Alternative Auction Institutions for Electric Power Markets

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Restructuring of electric power markets is proceeding across the United States and in many other nations around the world. The performance of these markets will influence everything from the prices faced by consumers to the reliability of the systems. The challenges of these changes present many important areas for research. For much of the northeastern United States, restructuring proposals include, at least for the short term, the formation of a single-sided auction mechanism for the wholesale market. This research uses experimental methods to analyze how these markets may function. In the experiments, the two basic uniform price auction rules are tested under three different market sizes. Early experimental results suggest the commonly proposed last-accepted-offer auction works well, but market power could be a real concern.

Restructuring of electric power markets is proceeding across the United States and in many other nations around the world. For much of the northeastern United States, restructuring proposals include, at least for the short term, the formation of a single-sided auction mechanism for the wholesale generation market. The performance of these auction markets will influence everything from the prices faced by consumers to the reliability of the systems.

This paper reports on research examining potential auction institutions for restructured markets for electric power through a series of economic experiments.[1] The primary factors for analysis in this research were efficiency and pricing. The potential for owners of electric generators to achieve market power was a major focus as well. The secondary concern in the experiments was to compare the induced cost curves and the actual offer curves in an effort to determine if strategic supply reduction should be a concern. The setting of these experiments was designed to match as well as could be the markets outlined in the various short-term restructuring proposals. The experiments were conducted in the absence of a network, the equivalent of a system where transmission of electric power occurs without loss of power and is costless.

Experimental methods were the best way to approach this area of research. By constructing similar markets in a laboratory setting, we were able to control extraneous variables that complicate real world situations. Furthermore, using experimental methods allowed us to compare prices from the auction with optimal prices and to determine actual achieved efficiencies. To see the importance of these abilities, imagine the expenses and difficulties in implementing an untested system on a wide scale and then discovering problems. By that stage, a substantial portion of the information necessary for analysis would be private and the extent of any problems difficult to gauge. As an example of the importance of experimental studies of new auction markets, consider the FCC's use of such methods during its design process for the spectrum auctions (see, for instance, the fall 1997 special issue of the *Journal of Economics and Management Strategy*).

The next section gives the necessary background to the discussion, reviewing first the typical form for restructuring electric power markets and then some of the basic principles of auctions. Following that section, details and results from the experiments are presented; then some early experiments conducted with a realistic network are noted briefly and important future areas for research are discussed. The final section presents the general conclusions observable at this point.

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[1] Auctions have been the subject for a large body of experimental research (see Kagel 1995 for a survey). For an example of experimental research pertaining to electric power markets in a different framework, see Backerman et al. 1997.

Background

Recent history has witnessed a fundamental shift in the traditional view of the electric power industry. Restructuring proposals have been advanced, and in places put into effect, attempting to bring competition to an industry long heavily regulated. A commonly proposed framework calls for the creation of an entity, referred to as an independent system operator (ISO), responsible for managing the relationships among the generation, transmission, and distribution sectors of the industry. Another task of the ISO, and the one that is the focus of this paper, would be to run a wholesale auction market for generation of electric power. These auctions would be run hourly to purchase enough generation to meet the forecast load demand. An important distinction of this market, at least in many short-term proposals, is that the ISO would, in effect, be the single buyer. Thus, the market to be examined is a single-sided auction, with many sellers and a single buyer. The rules of this auction could go far in determining the prices and efficiency within the restructured industry.

There exist different classes of auctions, and many variations in rules are possible within each. These differing institutional rules can lead to differing incentives on the part of participants and can lead to poor performance in terms of both efficiency and pricing. While William Vickrey spurred much of the current effort in auctions with his seminal work of 1961, there remains a great deal yet to be discovered in terms of performance and in understanding the incentives generated. An ideal auction for a generation market would be incentive compatible; in other words, it would contain the correct incentives for power producers to offer their full generating capacity at its actual cost.

In gauging the possibilities for problems, the experience of auctions elsewhere in the economy can be considered. Auctions have long been used to sell many agricultural commodities and other types of products. The U.S. government uses auctions to award rights (for such things as oil leases) and to sell debt. In such large-scale settings, auction performance is of particular concern. A recent example where concerns have been raised occurred in 1997, when the government auctioned off sections of the broadcast spectrum. To some observers, it appeared as if the auction had failed to extract an appropriate level of revenue. In this and other instances, some have also questioned whether certain auction mechanisms allow firms to signal each other of their bidding intentions (Weber 1997).

The potential for participants to control the auction is of obvious importance. In particular, the extent to which it may be possible to gain excess profits through gaming in these auctions is a major concern. Unfortunately, theoretical modeling of the complex markets for electric power would prove extremely difficult, if not intractable, in the case where network constraints are considered. In addition, there are no markets similar enough in form to gather data from and conduct an empirical analysis. These types of questions are thus best answered through the use of experimental testing.

Experimental Analysis

This section presents the design of the auction experiments and the results. The setting of the experiments consisted of the single-sided auction with multiple units being offered and a vertical, multiple-unit demand. While the experiments detailed here were conducted for analysis of a wholesale market for electric power, no underlying network or transmission grid was included. This analysis, rather, presents a best case for the performance of the tested auction mechanisms in different market sizes.

Auction Selection and Rules

The first step in the analysis was the selection of the most appropriate auction mechanisms for experimentation. Two different uniform price auctions were selected. The last-accepted-offer (LAO) version of the uniform price auction was selected because of its common inclusion in proposals for auction markets for wholesale electric power in states such as New York. In this auction, price and quantity offers are submitted in sealed bids. Once all offers have been received, they are ordered from lowest to highest. The single buyer than purchases the cheapest units up to the point where the total amount offered meets its demand. If this point occurs within a multiple-unit offer from a single seller, the buyer purchases just that portion needed to meet demand. The price it pays for these units is set at the highest offer price of the units it buys. This uniform price is paid to every seller.

The LAO auction is not incentive compatible. This can be understood easily by thinking about the strategy of a seller with a generator at the margin. If that seller sets the price and offers units at cost, the seller would make zero profits. Thus, such a seller would be indifferent between that strategy and not even participating in the auction.

The first-rejected-offer (FRO) uniform price auction was selected because of its superior theo-

retical properties in the single-unit case. In the case where a single unit is being purchased, or no seller can offer more than one unit, this auction is incentive compatible. Under the rules of this mechanism, the price is set at the lowest offer price of a unit(s) not purchased. As in the LAO auction, any offer crossing both sides of the point where supply equals demand is partially purchased. It is important to note in this situation that even though part of the offer is not purchased, the part not sold does not count in terms of setting the final price; the price is set at the lowest offer for which *none* of the units sold.

Unfortunately, as Ausubel and Cramton (1996) have proven, the favorable theoretical properties of the FRO auction do not carry over into the relevant case of multiple units. To understand why this is so, consider a firm with at least one very low cost generator and at least one higher cost, but beneath the competitive equilibrium price, generator. In most circumstances, the firm will be able to drive up the reigning price and increase its overall profits by withholding capacity from its higher cost generator. Clearly, this action both raises the price and lowers efficiency.

Experiment Design and Subjects

Group sizes of two, four, and six subjects were investigated. Six was selected as a group size in the hopes of creating a relatively competitive situation, while the duopoly scenario was included to see the potential for, and effects of, market power. Groups of four were added to the analysis as perhaps the most realistic for a wholesale market for electric power. Given the spatial and technical limits to transmitting electric power, it is doubtful that market areas would contain more than four competitors.

To give subjects in the different sized groups the opportunity to earn within the same range of money without altering the parameter setup of the experiments, three exchange rates were used, with more favorable rates going to larger groups. To keep earnings reasonable, all auctions were run with a reservation price of $.60. This allowed us to announce a range of potential earnings, $15 to $35, to students during recruitment of subjects.

Cost parameters were selected to mimic the three typical levels of costs for electric power generation: base load, midlevel, and peaking. Each subject had one generator on each cost level and a total possible output capacity of five units of power. Total capacity was divided such that each subject had two "high" capacity generators (able to generate a maximum of two units) and one "low" capacity generator (capable of only a single unit). There were two different cost and capacity structures, so that there were two subjects of each type in the groups of four, and three of each type in the groups of six. Demand was perfectly inelastic and set at one half the total capacity in the market. Demand was therefore five, ten, and fifteen, for the groups of two, four, and six, respectively. The cost and demand structure for the groups of two experiments can be seen in figure 1. In the other group sizes, the shape of the supply curve remains the same; only the scale changes.

While the parameters were the same for both auction types, the same cannot be said of the resultant optimal final prices. Optimal final prices were considered as those that would result if all participants in the auction offered their full capacity at its cost. From figure 1 again, it can be seen that the optimal price for the FRO auction would be $.22, while for the LAO a price anywhere from $.18 to $.22 could be considered optimal. For these auctions, the optimal prices remained constant regardless of group size.

Experiments ran for seventy-five periods. While this may seem to be a lot of repetition, recall that the actual markets will be run hourly. Therefore, seventy-five periods represent only slightly more than three days of experience in the new market. Repetition is also essential to allow subjects to acquaint themselves with the auction mechanism and, more importantly, the actions and strategies of others in their groups.

Subjects recruited for the experiments were undergraduate business students at Cornell University. These students were selected with the belief they would be the most representative of the types of employees that generation companies would be hiring to represent them in the actual auction markets. Most of the students were freshmen and sophomores who had had, or were currently enrolled in, both introductory micro and macro economics. Few of the students had participated previously in an economic experiment, and none were allowed to participate more than once. Students were told the experiments would not take more than an hour and a half. Students were paid their earnings in cash at the conclusion of experiments, with an additional $5 for participation. Subjects within groups that finished early were asked to wait patiently for everyone to be done so as not to disturb others and to maintain group anonymity.

Recruited student subjects participated in computerized experiments under controlled conditions in Cornell's Laboratory for Experimental Economics and Decision Research. The software was developed by Bernard, who used a generic frame

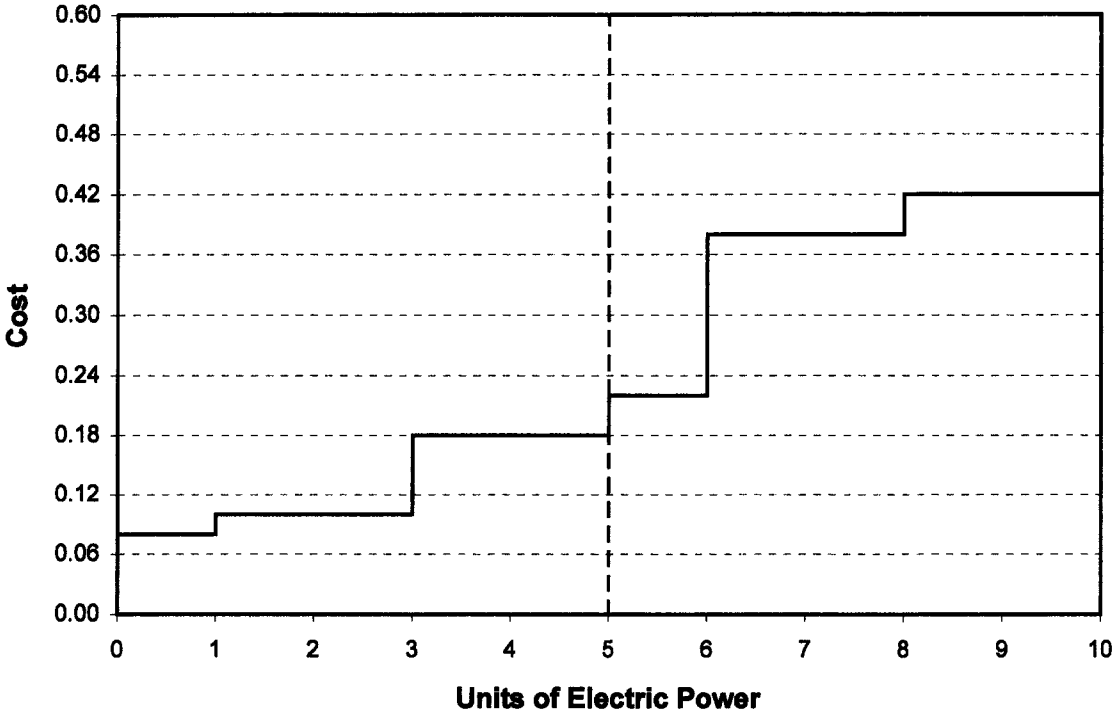

Figure 1. Demand and Generator Cost Curves for the Groups of Two Experiments

supplied by the Economic Science Laboratory at the University of Arizona. The experiment's user interface was designed to be as straightforward as possible. After all subjects have entered their personal information for record keeping, they are presented with the auction input/running screen. This screen, which is displayed throughout the experiment, details all information needed by subjects to make their price and quantity offer decisions. Specifically, students see how many generators they control, the maximum capacity of each, and the cost per unit of capacity. After each period, the subjects see what units they managed to sell, the final price, and their earnings for that period and overall. The interfaces for all of the auction programs are identical to eliminate concerns that presentation variations could effect performance. For similar reasons, the written instructions given to subjects were also crafted to be as similar as possible.

Information

Subjects were given written instructions prior to the start of the experiments and ample time for questions. The instructions detailed the rules of the auctions in a manner similar to the descriptions given above. However, no information on possible strategies was given to the subjects. Also, from the instructions, subjects knew other basic information, including the reservation price and how many periods the experiment would last, and knew that everyone's costs and capacities and demand would remain the same throughout. While demand was known to all, cost and capacity information was private. In addition, no information was given as to the specific distribution of the costs. Subjects were merely informed that others in their group had costs similar, possibly identical, to theirs for each of the three generators. It was common knowledge that everyone had the same total capacity, but it was not revealed what cost level another's low capacity generator was on.

While subjects knew the size of their group, they did not know which of the others in the room were in their group. Seating patterns in the room were carefully arranged to keep group members separated at seemingly random intervals and never to have more than two people with different cost structures seated next to one another.

Offers also remained private throughout the experiments. Only the final price was reported to the subjects after each auction. Subjects knew how much they sold but not how much any of the others in their group sold. While this amount is obviously

easy to deduce in the groups of two, there were instances where not enough supply was offered to meet demand. These instances were not reported to the subjects.

Price and Efficiency Findings

An assessment of the average final prices over the last twenty-five periods of the experiments reveals group size as a much greater determining factor than auction type. Only in the groups of four did auction type make a significant difference, with the LAO having a lower average final price. As can be seen graphically in figure 2, prices became progressively higher as group size became smaller. Prices were in fact nearly twice as high in the groups of two experiments as with the groups of six. Even in the groups of six, though, none of the auction mechanisms yielded prices at their optimal levels. Evidence does indicate that prices were headed downward, suggesting that experiments with more periods may be needed to find the true equilibrium.

Examining only average final prices over many sessions hides some of the interesting variations in the experiments. In individual sessions, there was a noticeable amount of heterogeneity. This was true for the groups of two experiments. In many of these sessions, groups were at the $.60 reservation price and at 100% efficiency over most of the last twenty-five periods. Groups that failed to reach the reservation price tended to have final prices in the range of the high cost generators. Beyond that point, subjects in these situations appeared determined to sell from their high cost generators, even if for only a $.01 or $.02 profit.

The extent of group differences was most evident in the groups of four. Although group behavior began to converge in the later periods, price results anywhere from the optimal level to the reservation price were observed in the early periods. Here, more than anywhere, results seemed dependant on who was in the group.

Efficiency levels are also displayed in graphical form in figure 3. As noted by Ledyard, Porter, and Rangel (1997), care needs to be taken in using and analyzing efficiency measures. Here, the design of the cost and capacity parameters had important implications for the measurement of efficiency. For instance, the set of possible efficiency values was not continuous. The possible cost realizations imposed by the parameters increased by $.04 intervals as production became less efficient. Group size had an even more important and noticeable effect on possible efficiency values. Specifically, the smaller the group, the more rapid the decline in

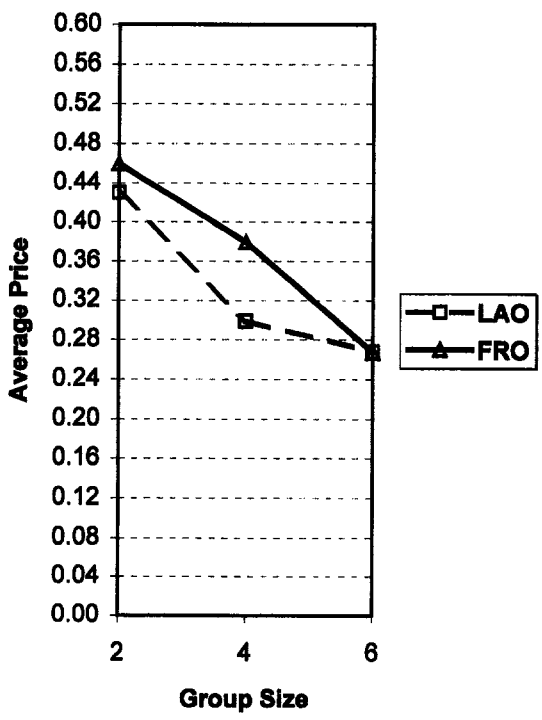

Figure 2. Average Final Prices Periods 51 to 75

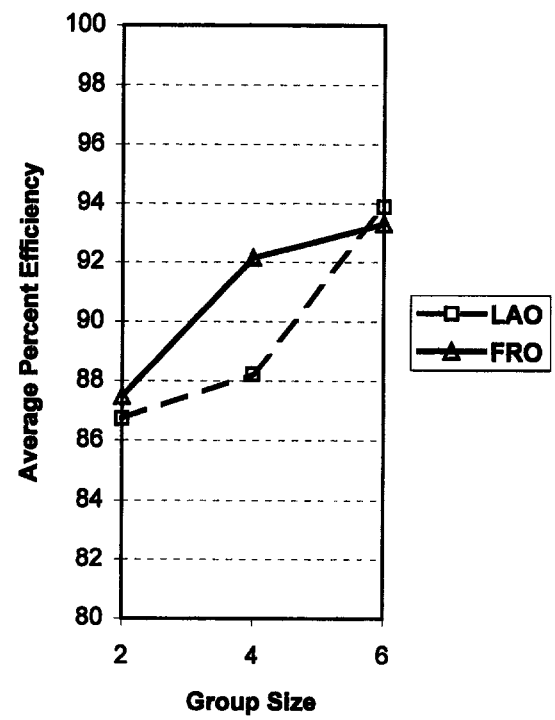

Figure 3. Average Efficiencies Periods 51 to 75

efficiency values as more costly units were produced to meet demand. Thus, participants in the groups of six actually needed to make more production errors than those in the groups of two to get the same value (consider that the second highest possible efficiency was .9789 in the groups of six, compared with .9394 in the groups of two). Efficiency values are thus not directly comparable across group sizes, and care must be taken not to become too negative in assessing auction performance, particularly in the groups of two.

Comparing efficiency across auction types does not reveal any superior performer. The FRO auction did perform surprisingly well, but its efficiencies were not significantly different from the levels reached by the LAO auction for any of the group sizes.

On the whole, efficiencies were lower than we hypothesized. While many groups were able to achieve and maintain 100% efficiency, many continued to exhibit low efficiencies even after sixty or seventy periods of experience with identical conditions. It was not entirely unheard of even after these lengths for some subjects still to offer units from a higher cost generator at a price less than from a lower cost generator. An error like this would not be expected to persist, if it existed at all, with bidders from actual generation companies. Restricting subjects from entering higher cost generators for less than any lower cost generators would have increased efficiencies in some instances.

Evidence on Incentive Compatibility

A secondary issue of concern was how well the auction institutions succeeded in getting subjects to reveal their true costs and capacities. Both auctions performed relatively closely in terms of cost revelation, but as expected, offers in the LAO auction tended to be slightly higher than those in the FRO auction. Despite the offers in the FRO auction being less inflated than those in the LAO auction, it was always the case that, given the price setting rule, the FRO auction ended up being more expensive.

For both auctions, the larger the group size, the better the offers revealed costs. Actual cost curves were least identifiable from offer curves in the duopoly setting. As group size increased, there was evident convergence both between the offer curves from the two auctions and between them and the cost curves. It would be an open question for future research if group sizes beyond six would continue this trend.

Supply reduction was evident in both auctions in all group sizes. It is questionable, however, if this was for any strategic reason. Given the information about cost and demand structure given to subjects, it should have been apparent to them that not all their capacity could be sold. This would certainly have been reinforced after even just the first few periods of the experiments. For all auctions, supply relevation was highest in the groups of two. In fact, percentage of capacity revealed tended to decrease for both auctions with larger group sizes.

Experiments with Network Constraints

Other factors beyond the basic rules of the auction mechanism and size of the market complicate the formation and performance of an electric power market. Complications with the operation of an electric grid, including the stochastic nature of load, the associated need to maintain reliability, voltage and line limits, and the locational variability of transmission losses, have to be incorporated into any market structure. Many of the constraints imposed by a network make even the measurement of important economic considerations in judging markets difficult to determine. For instance, the size of the market itself is highly dependent on the constraints of the network and can vary within areas dependent on which generators are dispatched. The answer in accounting for these complications is to create a smart market, where offers into the auction are adjusted for nodal pricing through transmission charges determined by the optimal power flow (McCabe, Rassenti, and Smith 1991). The next research being conducted at Cornell adds a smart market with a realistic, while simplified, electric power network.

This second research strand investigates a network environment using the LAO auction. The experimental platform used, developed by Ray Zimmerman (personal communication), has the added benefit of being web based. One group size has been studied, with the group containing a subset operating in a load pocket, enabling simultaneous analysis of different market situations. Results from three early pilot experiments are included in Bernard et al. (1998). In essence, these beginning experimental investigations support the above results. In a complex environment, with six generators, two of whom are located in a load pocket, prices approach duopoly levels inside the load pocket. In addition, nodal prices throughout the network are much more volatile under conditions where market power is exercised. This volatility could threaten system stability given current practices. These results have obvious implications for

the sale of generation assets in areas like the Northeast, where network constraints may give rise to areas of potential market power.

A Note on Future Research

Neither of the above sets of experiments comes near exhausting the areas for research. Electricity is not a standard type of commodity, and that fact gives rise to many further complications to market formation. Beyond the basic market for real power, there is the need to provide a series of what are called ancillary services. Ancillary services include such necessary elements as reactive power supply and voltage control, maintaining system frequency, and spinning reserve. Many of these services require separate markets that will have to operate in concert with the generation market. Wilson (1998) discusses the issues and interrelationships involved in these markets with an example to spinning reserves. The overall result is that the structure of these markets is relatively complicated, careful attention must be paid to the incentives across markets, and it is not clear how well the markets will perform. These new market systems provide rich avenues for further experimental investigation.

Conclusions

Experimental analysis has produced a number of preliminary conclusions relevant for restructuring of the electric power industry. First, in testing auction institutions, as Ausubel and Cramton (1996) have shown in theory, the uniform price first-rejected-offer auction fails to be incentive compatible in practice when sellers own multiple units. Somewhat surprisingly, a uniform price last-accepted-offer auction performs slightly better under the same cost and demand conditions. Since this is the institution most often proposed or used to date in electric power markets, this is a positive finding. Overall, the number of firms competing to supply the fixed demand proved to be a much more important determinant of price than the type of auction employed. Prices were near competitive levels with six sellers but doubled with two competitors. In the case of four sellers, there were instances of groups reaching results at the levels of both the other group sizes.

On the whole, there are performance questions to using either auction mechanism on a wholesale market for electric power. While restructuring proposals typically contain a single-sided market for the short term, results suggest that speed is desired in switching to a double-sided auction. The pricing and efficiency abilities of other market forms are another important application for experimental economics.

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