P. and J. McMillan (1987). "Auctions and Bidding." Journal of Economic Literature **25**(2): 699-738.

McAfee, R. P. and J. McMillan (1996). "Analyzing the Airwaves Auction." The Journal of Economic Perspectives **10**(1): 159-175.

McMillan, J. (1994). "Selling Spectrum Rights." Journal of Economic Perspectives **8**(3): 145-62.

Menezes, F. M. and P. K. Monteiro (2005). An introduction to auction theory.

Milgrom, P. and R. Weber (1982). "A Theory of Auctions and Competitive Bidding." **50**(5): 1089-1122.

This paper introduces "common values," where all bidders derive the same value from the object being sold but no bidder knows its exact value (e.g. bidding for the rights to drill for oil on a certain tract). The authors derive the theoretical equilibria of the first, second, and open ascending (English) auctions, and show that the English auction yields more revenue than a second-price, which in turn yields more revenue than a first price auction. This continues to be one of the most influential papers in auction theory, and one of the most cited.

Muller, R. A., S. Mestelman, et al. (2002). "Can double auctions control monopoly and monopsony power in emissions trading markets?" Journal of Environmental Economics and Management **44**(1): 70-92.

Myerson, R. (1981). "Optimal Auction Design." (6): 58-73.

This paper in one of the milestones contributions in the theory of auctions. It solves the sellers revenue maximization problem subject to the bidders incentive compatibility constraints, thus providing the optimal allocation and the corresponding payment scheme. To solve such problem it proves as a corollary result the important revelation principle that allows to restrict attention to direct mechanisms. The study yields Important practical insights. In particular, it shows that the optimal mechanism involves the use of a reserve price. It also shows that if bidders are asymmetric the

optimal mechanism should favor the weak bidder. Finally, it provide a formal proof of the revenue equivalence theorem, anticipated but not formally proven by Vickrey in his 1961 classic.

Neuhoff, K., K. K. Martinez, et al. (2006). "Allocation, incentives and distortions: The impact of EU ETS emissions allowance allocations to the electricity sector." Climate Policy **6**(1): 73-91.

Pagnozzi, M. (2007). Should speculators be welcomed in auctions?
This paper looks at the effect of introducing resale in the sale of multiple-objects via a uniform price auction. The possibility of being able to buy the object in the resale market is shown to affect the incentive for demand reduction (see Ausubel and Crampton (1998)) making it stronger and thus suppressing revenues. It then looks at the effect of the introducing the presence of speculators that attach no value to the object but may be willing to pay a positive price for the object to resell in the resale market. The presence of speculators has the positive effect of increasing competition. This fact needs to be trade-off with the demand reduction effect. Pagnozzi shows that indeed sometimes a strong bidders optimally chooses and accommodating strategy and lets the speculator win some unit thus decreasing revenues. This is not always the case. It is shown that the effect is in general ambiguous and depends on how clustered bidders valuations are.

Palfrey, T. (1983). "Bundling Decisions by a Multiproduct Monopolist with Incomplete Information." Econometrica **51**(2): 463-483.

Persico, N. (2000). "Information Acquisition in Auctions." Econometrica **68**(1): 135-148.
This paper studies the impact of information acquisition (prior to the auction) on the revenue performance of two auction formats: the First Price Auction (FPA) and the Second Price Auction (SPA) (the paper has also more general results but the auction environment represents his main application). The setting studied is one in which bidders information is affiliated (a form of positive correlation). Milgrom-Weber (1982) in such case rank the SPA as superior to the FPA in the absence of information acquisition. Persico shows that the incentive to acquire information is greater in the FPA and that sometimes such effect is sufficient to reverse the ranking. The basic intuition is rather simple. If values are correlated getting a more precise signal enables a bidder to have a better estimate

also regarding his opponents. This allows him to leave on the table only the amount that is really needed to win. Such information is less valuable in the SPA as there the amount paid is independent of your own bid.

Plott, C. R. (1983). "Externalities and Corrective Policies in Environmental markets." The Economic Journal **93**(369): 106-127.

This paper compared three policy measures using laboratory experiments. The policies were a tax, standard and pollution license. The experiments examined price behavior, efficiency and distributional consequences. In the absence of policies, subjects ignore the externality in their private market behavior. The key result is that experiments confirm economic theory in a variety of ways, including specifically the internalization of social costs when taxes and pollution licences are used. The most efficient policy was the pollution licence, and second the tax. The paper allocates the emission licences in a somewhat random way so that the secondary market plays an important role in their use.

Rassenti, S., V. Smith, et al. (2002). "Using Experiments to Inform the Privatization/Deregulation Movement in Electricity." Cato Journal **21**(3): 29.

This survey article summarizes a body of work done by the authors and others in the late 1980s and 1990s related to the question of efficiency gains from restructuring or liberalizing electricity markets. A main focus of the Rassenti and Smith papers summarized here was testing the feasibility of trading electricity in decentralized markets where offers and bids are submitted to a centralized computer program which uses an algorithm that maximizes the gains from trade, given the physical limitations of the electricity grid and associated electricity losses, to decide who sells and who buys and the market clearing prices at each node on the grid. Prior to this work, the conventional wisdom (Joskow and Schmalensee 1983) was that decentralized bidding might not be appropriate in electricity markets because of the externalities imposed by the grid. Experiments showed that decentralized markets would achieve 90 ‚Äì 100% efficiency as a result of simultaneous determination of allocations, which means that each agent bears the opportunity cost imposed on others by its actions at the margin. The second question that was addressed in this series of experiments was regarding the importance of allowing demand side bidding on the efficiency of this decentralized market approach. They found that adding demand side bidding brought prices in shoulder and off-peak periods much closer to competitive prices and reduced the volatility of electricity prices across days.

Rassenti, S., V. Smith, et al. (2003). "Controlling Market Power and Price Spikes in Electricity Networks: Demand-side bidding." Proceedings of the National Academy of Sciences **100**(5): 7.

This article looks at the effect of ownership concentration and demand side bidding on price realization and efficiency of electricity spot markets using experimental methods. The exercise uses a simple representation of electricity markets and the transmission grid with a three node radial network, negligible transmission losses, no obligation to serve on the part of load serving entities and no reserve market. The ownership of generation assets in the ‚Äúmarket power‚Äù treatment is designed in such a way that particular generators can increase their profits by increasing their bids or withholding capacity. In another treatment, the ‚Äúno power‚Äù treatment, generation ownership is redefined in such a way that the ability to exercise market power is no longer possible. In these experiments, subjects who were suppliers submit offers to supply powers that are expressed as a step function that indicates the amount of power they are willing to produce and sell at each price. With no demand side bidding , the demand side of the market is represented by a willingness to pay schedule within the software. With demand side bidding, real load serving agents participate as buyers in the market. The market clearing price at each node in the transmission grid is found by identifying the combination of bids that maximizes the gains from trade in electricity. The main results of this article are that the market power treatment results in substantially higher prices in shoulder and off-peak periods, but adding demand slide bidding neutralizes market power. In the no-power treatment, demand side bidding reduces prices to close to the 100% efficient levels.

Robinson, M. (1985). "Collusion and the Choice of Auction." The RAND Journal of Economics **16**(1): 141-145.

This short paper clearly points out that when the possibility that bidders may form a collusive cartel is a concern, the use of an open format may not be ideal. In fact, such format intrinsically provide bidders with a better institution where to credibly implement a collusive agreement compared to a sealed format such as the First Price Auction (FPA). The insight is rather simple. The open format allows the other members of the cartel to observe a bidder not respecting the agreement and allows them to react and punish such bidder. Unless the same auction is repeated many times, the possibility of punishing a deviator is not allowed by the sealed format, which in turn discourage the formation of such agreement. For a more formal study of collusion in open auctions, see Graham and Marshall (1987). For a study of collusion in FPA, see McAfee and McMillan (1992).

Staropoli, C. and C. Jullien (2006). "Using Laboratory Experiments to Design Efficient Market Institutions: The Case of Wholesale Electricity Markets." Annals of Public and Cooperative Economics **77**(4).

This paper surveys the main contributions of experimental economics to the design of wholesale electricity markets. It says nothing of allowance markets. Experiments on market design should be taken as a complement to theoretical market design.

The introduction of competition into electricity markets raises two sets of issues: issues of market architecture and issues auction design. Market architecture refers to the replacing of a centrally controlled system with a decentralized market for deciding which generating units will operate when and how much they will be paid. The auction design issue refers to how specific auction rules are structured. The specific issues covered here are bilateral versus unilateral auctions (whether the demand side is actively bidding), sealed bid versus continuous bid and uniform price versus discriminatory price.

With respect to the former, the article summarizes the work of Vernon Smith and his colleages to study the feasibility of decentralized bidding in electricity markets. This set of articles showed that decentralized markets that combined offers to sell with active bids to buy power were both feasible and efficient. Later work added transmission network constraint considerations to the mix. Work by Backerman and colleagues determine whether generators, distributors or transmission owners reap the benefits of congestion rents when transmission is constrained. They find that with a uniform double price auction transmission owners don't capture rents from transmission congestion (generators can) and thus have no incentive to expand capacity.

The first part of the paper addresses experimental contributions toward the understanding of 'the general architecture of the market' (Wilson, 1999). The second part addresses the details of the auctions rules in the insights garnered from experimentation.

General Architecture

The work of Vernon Smith of the U of Arizona in the mid-1980s found that experimental markets figuring energy sales and purchases expressed as 'offers to sell' and bids to buy', with simultaneous determination of allocations and physical constraints imposed by the grid, are feasible and efficient. This peaked interest and led to more studies.

Transmission constraints

The three main issues that arise from the possibility of transmission constraints are monopoly power of the owner of wires, local market power of generators, and the allocation of ownership rights to use the network.

The vertical disintegration of a utility that own generation capacity and transmission capability modifies incentives and may lead to a distortion of information on congestion to manipulate the expectations of procuders'. Beckerman et al (2000) conducted an experiment to asses who, among the supply side, demand side and transmission owners, can capture the rents from such distortions. They also addressed how the distribution of rents varies under alternative auction rules. The experiment uses a uniform price double auction mechanism. The two variants of the auction mechanism are 'both-sides rule' that gives the opportunity to any market participant to accept any offers on each side of the market before the market is called, and 'other-side rule' in which in order to have an offer accepted, each participant must meet the terms of the unaccepted bid or ask on the other side of the market. In theory the transmission owners will capture congestion rents. Under experimentation, generators capture some of the congestion rents and demanders are unaffected by who receives the rents. Also, 'both-sides rule' is more efficient than 'other-side rule'. Staropoli et al. conclude that "this experiment suggests that in this environment, no incentives are given to transmission line owners to invest in new transmission capacities as they do not capture the rents in the system."

Transmission constraints can create local market power in which generation on one part of the grid can have consequences for generation scarcity on other parts of the grid. Those in small areas of generation scarcity may exercise market power to yield inefficiently high prices. Zimmerman et al. (1999) experimentally showed that using a uniform price sealed-bid auction with two competing generators in the area of generation scarcity will yield market prices close to duopoly levels.

The ownership rights on the transmission grid matter, especially at points of congestion. There are two types of property rights, as defined by Kench (2004): financial and physical. Financial right entitle the owner of a wire to collect congestion rents across it. Physical right authorizes owners to send power through a line. Kench experimented with a model market governed by a continuous double auction, where both the demand-side and the supply-side are active. He finds that the assignment of either type of right yields greater efficiency than a failure to assign either right to anyone. At points of congestion, the assignment of physical rights yield

more an efficient equilibrium than the assignment of financial rights.

Demand-side participation

Demand for electricity has long been considered quasi-inelastic, but real demand response in electricity markets could bring discipline to generators. Rassenti et al (2002) tested this and concluded that active participation on the demand side “neutralizes market power and price spikes on peak in the laboratory as well as it lowers prices”.

Auction Details

Electricity markets are inherently complicated. The types of auctions that might govern them vary along four dimensions: single unit vs. multiple unit, uniform pricing vs. discriminatory pricing, sealed-bid vs. sequential-bid, and repeated vs. non-repeated. The theoretical analytics of the entire four-dimensional matrix of auction options remain incomplete. The experimental analyses of these details addresses two of the dimensions: uniform vs. discriminatory pricing and sealed vs. sequential bids.

Sealed-bid vs. Sequential-bid

Bernard et al. (1998) compares two uniform price auction rules: lasted accepted offer (LAO) is a sealed-bid auction, first rejected offer (FRO) is a sequential-bid auction. In a single unit auction FRO is incentive compatible whereas LAO is not. In a multiple unit auction the incentive compatibility of FRO is lost.

Denton et al. (2001) show that when generators are endowed with identical portfolios, i.e. the auction acts like a single unit auction, a sealed-bid offer (SBO) rule is significantly more efficient than a real-time uniform price double auction (UPDA) rule.

Uniform price vs. Discriminatory price

Many different studies have shown that discriminatory auctions do not perform as well as uniform price auctions in electricity markets. Specifically, Hahn and Van Boenig (1990) showed that SBO beats the split-saving rule (SSR) in terms of price outcome deviations from the competitive equilibrium. Olson et al. used experimentation to compare a day-ahead sealed-bid auction (SB) and a simultaneous continuous double auction (CDA). The SB was slightly more efficient than the CDA. Moreover, the CDA equilibrium yielded higher prices than the SB auction. So under a CDA institution, the consumers of electricity are nearly as

efficient as under an SB institution, but more poorly so.

Sunnevag, K. J. (2003). "Auction design for the allocation of emission permits in the presence of market power." Environmental & Resource Economics **26**(3): 385-400.

TradingDynamics, I. (1999). FTR Auction Design for the California ISO.

Velthuijsen, J. W., M. Beeldman, et al. (2005). Allocation of Allowances in the European Emission Trading Scheme after 2012, Price Waterhouse Coopers for the Dutch Ministry for the Environment.

Vickrey, W. "Counterspeculation, Auctions, and Competitive Sealed Tenders." **16**(8-37).

This is the pioneer work in auction theory and as such is among the most cited ones. It introduces the independent private value model under which each bidder valuation is independent of the information held by his opponents. It provides the equilibrium bidding behavior for open ascending price auction (English Auction), Second Price Auction. It notes how the revenues generated by those formats coincide. Such a remarkable result, known as revenue equivalence theorem, is proven more formally (showing under which assumptions holds true) in subsequents paper.

Whitford, A. B. (2007). "Designing Markets: Why Competitive Bidding and Auctions in Government Often Fail To Deliver." Policy Studies Journal **35**(1): 61-85.

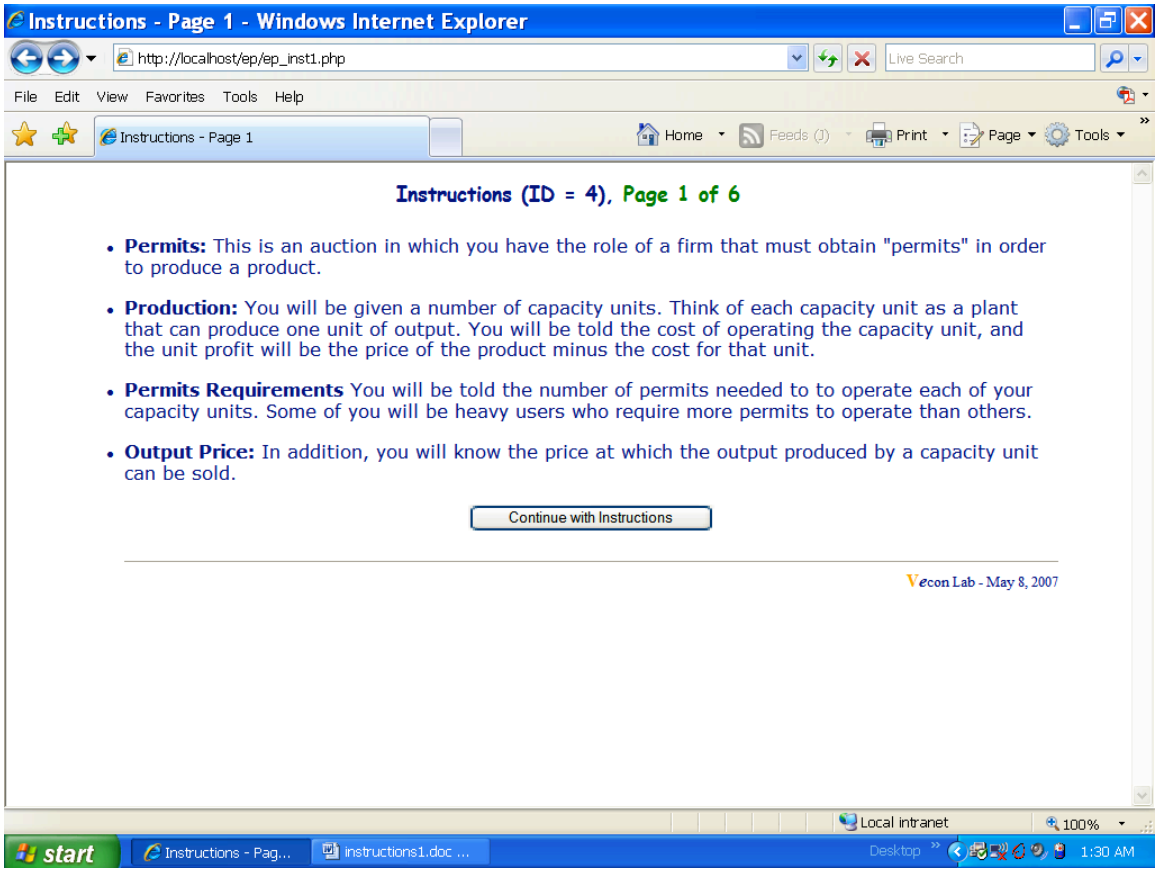
Zheng, C. (2002). "Optimal Auction with Resale." Econometrica **70**(6): 2197-2224.

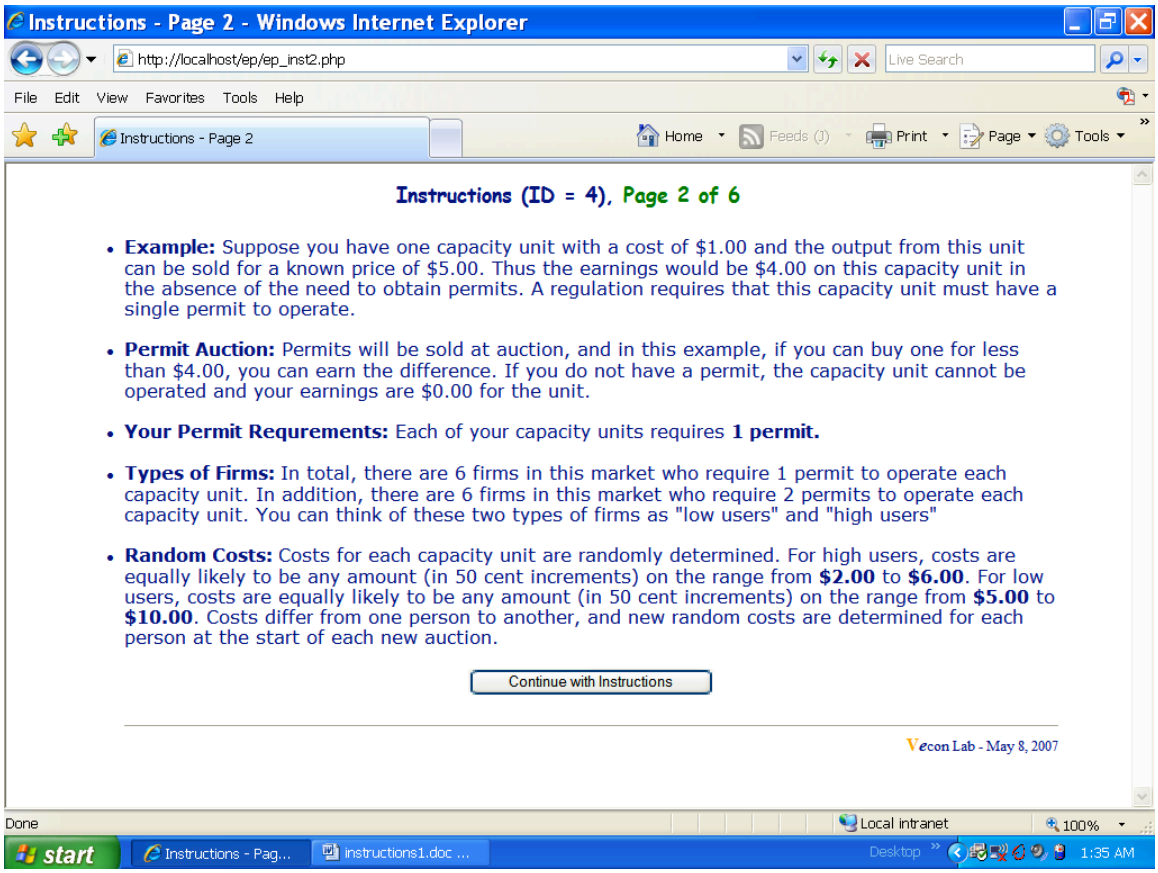
Myerson (1981) solves the seller revenue maximization problem and determines the optimal allocation from the seller point of view. This paper adds the often realistic assumption that the winning bidder may try to resell the object to some of the loosing bidder. The paper defines conditions under which Myerson (1981) original optimal allocation can still be achieved. This is done for the two bidders case. For the generic n bidders case the result can be proven only for some special cases.

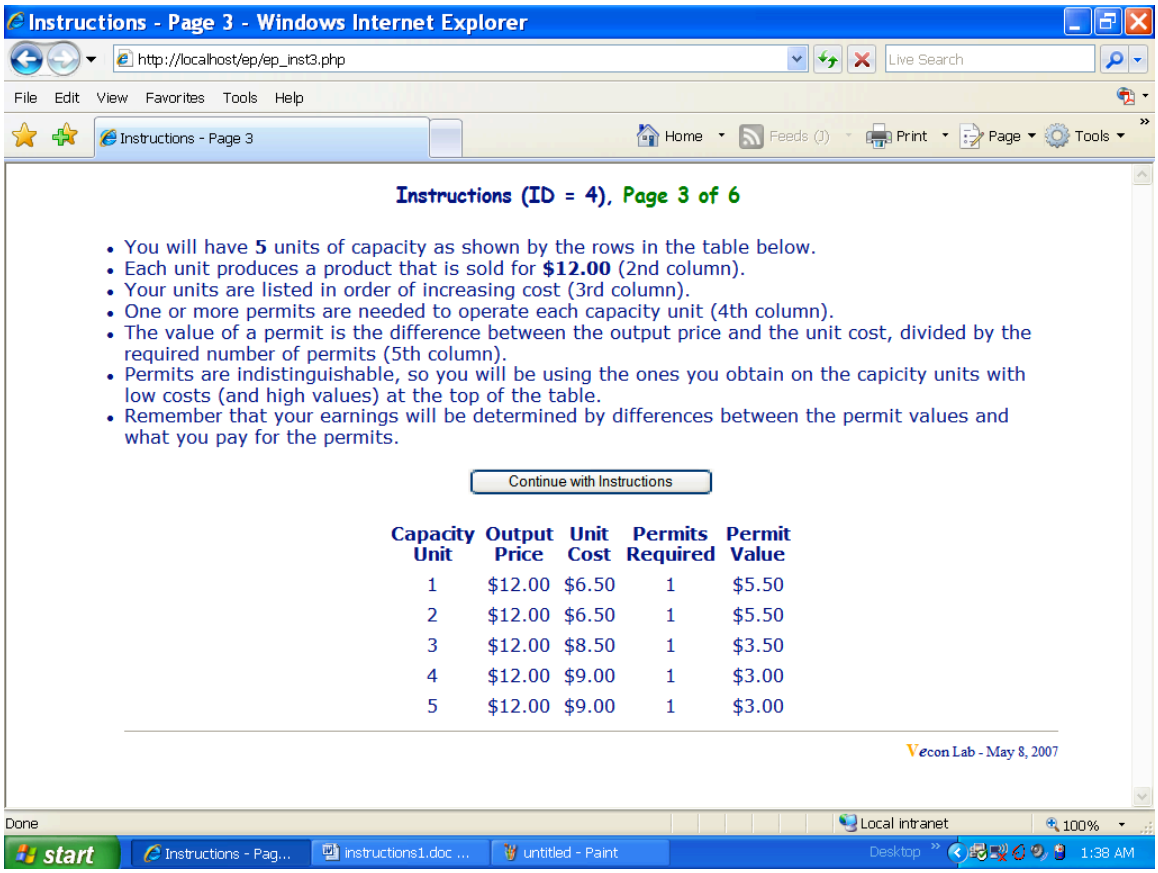
Zimmerman, R., J. Bernard, et al. (1999). Energy Auctions and Market Power: An Experimental Examination.

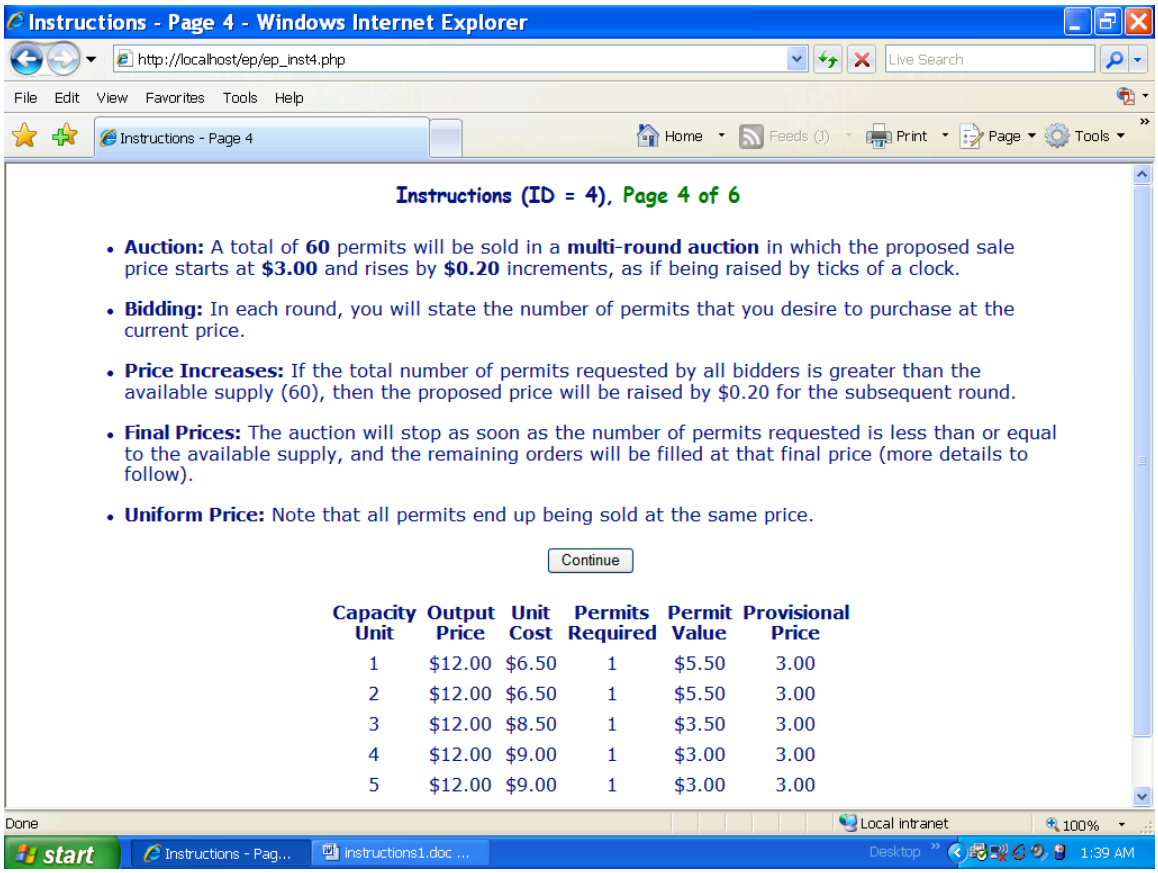
The research reported in this paper has two parts. The first looks at the performance of different auction types with markets of different sizes and numbers of competitors. The auction types analyzed include the last accepted offer (LAO) version of the uniform price auction, the first rejected offer (FRO) form of the uniform price auction and a multiple unit Vickrey auction, under which winners pay the opportunity cost they impost by being in the auction. These auction types were tested in settings with 2, 4 and 6 subjects, each offering to supply electricity. Demand was assumed to be perfectly inelastic. All auctions included a reservation price. Optimal prices in these auctions were defined as the equilibrium prices that would result if all participants offered all of their capacity at its marginal cost. The optimal price depends on the auction type, with slightly lower offers potentially prevailing in the last accepted offer auction than in the first rejected offer auction, but does not vary with number of participants in the auction. However, the optimal price does vary with the number of participants in the Vickrey auction. The results show that group size is a much more important determinant of price outcome than auction type with the price in a two party auction being nearly double the competitive level. In general, the LAO auction type, the form often used in wholesale electricity spot markets, performs slightly better than the FAO type. The LAO and FRO auctions had similar effects on getting bidders to reveal their true costs but with the Vickrey auction low cost units tended to bid under cost. The second issue is the effect of a transmission network with a single auction type, the LAO. In these experiments, the authors constructed a network with 30 nodes and transmission constraints between regions that gave two of the six generators market power in a particular part of the grid as given transmission constrains those generators must operate to meet demand. In the experiments they found that in most sessions the generators with market power were able to coordinate their bidding strategies and exploit that market power. In one session this took a while and in others, including those that involved professional electricity traders instead of students, it happened right away. In one session, prices remained near competitive levels throughout the 75 round auction. The authors also demonstrate that voltage limits and reactive power requirements can create opportunities for market power on their network.

Appendix F: Sample instructions from auction experiments

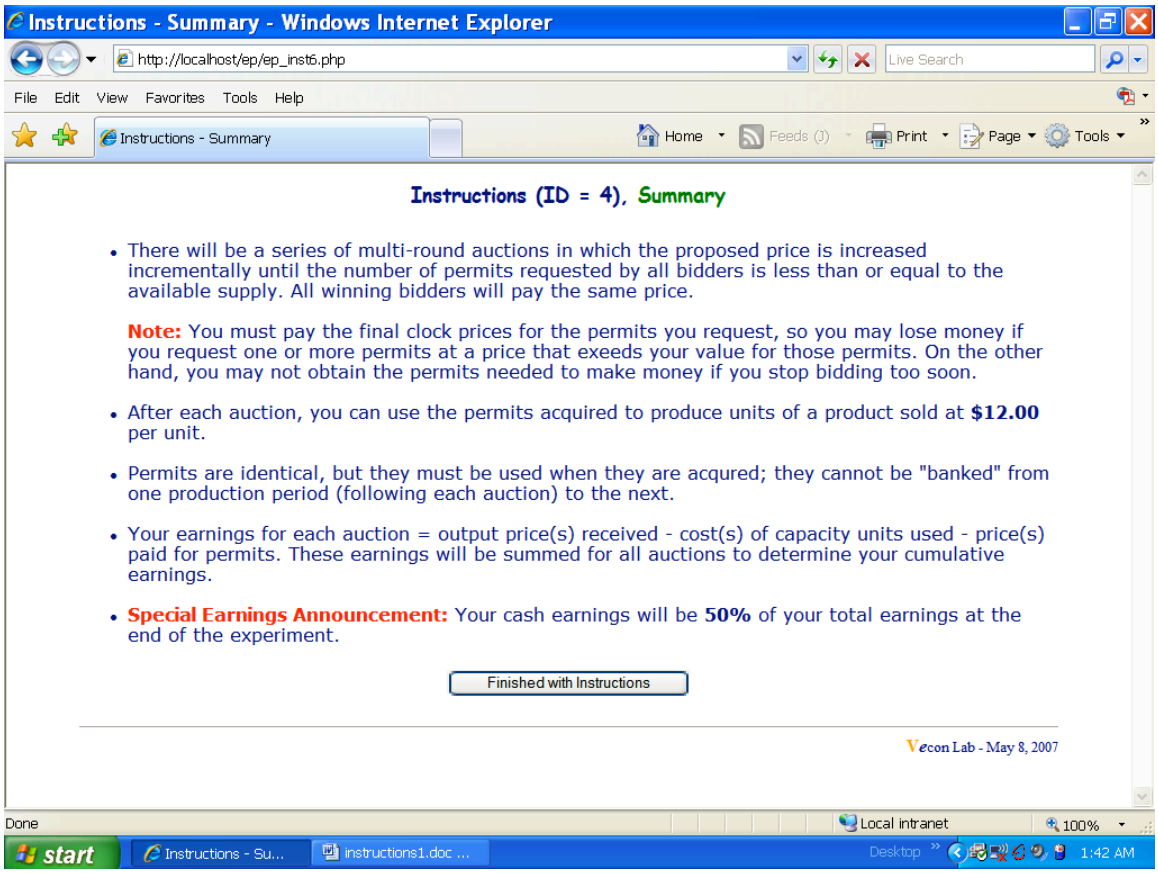



Instructions - Page 2 - Windows Internet Explorer
http://localhost/ep/ep_inst2.php
Live Search
File Edit View Favorites Tools Help
Instructions - Page 2
Home Feeds (J) Print Page Tools
Instructions (ID = 4), Page 2 of 6
Example: Suppose you have one capacity unit with a cost of $1.00 and the output from this unit can be sold for a known price of $5.00. Thus the earnings would be $4.00 on this capacity unit in the absence of the need to obtain permits. A regulation requires that this capacity unit must have a single permit to operate.
Permit Auction: Permits will be sold at auction, and in this example, if you can buy one for less than $4.00, you can earn the difference. If you do not have a permit, the capacity unit cannot be operated and your earnings are $0.00 for the unit.
Your Permit Requrements: Each of your capacity units requires 1 permit.
Types of Firms: In total, there are 6 firms in this market who require 1 permit to operate each capacity unit. In addition, there are 6 firms in this market who require 2 permits to operate each capacity unit. You can think of these two types of firms as "low users" and "high users"
Random Costs: Costs for each capacity unit are randomly determined. For high users, costs are equally likely to be any amount (in 50 cent increments) on the range from $2.00 to $6.00. For low users, costs are equally likely to be any amount (in 50 cent increments) on the range from $5.00 to $10.00. Costs differ from one person to another, and new random costs are determined for each person at the start of each new auction.
Continue with Instructions
Vecon Lab - May 8, 2007
Done
Local intranet
100%
start
Instructions - Pag...
instructions1.doc ...
Desktop
1:35 AM


Instructions - Page 3 - Windows Internet Explorer
http://localhost/ep/ep_inst3.php
Live Search
File Edit View Favorites Tools Help
Instructions - Page 3
Home Feeds (J) Print Page Tools
Instructions (ID = 4), Page 3 of 6
You will have 5 units of capacity as shown by the rows in the table below.
Each unit produces a product that is sold for $12.00 (2nd column).
Your units are listed in order of increasing cost (3rd column).
One or more permits are needed to operate each capacity unit (4th column).
The value of a permit is the difference between the output price and the unit cost, divided by the required number of permits (5th column).
Permits are indistinguishable, so you will be using the ones you obtain on the capicity units with low costs (and high values) at the top of the table.
Remember that your earnings will be determined by differences between the permit values and what you pay for the permits.
Continue with Instructions
Capacity Unit | Output Price | Unit Cost | Permits Required | Permit Value
1 | $12.00 | $6.50 | 1 | $5.50
2 | $12.00 | $6.50 | 1 | $5.50
3 | $12.00 | $8.50 | 1 | $3.50
4 | $12.00 | $9.00 | 1 | $3.00
5 | $12.00 | $9.00 | 1 | $3.00
Vecon Lab - May 8, 2007
Done
Local intranet
100%
start
Instructions - Pag...
instructions1.doc ...
untitled - Paint
Desktop
1:38 AM


Instructions - Page 4 - Windows Internet Explorer
http://localhost/ep/ep_inst4.php
Live Search
File Edit View Favorites Tools Help
Instructions - Page 4
Home Feeds (J) Print Page Tools
Instructions (ID = 4), Page 4 of 6
• Auction: A total of 60 permits will be sold in a multi-round auction in which the proposed sale price starts at $3.00 and rises by $0.20 increments, as if being raised by ticks of a clock.
• Bidding: In each round, you will state the number of permits that you desire to purchase at the current price.
• Price Increases: If the total number of permits requested by all bidders is greater than the available supply (60), then the proposed price will be raised by $0.20 for the subsequent round.
• Final Prices: The auction will stop as soon as the number of permits requested is less than or equal to the available supply, and the remaining orders will be filled at that final price (more details to follow).
• Uniform Price: Note that all permits end up being sold at the same price.
Continue
Capacity Unit | Output Price | Unit Cost | Permits Required | Permit Value | Provisional Price
1 | $12.00 | $6.50 | 1 | $5.50 | 3.00
2 | $12.00 | $6.50 | 1 | $5.50 | 3.00
3 | $12.00 | $8.50 | 1 | $3.50 | 3.00
4 | $12.00 | $9.00 | 1 | $3.00 | 3.00
5 | $12.00 | $9.00 | 1 | $3.00 | 3.00
Done
Local intranet
100%
start
Instructions - Pag...
instructions1.doc ...
Desktop
1:39 AM


Instructions - Page 5 - Windows Internet Explorer
http://localhost/ep/ep_inst5.php
Live Search
File Edit View Favorites Tools Help
Instructions - Page 5
Home Feeds (J) Print Page Tools
Instructions (ID = 4), Page 5 of 6
Final Price: If the number of permits requested falls below the number available (60), the auctioneer may decide to roll back the price one bid increment ($0.20) in order to sell all permits. In this case, the orders placed at the higher price will be filled first (at the lower price), and the remaining permits will be sold to those who had indicated a desire to purchase at the lower price and did not bid at the higher price. This residual is allocated to the eligible bidders according to the time at which their bids had been submitted at the lower price, so there is some advantage in submitting bid quantities early in each round.
Bidder Activity Limits: The auction rules and financial pre-qualifications have determined a maximum number of permits that can be bid for initially by each person. Your activity limit is 5. If you lower your request in one round, you cannot raise it in a subsequent round, so activity limits have a "use it or lose it" feature.
Activity and Final Bids: When the auction stops, you will have to pay the final price for the permits that you have requsted. Therefore, you should consider letting your activity drop if the price becomes too high. Note that you can only purchase permits for which you have activity in the final round, so you should think carefully before letting your activity drop.
Continue
Econ Lab - May 8, 2007
Done
Local intranet
100%
start
Instructions - Pag...
instructions1.doc ...
Desktop
1:41 AM


Instructions - Summary - Windows Internet Explorer
http://localhost/ep/ep_inst6.php
Live Search
File Edit View Favorites Tools Help
Instructions - Summary
Home Feeds (J) Print Page Tools
Instructions (ID = 4), Summary
There will be a series of multi-round auctions in which the proposed price is increased incrementally until the number of permits requested by all bidders is less than or equal to the available supply. All winning bidders will pay the same price.
Note: You must pay the final clock prices for the permits you request, so you may lose money if you request one or more permits at a price that exeeds your value for those permits. On the other hand, you may not obtain the permits needed to make money if you stop bidding too soon.
After each auction, you can use the permits acquired to produce units of a product sold at $12.00 per unit.
Permits are identical, but they must be used when they are acqured; they cannot be "banked" from one production period (following each auction) to the next.
Your earnings for each auction = output price(s) received - cost(s) of capacity units used - price(s) paid for permits. These earnings will be summed for all auctions to determine your cumulative earnings.
Special Earnings Announcement: Your cash earnings will be 50% of your total earnings at the end of the experiment.
Finished with Instructions
Vecon Lab - May 8, 2007
Done
Local intranet
100%
start
Instructions - Su...
instructions1.doc ...
Desktop
1:42 AM