Testing the Performance of Uniform Price and Discriminative Auctions*

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* This paper was presented at the Rutger's Center for Research in Regulated Industries 14th Annual Western Conference: Advanced Workshop in Regulation and Competition, Competitive Change in Network Industries, San Diego, California (June, 2001). The authors wish to thank Thomas Overbye at the University of Illinois and Andrew Harvey at the New York State Department of Public Service for their help in organizing the experiments,and Richard Schuler at Cornell University for valuable editorial suggestions. The research was supported by the Power System Engineering Research Consortium (PSERC), the Consortium for Electric Reliability Technology Solutions (CERTS) program on Reliability and Markets at the U.S. Department of Energy and the California Energy Commission.

Abstract

The high prices that occurred in southern California since the Summer, 2000 led to a substantial amount of regulatory and political intervention. Price caps were lowered and the Federal Energy Regulatory Commission (FERC) proposed that a new type of "soft cap" auction should be adopted. This auction combines a standard uniform price auction with a discriminative auction for offers higher than a specified level ($150/MWh). Nevertheless, there is little available evidence to show that this new auction works well, or guarantees lower average prices. The objective of this paper is to provide some experimental evidence about the relative performance of different types of auctions for electricity markets. The experiments involved engineering and economic graduate students at Cornell University and the University of Illinois, and regulators in the New York State Department of Public Service. These individuals represent generators in a "smart" market, POWERWEB. This market replicates the physical constraints of meeting loads in an electrical grid. The first part of this paper describes how the high price volatility observed in many electricity markets can be replicated. The key features are 1) load is stochastic, 2) incentives are provided to withhold capacity from the market, and 3) the price is determined by a uniform (last accepted offer) price auction. The results with six identical generators in the auction show 1) price spikes are common, and 2) average prices are higher than competitive levels. This confirms the belief that electricity markets with totally inelastic demand need more participants than typical markets to ensure competitive prices.

The second part of this paper describes experiments using four different types of auctions. In a "smart" market, the total cost of meeting load is minimized, subject to operating constraints, in all cases. The four auctions are 1) a uniform price auction with price inelastic load, 2) a uniform price auction with price-responsive load, 3) a discriminative auction in which generators are paid their actual offers instead of a uniform clearing price (commonly, and incorrectly, called pay-as-bid), and 4) a "soft-cap" auction combining a uniform price and a discriminative auction.

The main result for all three groups of participants shows that both the uniform price auction (1) and the discriminative auction (3) produce average prices fifty percent above competitive levels. However, the prices for the uniform price auction are more volatile with many price spikes. The soft-cap auction (4) has price characteristics similar to the discriminative auction. In contrast, the uniform price auction with price-responsive load (2) has lower average prices (about thirty percent above competitive levels). The lower price volatility associated with the discriminative auction and the soft-cap auction is caused by the flatter offer curves in these auctions. However, this flat shape is likely to undermine the effectiveness of demand conservation as a way to reduce average prices. The uniform price auction with price-responsive load is the best among the four auctions tested, because it produces the lowest average price and has relatively low price volatility.

1 Introduction

Signs of trouble in the Californian market for electricity became obvious in the summer of 2000. James Hoecker, Chairman of the Federal Energy Regulatory Commission (FERC) was quoted as saying, “Never has the Commission had to address such a dramatic market meltdown as occurred in California's electricity market this summer. Never have residential customers been exposed to economic risk and financial hardship as they were in San Diego” (FERC, 2000). As a result, the FERC proposed major modifications to the structure of the wholesale market for power (FERC Order, 11/1/00). One of the proposals was to implement a soft-cap on market prices at $150/MWh. This represented a radical modification to the structure of the auction used to determine spot prices for electricity in the wholesale market. The new auction proposed by the FERC was implemented in January, 2001.

In a soft-cap auction, offers to sell below the cap of $150/MWh are used to determine a single market clearing price for all accepted offers in a standard uniform price auction. If the total capacity offered below $150/MWh is insufficient and some offers greater than $150/MWh are needed to meet the load, suppliers are paid their actual offers in a discriminative auction for all offers above $150/MWh. Hence, a soft-cap auction is a hybrid between a conventional uniform price auction and a discriminative auction.

The soft-cap market has not worked well. Spot prices for electricity in California remained consistently around $300/MWh from January to April, 2001, or roughly ten times higher than the previous year. Since the soft-cap market did not bring spot prices down to competitive levels, a new FERC Order (April 26, 2001) proposed to “replace the $150/MWh breakpoint plan adopted in its December 15, 2000 order” (FERC Docket No. EL00-95-012, p. 1). The proposed modifications to the market combine a highly regulated uniform price auction, based on “true” costs, with a discriminative auction for higher offers. Additional modifications to expand the regional and temporal coverage of this new market structure were adopted in FERC Order (EL00-95-031)

This paper reports on a series of laboratory experiments to assess the performance of different electric power markets with respect to price volatility and the average market price. In particular, the experiments compare conventional uniform price auctions, with and without price responsive load, with a discriminative auction and a soft-cap auction like the one proposed by the FERC for California. Since the computational complexity of determining equilibrium strategies in a multi-player, multi-unit game is too intractable to derive useful analytical results (Klemperer and Meyer, 1989), testing market performance using experimental economics is a practical way to proceed. Green and McDaniel (1999) have explored some of the implications for electricity markets in a theoretical analysis for a competitive generator which is consistent with our experimental results. Revenue neutrality holds, implying revenues to generators and average prices are similar in the uniform price and in the discriminative auctions.

For multi-unit auctions with asymmetric participants (e.g. firms of different sizes), Swinkels (2001) has shown that uniform price and discriminative auctions are both asymptotically efficient if the number of participants is large.

The key to this result is the concept of Asymptotic Environmental Similarity (AES), which implies that shared values dominate private values in large auctions. In repeated auctions for electricity, shared knowledge about the costs of other generators will be high and AES is a reasonable assumption. Nevertheless, theoretical results for the relative efficiencies of uniform price and discriminative auctions in small auctions are not available. Using experiments to test the performance of different auctions with relatively few participants is definitely warranted.

Our software platform, POWERWEB, implements a “Smart-Market” first proposed by Vernon Smith and his colleagues at the University of Arizona (McCabe, *et al*., 1991). POWERWEB simulates a thirty node AC electrical network (that is a stylized representation of the New England market) and constrains an auction for dispatching generators to the physical limits of that network.

Earlier experiments using POWERWEB have shown that generators are able to identify and exploit load pockets and drive up prices (Ede *et al*., 2000). With no constraints on transmission, however, six generators are sufficient to make prices competitive (Bernard *et al.*, 1998). For these experiments system load was fixed. When load is stochastic, other types of opportunities arise for raising prices above competitive levels. The objective of the new experiments is to understand the causes of high prices and price volatility in electric power auctions. In a uniform price auction, we find that average prices can be driven above competitive levels even when there are six firms and no transmission constraints. Our results demonstrate the cognitative ability of participants to raise average market prices by withholding capacity from the auction and submitting high offers for marginal units thus producing a few highly lucrative price spikes. A key determinant of the behavior is to incorporate an opportunity cost of submitting an offer to the auction, as well as to face some uncertainty about the load. The results also show that price-responsive load is an effective way to mitigate both high average prices and price volatility in a uniform price auction. In contrast, although the discriminative and soft-cap auctions reduce price volatility, the average prices are slightly higher than they are in a uniform price auction. Since the aggregate offer curves in these auctions are relatively flat compared to the uniform price auctions, the market price is less sensitive to load reductions due, for example, to energy conservation.

In the following section, the general procedures used to test markets with POWERWEB are described. In Section 3, the specific characteristics of a market needed to produce price spikes are identified. The results of the experiments are presented in Section 4, and the final section gives the conclusions.

2 Conducting Experiments with POWERWEB

2.1 The Experimental Framework

A smart market for electricity has been developed to account for the operational constraints imposed by the physical transmission network. In this context, the sellers and the buyers are connected by a transmission network which must be operated at all times in a manner consistent with the laws of physics governing the flow of electricity.

The operation of the network is also constrained by the physical limitations of the equipment used to generate and transmit the power. This results in two phenomena that may affect an auction: (1) transmission losses and (2) congestion.

Our experimental platform, POWERWEB, handles the effects of losses and transmission system constraints by determining the nodal price for each location that represents the shadow price of generating electricity at that location. Generating units are chosen to satisfy fixed loads in the least expensive manner while still satisfying the operational constraints of the transmission system. In previous experiments (Murillo-Sanchez *et al*, 2001), we have shown how congestion on transmission lines leads to high prices by limiting the number of effective suppliers in a load pocket. For the experiments discussed in this paper, however, there are no binding transmission constraints and high prices are caused by other factors. For each trading period, generators submit price/quantity offer curves to a central auction, and an Optimal Power Flow (OPF) is used to determine the least cost pattern of dispatch to meet load. Units are included for sale, starting from the low priced units and moving toward the higher priced units, until the supply reaches the total demand plus transmission losses. The remaining, higher priced, units are not dispatched. The market clearing price is set to the offer of the last (most expensive) unit chosen. In prior research (Bernard (1999)) when individual sellers have multiple units and load is held constant, the Last Accepted Offer (LAO) auction performs as well, or better, than a Vickrey auction and alternative uniform price auctions that set the price equal to the first rejected offer.

2.2 Subject Remuneration

It is important that participants in the experiments receive “salient” rewards that correspond to the incentives assumed in the experiments. Performance related payment tends to reduce variability in performance and improve the quality of results from the experiments. Davis and Holt (1993) define saliency to require:

(1) subjects perceive the relationship between decisions made and the payoff outcomes
(2) induced rewards are high enough to dominate the subjective costs of making decisions and trades.

In our experiments, subjects receive monetary rewards based on their profits in the experiments. During the experiment each of the subjects see their earnings expressed in both *experimental dollars* and in real dollars. Real dollar earnings are calculated through the following formula:

Real Dollars = Exchange Rate * Experimental Dollars

The exchange rate can differ for each generator and across experiments. The purpose of the exchange rate is to balance actual earnings across generators when different generators have different cost structures and therefore different profit making abilities. There is, however, no specified limit on potential profits for subjects. Student subjects make on average $30 for a two-hour experiment, while utility executives, who are given a more lucrative exchange rate to assure salient rewards, might make more than $100 for the same experiment. A single experiment to test a specific auction may take 50 trading periods to reach a stable pattern of prices.

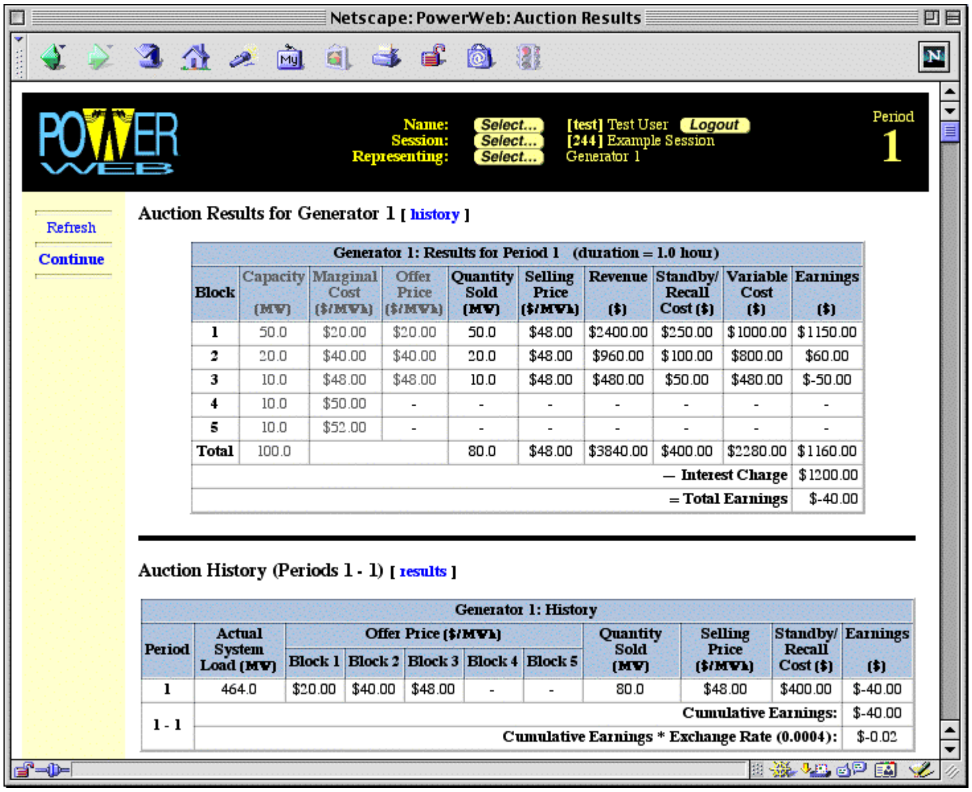
2.3 The POWERWEB Platform

POWERWEB is designed to be a flexible web-based platform for performing economic experiments on electricity markets. To date, the experiments implemented using this platform focus on examining the behavior of electricity markets using realistic modeling of the physical transmission network and human decision-makers. The Internet-based architecture eliminates the need for participants to be physically present in a specially equipped laboratory. The POWERWEB server handles application logic, data handling and computation. Users interact through a standard web browser (Netscape).

In the electricity markets currently implemented in POWERWEB, each participant in a session plays the role of the owner of a number of blocks of generating capacity offering to sell power through an independent system operator (ISO). The offer submission page is shown below in Figure 2-1. All generators know the true costs of their own capacity, the total installed capacity of all generators, the forecast of total load for the next trading period, and the maximum offer allowed in the auction (i.e., a hard cap on prices). The objective of all generators is to maximize their own profits by submitting offers to sell each block of capacity. In some cases, generators may chose to withhold capacity from the auction, and the importance of “standby” costs (these costs are incurred when a unit is offered into the auction regardless of whether the unit is dispatched) is discussed in the following section.

POWERWEB coordinates the offers from competing generators through a specified type of auction. It produces the market clearing prices and the generation schedules to meet the demand from all loads on the network (while respecting all of the physical limitations of the power system). Figure 2.2 displays the results of a single trading period, including the market prices and dispatch of each block of capacity, the associated costs and net revenues, and the cumulative earnings in real dollars.

Figure 2.3 is a diagram of the 30 bus, 6 generator power system which underlies POWERWEB’s “smart market”. For other experiments, a full AC system can be modeled with constraints on transmission lines to investigate, for example, the effects of “load pockets” (Murillo-Sanchez *et al*, 2001).



Netscape: PowerWeb: Auction Results

POWER WEB

Name: Select... [test] Test User Logout

Session: Select... [244] Example Session

Representing: Select... Generator 1

Period 1

Refresh

Continue

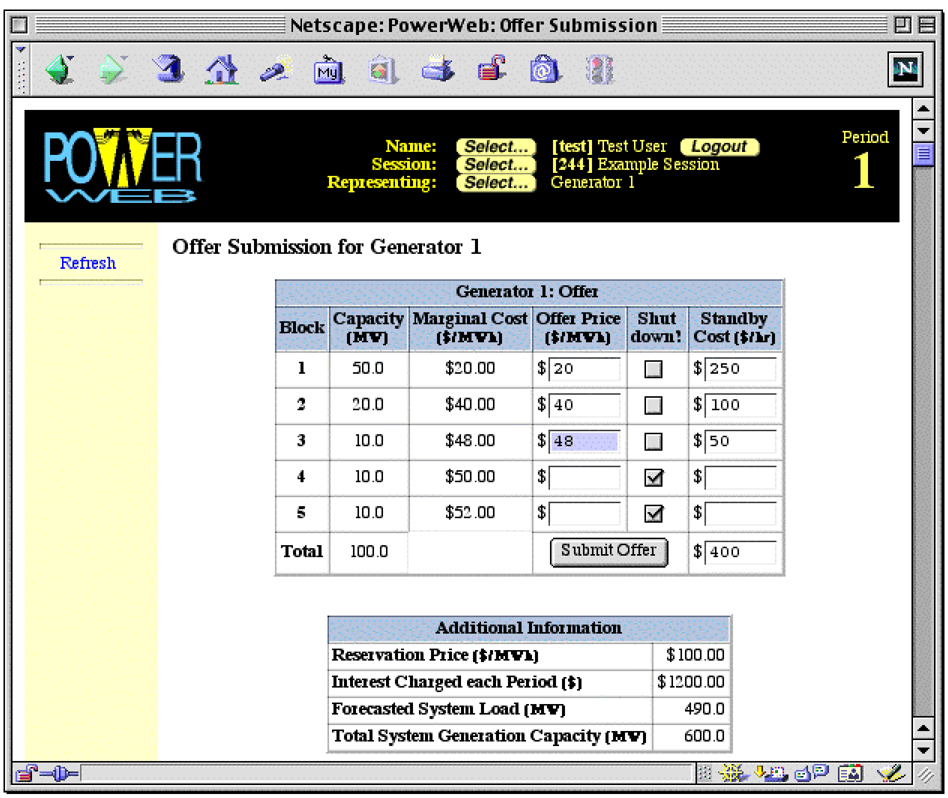
Auction Results for Generator 1 [history]

Generator 1: Results for Period 1 (duration = 1.0 hour)									
Block	Capacity (MW)	Marginal Cost ($/MWh)	Offer Price ($/MWh)	Quantity Sold (MW)	Selling Price ($/MWh)	Revenue ($)	Standby/ Recall Cost ($)	Variable Cost ($)	Earnings ($)
1	50.0	$20.00	$20.00	50.0	$48.00	$2400.00	$250.00	$1000.00	$1150.00
2	20.0	$40.00	$40.00	20.0	$48.00	$960.00	$100.00	$800.00	$60.00
3	10.0	$48.00	$48.00	10.0	$48.00	$480.00	$50.00	$480.00	$-50.00
4	10.0	$50.00	-	-	-	-	-	-	-
5	10.0	$52.00	-	-	-	-	-	-	-
Total	100.0			80.0	$48.00	$3840.00	$400.00	$2280.00	$1160.00
								— Interest Charge	$1200.00
								= Total Earnings	$-40.00

Auction History (Periods 1 - 1) [results]

Generator 1: History										
Period	Actual System Load (MW)	Offer Price ($/MWh)					Quantity Sold (MW)	Selling Price ($/MWh)	Standby/ Recall Cost ($)	Earnings ($)
		Block 1	Block 2	Block 3	Block 4	Block 5				
1	464.0	$20.00	$40.00	$48.00	-	-	80.0	$48.00	$400.00	$-40.00
1 - 1									Cumulative Earnings:	$-40.00
									Cumulative Earnings * Exchange Rate (0.0004):	$-0.02

Figure 2-1: Offer Submission Page from POWERWEB



Netscape: PowerWeb: Offer Submission

POWER WEB

Name: Select... [test] Test User Logout

Session: Select... [244] Example Session

Representing: Select... Generator 1

Period 1

Refresh

Offer Submission for Generator 1

Generator 1: Offer					
Block	Capacity (MW)	Marginal Cost ($/MWh)	Offer Price ($/MWh)	Shut down?	Standby Cost ($/hr)
1	50.0	$20.00	$ 20	☐	$ 250
2	20.0	$40.00	$ 40	☐	$ 100
3	10.0	$48.00	$ 48	☐	$ 50
4	10.0	$50.00	$	☑	$
5	10.0	$52.00	$	☑	$
Total	100.0		Submit Offer		$ 400

Additional Information	
Reservation Price ($/MWh)	$100.00
Interest Charged each Period ($)	$1200.00
Forecasted System Load (MW)	490.0
Total System Generation Capacity (MW)	600.0

Figure 2.2: Auction Results Page from POWERWEB

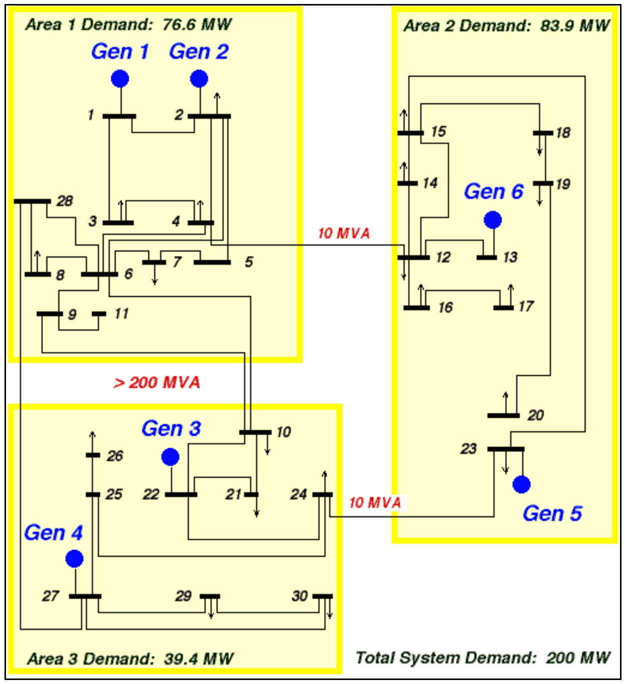


Figure 2.3: The network used in POWERWEB

3 Producing Price Spikes in Experiments

In earlier experiments, the forecasted load for the next trading period remained fixed for the whole experiment, and there was no uncertainty about load. By the end of an experiment, prices were relatively stable from period to period, and more importantly, six generators were sufficient to make the market competitive (Bernard *et al*, 1998). Since these results were very different from the price volatility observed in real markets, efforts were made to determine how to modify the experiments to reproduce the price spikes seen in many restructured markets for electricity. Experiments conducted in February 2000 using POWERWEB have shown that uncertainty about load and the existence of standby costs contribute to volatile price behavior. Since standby costs must be paid regardless of whether or not a unit is actually dispatched, there is an economic incentive to withhold marginal capacity from the auction if the probability of being dispatched is thought to be low. Consequently, capacity offered into an auction may be much less than the total installed capacity. Uncertainty about the actual load in the next period increases the incentive to use marginal units to speculate by submitting offers that are substantially higher than the true costs. Both of these actions lead to price volatility.

The experimental results in Figures 3.1-4 show the total capacity offered into the auction and the corresponding clearing prices for experiments with and without standby costs. In both cases, the actual load is stochastic and falls somewhere within a known interval from the forecasted load. When no standby costs are charged, the total capacity offered into the auction remains relatively high even when the forecasted load is reduced (see Figure 3.1). The corresponding prices are relatively close to the competitive prices throughout the 60 rounds (see Figure 3.2). When the final drop in forecasted load occurs in round 41, the competitive price drops substantially, but it takes a number of rounds before the market price reaches the efficient level. The implication is that competition still works in repeated auctions with six generators when the load is stochastic.

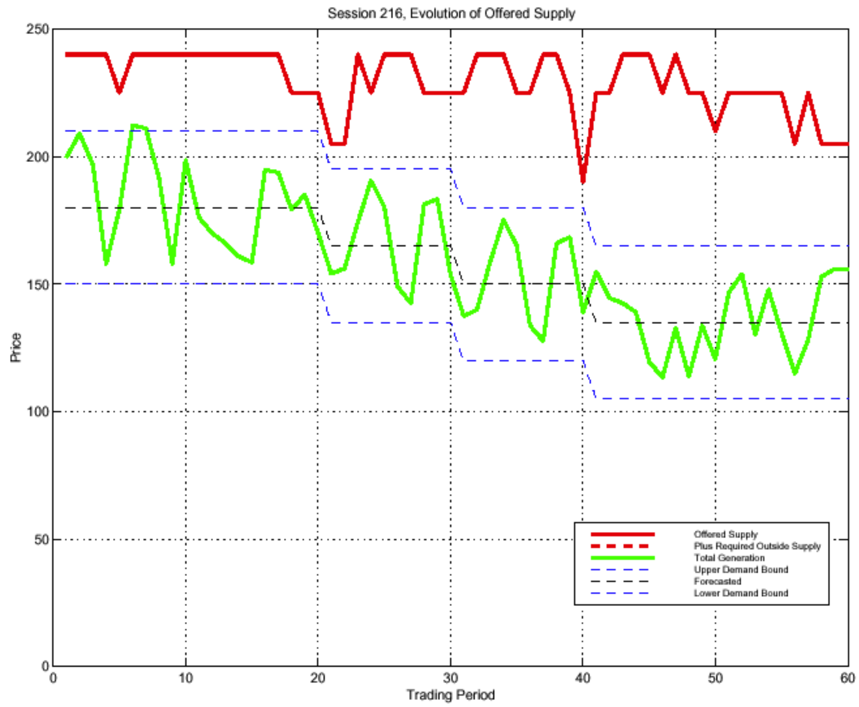


Figure 3.1: Capacity Offered into an Auction Without Standby Costs

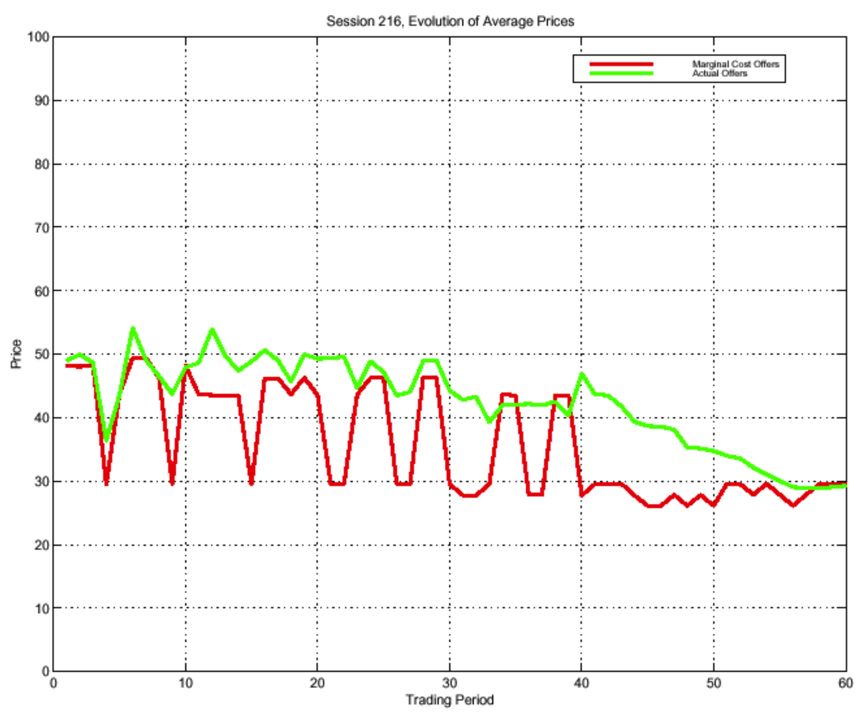


Figure 3.2: Market Prices Without Standby Costs

When standby costs are incurred for all units offered into the auction ($2/MW in this example), the total capacity offered into the auction drops when the forecasted load drops (see Figure 3.3). The operating reserve margin remains about the same. For five rounds, actual load is above the total capacity offered. For one round, the forecasted load is higher than the capacity offered. In these circumstances when there is a shortfall of capacity, emergency capacity was provided at the price of the highest offer to meet the load and avoid a blackout. The interesting result for prices is that players speculate more with marginal units, and price spikes occur (see Figure 3.4). In period 39, a price spike occurs when the load is relatively low because offered capacity is insufficient to meet load. When some capacity is withheld from the auction, the probability of setting the market price with a high offer on a marginal unit is much higher, and therefore, the incentive to speculate with marginal units is also much higher.

Since standby costs are important for producing price volatility in an auction, some explanation of why these costs exist is needed. In economic terms, every action has an opportunity cost. Thus the action of submitting an offer by a generator into an auction for electricity has a number of indirect costs as well as the direct costs of generating. All of these costs will be taken into account by the owners of a generator in deciding whether or not to submit an offer. We term these indirect opportunity costs standby costs. The potential sources of standby costs are described below in ascending order of likely importance:

First, by submitting an offer, a generator commits to being available for a particular time period (e.g., for the next day). This precludes cost reductions in labor force such as scheduling days off and vacation days. This is obviously a small factor, but it is still likely that some generators will shut down for extensive periods during off-peak seasons.

Second, by submitting an offer, the generator forgoes the opportunity to sell that unit of power in a bilateral trade to another market. (Some markets allow sales of non-firm energy to other markets even if the capacity has been sold in the local market for capacity.)

Third, some power plants are subjected to environmental restrictions, which may limit the number of hours of operation or the total quantity of a pollutant emitted (e.g., nitrogen oxides). In these situations, the opportunity cost measures the value of waiting for period when prices are high.

Fourth, since shut downs to meet maintenance requirements consume between 10 and 20 percent of the available hours for a typical power plant, maintenance is implicitly a very valuable activity. It should be noted that maintenance can be delayed, but this will result in an increasing risk of failure and large repair expenditures. An economic model of optimal maintenance can determine the trade-off between this rising risk of damage against the benefits of continued power production, which is obviously determined by the expected price of electricity.

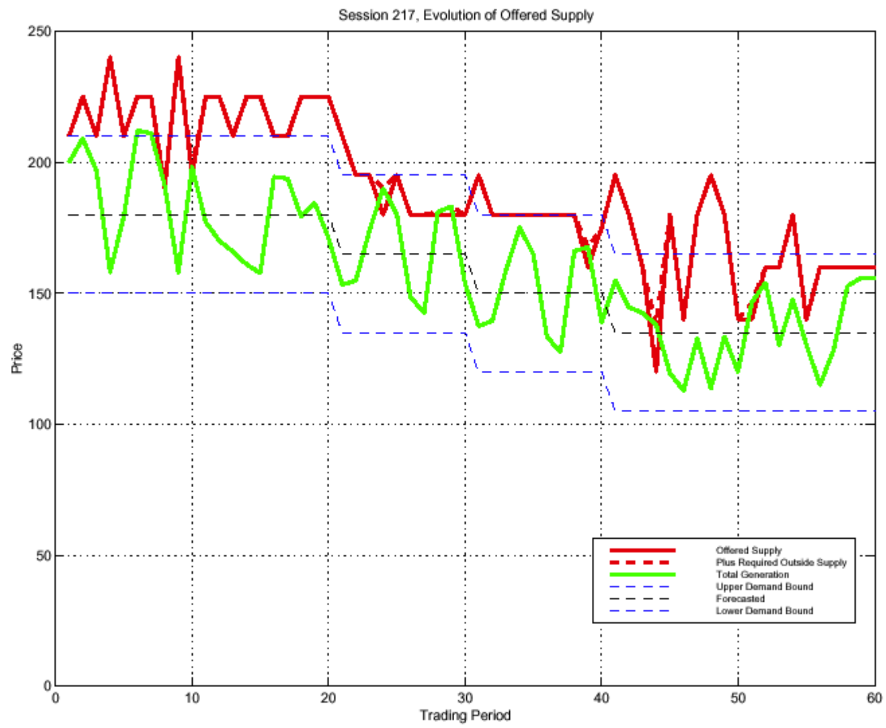


Figure 3.3: Capacity Offered into an Auction with Standby Costs

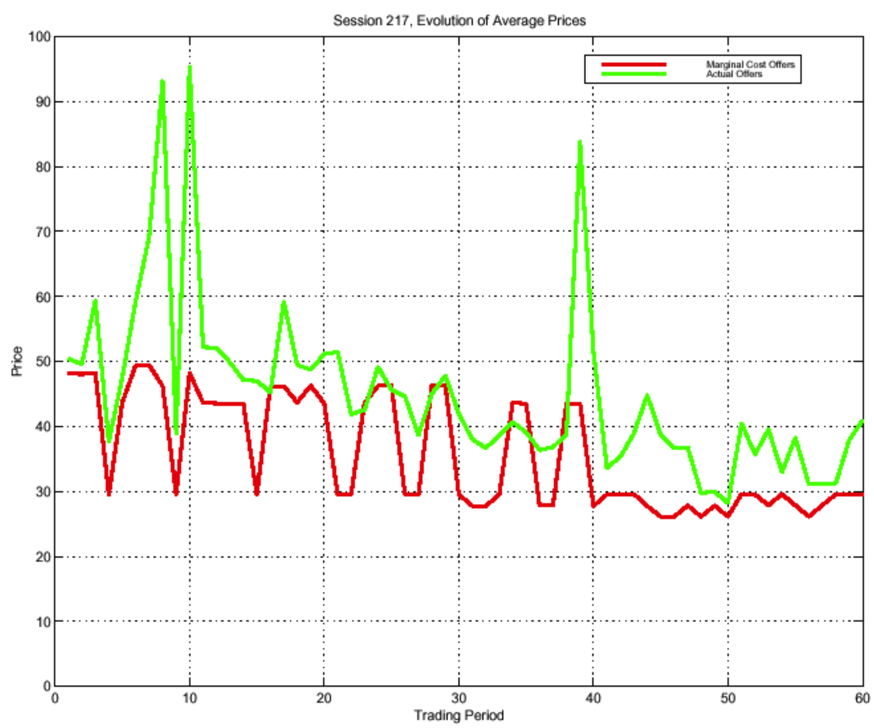


Figure 3.4: Market Prices with Standby Costs

Thus if firms are price takers in the auction, and anticipate a very low price, they will choose not to make an offer and either schedule maintenance or sell power in a bilateral trade to another market. Alternatively, if a company owns several generators and has market power, withdrawing some units from production will raise the market price paid for the electricity sold by the remaining generators. This Cournot behavior may result from the experience generators gain when withholding capacity from the auction for any of the four reasons listed above. Hence, these legitimate reasons for withholding capacity from the auction may, in fact, be used to mask the true motive of exploiting market power to raise prices.

4 The Experimental Results

4.1 Setting the stage

During Fall 2000, a graduate course was taught at Cornell University for students in engineering and economics. One of the objectives of the course was to use POWERWEB to test the performance of different market structures, and in particular, to investigate whether price volatility could be mitigated by modifying the type of auction. Since the FERC proposed a new form of soft-cap auction as a way to deal with high prices in California while our experiments were underway, this new form of hybrid market was also tested by the students. (The soft-cap auction was tested within two weeks of the announcement by the FERC, and shown to perform no better than a standard uniform price auction. This result demonstrates the benefits of using experimental economics to evaluate regulatory proposals before they are tested in real markets. After only a few months, the FERC decided in April, 2001 to abandon the soft-cap auction in California and to replace it with yet another new form of auction.)

The results obtained from the course were based on two groups of six students who performed a series of five different experiments. The exact specifications of this series of experiments evolved, and the designs of later experiments were influenced by the results of the earlier experiments and also by external events, such as the FERC proposal for California. Hence, these experiments were treated as pilots for a new series of four experiments that were conducted in Spring 2001.

There were some important benefits from conducting a series of experiments with the same students. Since high, volatile prices were produced in the first experiment using a uniform price auction, there was no doubt in later experiments that these students knew how to raise prices above competitive levels. Hence, the results from later auctions that mitigated price volatility or lowered average prices were more persuasive than they would be using new recruits for each experiment. (For example, one out of three groups of students failed to identify the potential for market power in earlier experiments on load pockets.) In real markets, the traders accumulate knowledge about the behavior of markets. When high prices or price spikes are observed in one market, traders in all markets inevitably try to determine why these price characteristics occurred, and for generators, how to duplicate them in their own market.

Hence, it makes sense to plan to conduct a series of experiments with the same group of participants to simulate behavior in real markets. The results, however, will still be dependent on the order in which the different auctions are tested.

When specifying the order of experiments, practical considerations determine the first principle of moving from simple auctions to more complex auctions (e.g., adding auctions for reserves after testing auctions for energy only). The second principle is to begin with auctions that replicate known deficiencies, such as high price volatility, and then to test different ways to mitigate the deficiencies. It should be noted that these two principles are quite different from standard experimental practices of testing a set of auctions using specified permutations, for example. The underlying objective for a series of different auctions in our work has been to make the order consistent with the evolution of real electricity markets. Of course, the relevance of the work for policy purposes depends on the assumption underlying all scientific experimentation: Parallelism. The parallelism precept assumes that, if the salient features of a situation are replicated in a laboratory, then laboratory behavior can predict "real world" outcomes.

4.2 The Four Auctions

The results of earlier experiments on producing price spikes in electricity markets were discussed in Section 3, and the implications were that stochastic load and standby costs for participating in the auction were both contributing factors. These two features were treated in the same way in all four auctions. An additional common feature was the treatment of shortfalls of capacity. Whenever the total capacity offered into an auction was insufficient to meet the actual load, additional capacity was selected at random from the capacity withheld. Capacity selected in this way was paid the price of the highest offer submitted to the auction, but a recall cost, equal to twice the standby cost per MW, is added to a recalled generator's costs to account for disrupting plans (e.g., having to break a contract to sell non-firm energy to another market). This procedure is consistent with a situation in which the capacity withheld has been sold into a capacity market and must, therefore, be available for generation when needed to avoid a blackout in the local market. This type of procedure has been used in the Pennsylvania, New Jersey, Maryland (PJM) market.

In all four auctions, there are six generators with five identical blocks of capacity giving each generator a total of 100MW. Each generator has 50MW of baseload capacity costing $20/MWh to generate, 20MW of intermediate capacity costing $40/MWh, and three blocks of 10MW peaking capacity with costs ranging from $48/MWh to $52/MWh. Only complete blocks can be submitted to the auction, and a standby cost of $5/MW is incurred for each block submitted to the auction, regardless of whether or not it is dispatched (the corresponding recall cost is $10/MW). Offers to sell each block of capacity must be non-decreasing, and a maximum reservation price of $100/MWh is enforced (i.e., a hard price cap). Finally, a fixed cost of $1200 is incurred each trading period by each generator to cover the cost of financing capital investments. The reason for implementing this fixed cost is to make the earnings of generators roughly proportional to the excess profits earned above competitive levels, but it also adds realism by capturing the cognitive effects of knowing that fixed costs must be paid regardless of the level of earnings in any trading period.

For every trading period, each generator is told the forecasted load, and the actual load is known to be in a range of ±20MW from the forecasted load. The generators then determine the offers for selling each block of their own capacity, including the decision to withhold some blocks. When all offers have been submitted, the smart market in POWERWEB determines the optimal pattern of dispatch to minimize the total cost for the given type of auction, and the prices paid for every block of capacity that is dispatched. Once the results have been reviewed by the generators, the process is repeated until the end of the experiment when a pre-specified, and known, number of periods have been completed.

The four auctions tested were:

1) a uniform price auction using the last accepted offer (LAO) to set the market clearing price. For every trading period, the total load is completely price inelastic even though load does vary from period to period.
2) the same auction as (1) except that some load is interruptible at high prices. Blocks of 10MW, 20MW, 30MW and 40MW of interruptible load are essentially equivalent to adding a 7th generator or to reducing load by a maximum of 16%. This auction simulates the effects of price-responsive load.
3) a discriminative auction in which generators are paid their actual offers for blocks of capacity that are dispatched. After each trading period, the results of the auction are reported to each generator and include the average price paid in the market and the average price paid to that generator. Load is price inelastic.
4) a soft-cap auction with a uniform price LAO auction for offers less than $75/MWh. Offers greater than $75/MWh are treated as a discriminative auction, and they do not set the market price for other capacity. Load is price inelastic.

The four auctions were tested by two groups of graduate students in engineering at the University of Illinois at Urbana-Champaign and three groups of graduate students in engineering and economics at Cornell University. The students at Illinois were enrolled in a course and tested one auction each week for 50 trading periods. The students at Cornell were recruited, and they tested two auctions in sequence in two sessions for 25 trading periods each. Finally, four groups of regulators from the New York State Department of Public Service (NYSDPS) tested the first and third auctions in sequence in one session of 30 trading periods each. The experiments at Cornell and the NYSDPS were run by the authors, but the experiments at Illinois were run independently by Thomas Overbye. Hence, the experiments at Illinois provide a check on any possible biases in the procedures by the people who also designed the experiments at Cornell. The fact that the results for all three types of participants were consistent with each other, and also with the pilot experiments, is very reassuring.

4.3 The Results

In this section, a descriptive analysis of the basic results of the experiments is presented (more formal analyses of the data are being conducted). Since the underlying theme of the experiments is price volatility, the main focus is on the performance of the market, and not on other interesting issues such as the strategies used by individual participants in the auction. However, it is important to note that a necessary condition for a high market price is that there is at least one high offer submitted to the auction. For the experiments discussed here, all participants were subjected to an initial presentation showing the price spikes observed in the PJM market during Summer, 1999. This approach was designed to mimic the information available to traders in real markets who had observed high prices in another market.

The average market prices for all experiments are summarized in Table 4.1. In all cases, the efficient competitive price is roughly $50/MWh. Only one of the 28 experiments has an average price less than $60/MWh, and eight experiments have prices over $80/MWh. Clearly, six competitors is not enough to reach efficient prices in any of the auctions. This confirms the findings of Rudkevich *et al*. (1998) and Bower and Bunn (2000) that to be competitive electricity markets need more competitors than typical markets. (The current standards used by the U.S. Department of Justice and the FERC assume that four or more firms are needed to make a market workably competitive.)

EXPERIMENTAL RESULTS FOR UNIFORM AND DISCRIMINATIVE AUCTIONS				
PowerWeb,Six Generators				
April/May 2001				
Average Clearing Price **$/MWh**	**Experiment 1** Uniform price auction with stochastic load: Inelastic load	**Experiment 2** Uniform price auction with stochastic load: Price responsive load	**Experiment 3** Discriminative price auction with stochastic load: Inelastic load	**Experiment 4** Hybrid uniform/discriminative auction with stochastic load: Inelastic load
University of Illinois:				
50 Trading Periods				
Group 1	**67.84**	**68.36**	**85.80**	**76.03**
Group 2	**76.71**	**69.96**	**83.20**	**79.46**
Average Price	**72.28**	**69.16**	**84.50**	**77.75**
Cornell University				
25 Trading Periods				
Group 1	**70.12**	**63.11**	**77.50**	**80.44**
Group 2	**78.84**	**66.01**	**55.42**	**66.96**
Group 3	**88.08**	**65.58**	**77.39**	**86.32**
Average Price	**79.01**	**64.90**	**70.10**	**77.91**
NYSDPS				
30 Trading Periods				
Group 1	**79.40**		**77.76**	
Group 2	**66.14**		**87.31**	
Group 3	**72.22**		**84.69**	
Group 4	**68.40**		**84.09**	
Average Price	**71.54**		**83.46**	
Overall Average Price	**74.19**	**66.60**	**79.24**	**77.84**
Competitive Price*	**49.08**	**50.74**	**49.44**	**49.24**
***For 50 Trading Periods**				

Table 4.1: Average Clearing Price

The overall average prices for three of the four auctions are well over $70/MWh. Price-responsive load in Experiment 2 (with a uniform LAO auction) has the lowest price of $67/MWh. Both the discriminative auction (Experiment 3) and the soft-cap auction (Experiment 4) have average prices higher than the corresponding uniform price auction (Experiment 1). Hence, there is no evidence to support the belief that paying generators their actual offers will alleviate market power. In particular, the soft-cap auction, like the one proposed by the FERC for California, has higher average prices than a standard uniform price auction with price-inelastic load.

Figures 4.2-5 show the market prices for each trading period in the four experiments for one of the graduate student groups at Illinois. The uniform price auction shown in Figure 4.2 has many price spikes, as expected. These price spikes are mitigated quite well in Figure 4.3 where load is price responsive. (The patterns of load in the different experiments are not identical, and therefore, participants could not use the results of an earlier experiment to predict load. The patterns of load for groups in the same experiment are identical). The prices are much less volatile in the discriminative auction and the soft-cap auction (Figures 4.4 and 4.5), compared to the uniform price auction (Figure 4.2), but these prices are also consistently high. This contrast in price behavior agrees with the conclusions reached by Mount (1999) and by Green and McDaniel (1999) that discriminative auctions will reduce price volatility but not necessarily reduce average prices. It will be shown below why it is easier to deal with the price spikes in a uniform price auction than it is to deal with the sustained high prices in a discriminative auction or a soft-cap auction.

Most participants in the experiments were familiar with the characteristics of a uniform price auction, particularly after the initial briefing and reading through the general instructions for POWERWEB. Hence, there was no obvious learning period before price spikes were produced in Experiment 1. In more complicated experiments, such as dealing with startup costs and self-commitment by generators into a market, 20 to 30 trading periods may be needed to develop consistent behavior in the auction. For the discriminative auction in Experiment 3, however, the participants had to develop a completely new strategy. This learning process is reflected in the increases of average price that occur over the first 10 trading periods in Figure 4.4

The basic strategy in a uniform price auction is to submit low offers for the baseload units, and possibly, to speculate with or withhold marginal units. (The aggregate offer curve in the PJM market, for example, looks like a hockey stick, with low prices for most of the capacity and high prices for a few small units.) Since each unit dispatched is paid the actual offer in a discriminative auction, the aggregate offer curve becomes relatively flat in Experiment 3. The learning process in the first few trading periods corresponds to raising the offers on baseload units to levels close to the offers on marginal units. It was remarkable how effectively each group of six generators was able to reach a tacit agreement about the price in the next trading period, and the high prices in this auction were much more stable than they were in the uniform price auction. Given the flat offer curves in a discriminative auction, however, it is likely that the market shares of individual generators varied a lot from period to period. Small differences in the offers among generators could have large consequences on the amount of capacity dispatched for an individual generator.

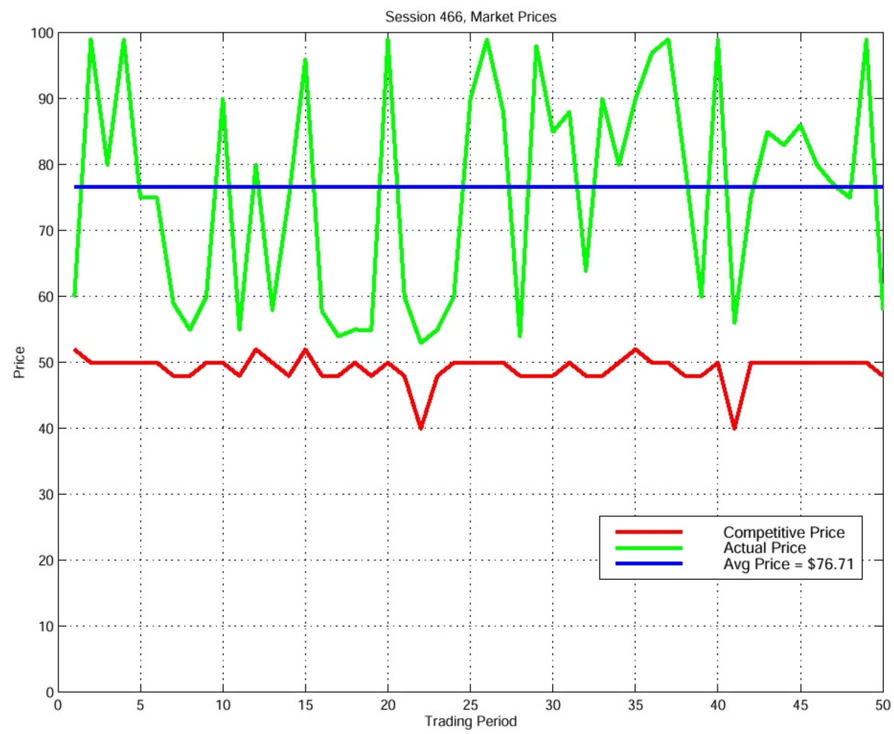


Figure 4.2: Average Prices for Experiment 1 (uniform)

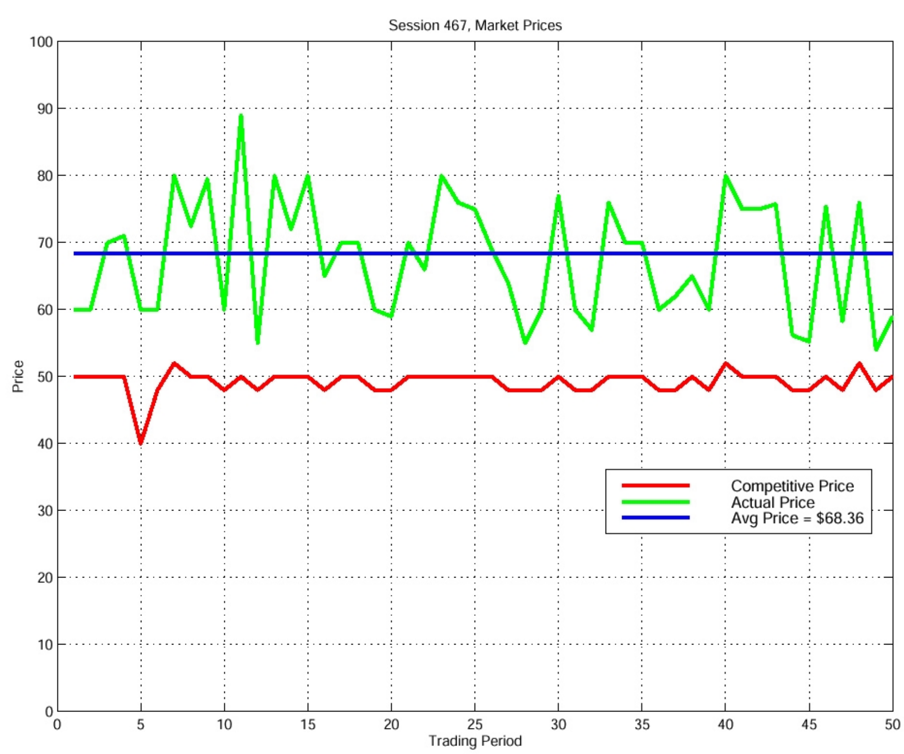


Figure 4.3: Average Prices for Experiment 2 (price responsive)

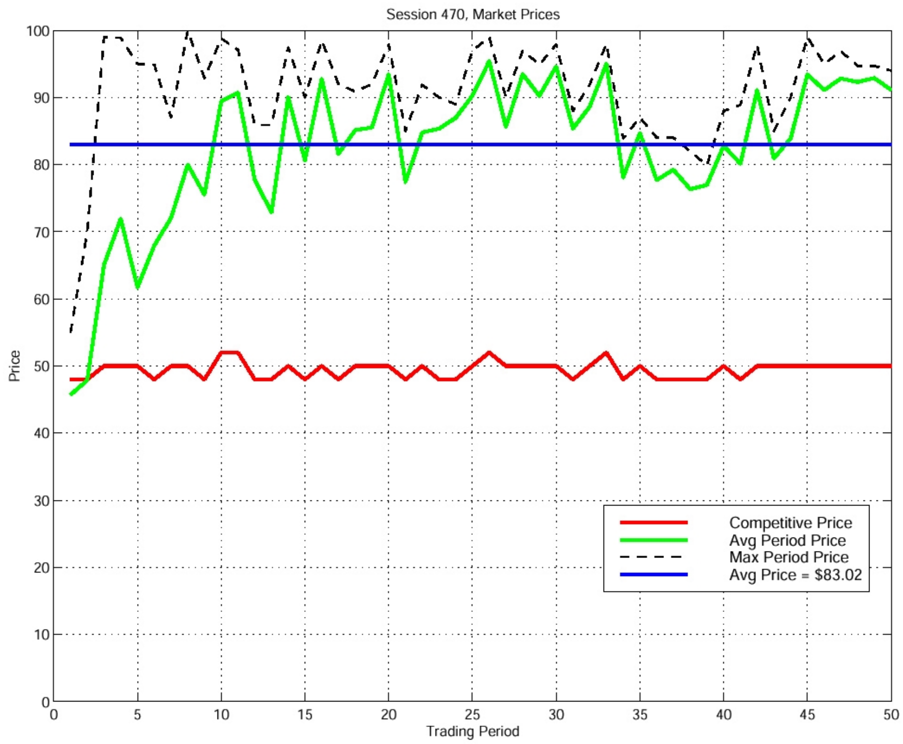


Figure 4.4: Average Prices for Experiment 3 (discriminative)

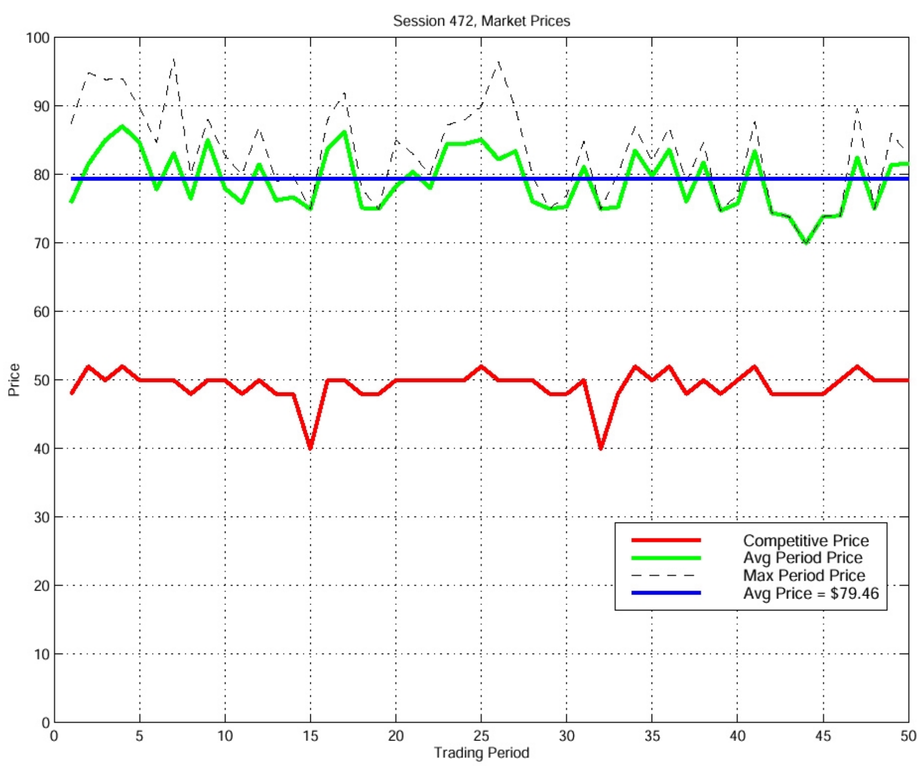


Figure 4.5: Average Prices for Experiment 4 (soft cap)

Examples of the aggregate offer curves for the two uniform price auctions are shown in Figures 4.6 and 4.7. Neither of them looks like a hockey stick, but this is primarily due to setting a low maximum reservation price at $100/MWh (the maximum is $999/MWh in the PJM market). In Figure 4.6, the offers are ranked from least expensive ($20/MWh) to the most expensive ($99/MWh), and six marginal units are withheld. The solid colors show the markup of each offer above the true cost. The market price is set by Generator 3 at $80/MWh to meet the system load of 490 MW. In this example, the order of the units in the offer curve is relatively close to the ranking of the true costs.

Two different features are shown in Figure 4.7. The first feature is the effect of making the load responsive to price. The steps in the demand curve correspond to blocks of interruptible load. The load would be 490 MW with no price response, and the market price would be set by Generator 3 at $90/MWh. However, using only 10 MW of interruptible load, Generator 4 sets the price $20/MWh lower at $70/MWh. The second feature of the offer curve in Figure 4.10 is that the order of units in the offer curve is very different from the ranking of true costs. This second feature is an indication of aggressive speculation in a uniform price auction.

There was a tendency for most groups in Experiments 1 and 2 to speculate with baseload units much more than expected. This proves to be a risky strategy. Even if the market clearing price is competitive ($50/MWh), the net revenue for a baseload unit is $1500, which is more than enough to cover the fixed costs of $1200 that is paid each period by all generators. Being shut out of the market completely leads to a loss equal to the fixed cost plus the standby costs of any units submitted to the auction. Excessive speculation by one or two generators is a tremendous benefit for the other generators, but not for the excessive speculators. For example, the group with the highest average price in Experiment 1 ($88/MWh for Cornell Group 3) included a chronic speculator who made much less profit than any other participant in that group. In real markets, traders who perform poorly would be removed from the market. (We have had discussions at Cornell about intervening in an experiment after a specified number of rounds if a participant is consistently earning much less money than everyone else.) The goal for testing the performance of electricity markets should be to use groups of knowledgeable players who understand how to maximize their own profits. This is not easy to do in practice because it only take a single player to produce strange results in an auction. For simple experiments, running more rounds, increasing the payouts in real dollars and using more groups (replications) are the standard ways to reduce the overall variability of results for a given experiment. For complicated experiments, like testing a realistic electricity market, these approaches may be prohibitively expensive and new ways of organizing experiments are needed. One promising approach is to use computer agents to represent players in the market (see Bower and Bunn (2000)).

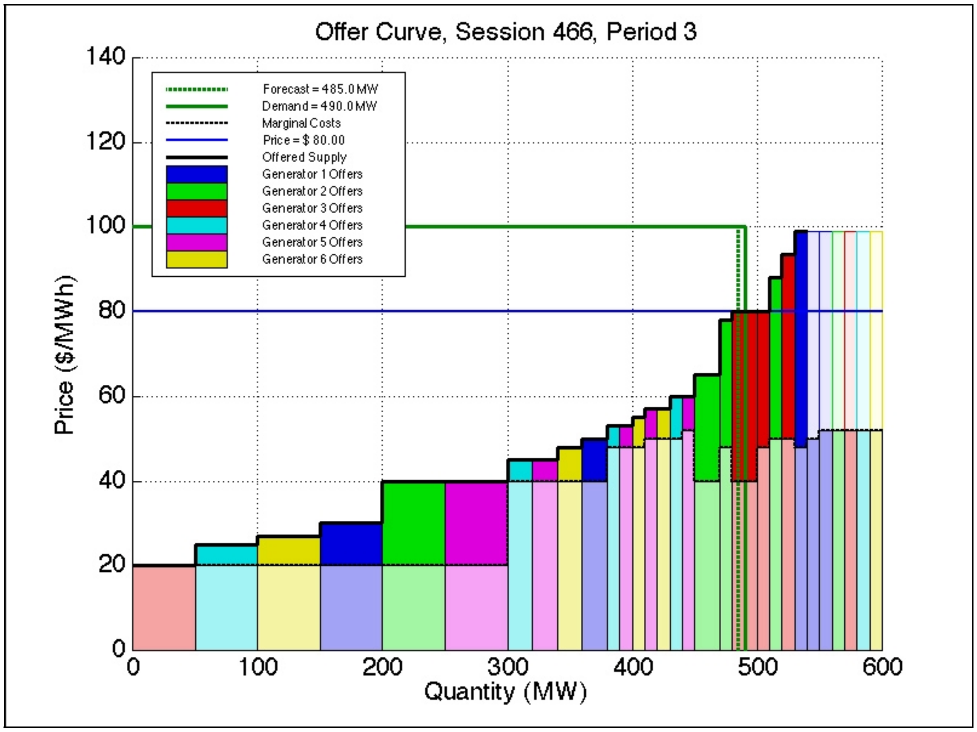


Figure 4.6: Illustrative Offer Curve for Experiment 1 (uniform)

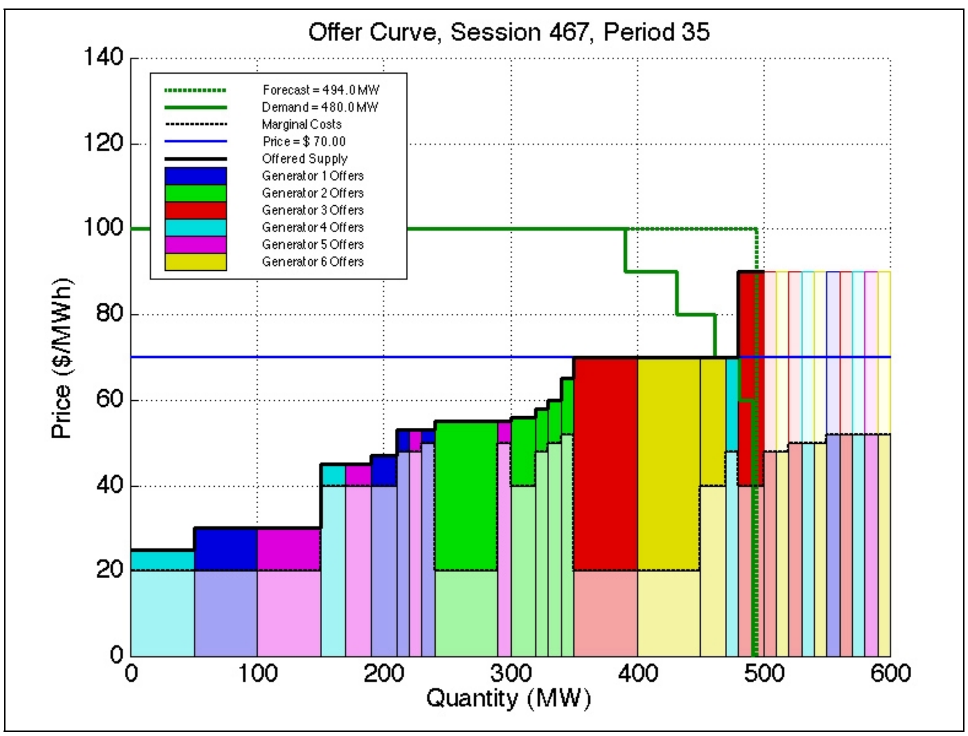


Figure 4.7: Illustrative Offer Curve for Experiment 2 (price responsive)

In spite of these concerns about excessive speculating with baseload units by some generators in the uniform price auctions, the ability of participants to adjust their behavior to a completely new type of auction was impressive in Experiment 3. Using a discriminative auction, the aggregate offer curves were relatively flat after a few trading periods. Figure 4.8 illustrates the typical behavior. Instead of having a wide range of offers (e.g., from $20/MWh to $90/MWh in the uniform price auction in Figure 4.6), the offers differ by only $11/MWh from $78/MWh to $89/MWh in Figure 4.8. The implications for demand conservation are important. With a relatively flat offer curve, reducing the load in a discriminative auction will be a much less effective way to reduce the average price compared to a uniform price auction.

A second problem with the discriminative auction is that the ranking of the offers is very different from the ranking of the true costs. In Figure 4.8, Generators 4 and 5 submit all five of their units at the same price, and in this example, all 100 MW of their units are dispatched. In contrast, Generator 2 only sells 35 MW of the baseload unit. This leads to economic inefficiency because some of the units dispatched to meet load have much higher true costs than other excluded units. The basic strategy for submitting offers in a discriminative auction is to specify higher markups on baseload units than on marginal units. This is exactly the opposite to the basic strategy in a uniform price auction, and as a result, the chance of not dispatching baseload units is higher in a discriminative auction.

Since the soft-cap auction in Experiment 4 is a hybrid between a uniform and a discriminative auction, the interesting question is how units will be divided between the two auctions. One has to conclude that regulators in the FERC assumed that most generators in California would submit offers into the uniform price auction below the cap and that only a few units would be submitted above the cap. If the offer curve looked like the uniform price auction in Figure 4.6, then setting a soft-cap at $75/MWh would reduce average prices. 470 MW of capacity would be paid $65/MWh instead of $80/MWh, and only 20 MW would be paid the actual offers above $75/MWh. Unfortunately, this is not how generators behave in a soft-cap auction.

Figure 4.9 shows a representative offer curve for the soft-cap auction in Experiment 4. This offer curve is relatively flat and quite similar to the offer curve for the discriminative auction in Figure 4.8. Only one baseload unit is submitted into the uniform price auction, and the offer for this unit is equal to the soft-cap of $75/MWh. The range of offers is relatively small, from $75/MWh to $90/MWh, just like a discriminative auction, and the average price paid to generators in $85/MWh. The implication is that if the participants believe that offers higher than the soft-cap will be accepted in the auction, they want to sell all of their capacity at that high price. Consequently, the soft-cap auction does not offer an effective way to deal with market power. In addition, it is similar to a discriminative auction in making it difficult for demand conservation to reduce market prices because the offer curves are flat.

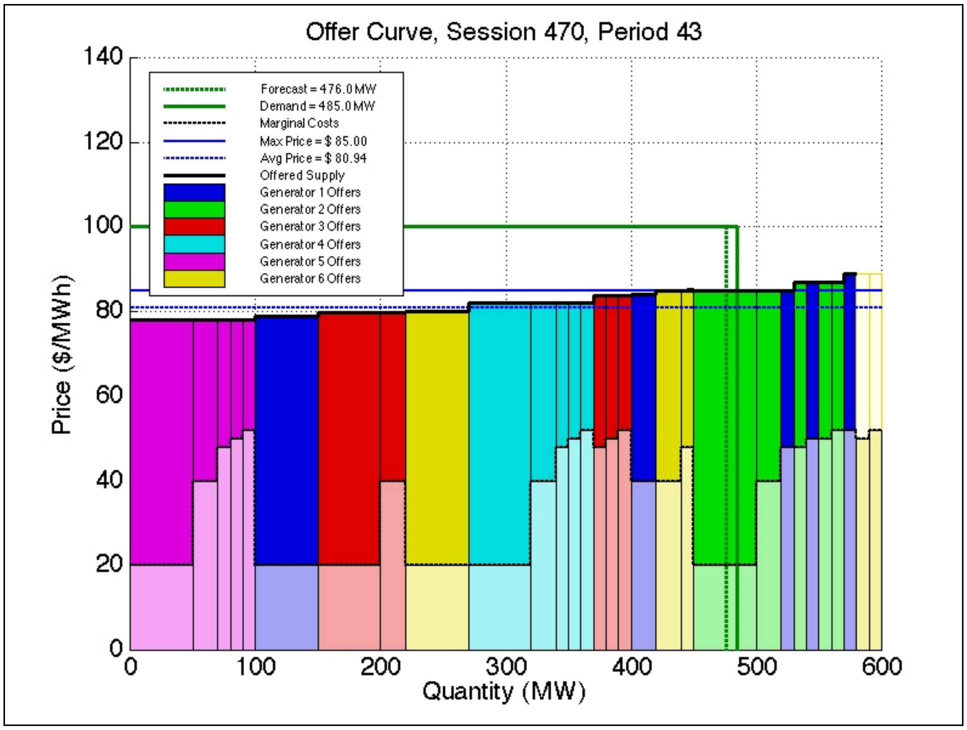


Figure 4.8: Illustrative Offer Curve for Experiment 3 (discriminative)

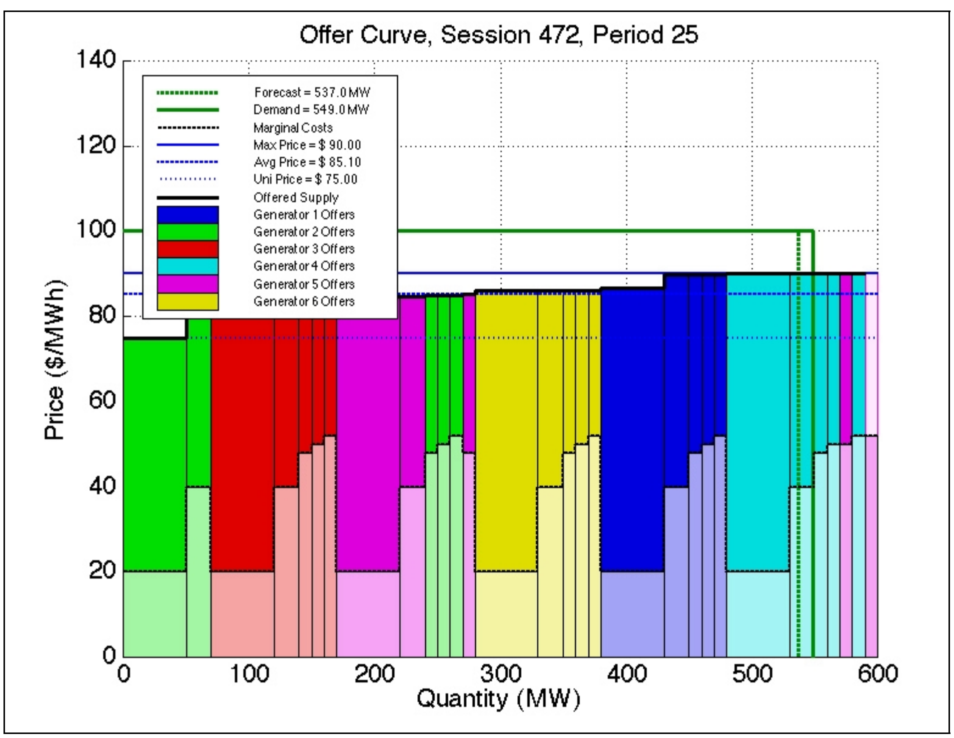


Figure 4.9: Illustrative Offer Curve for Experiment 4 (soft cap)

The average prices for high loads and low loads summarized in Table 4.2 provide some additional evidence about price responsiveness. Since the forecasted load for each trading period has an error of ±20 MW, all generators are essential if the forecasted load is >520 MW (each generator owns 100MW of capacity and the total installed capacity is 600 MW). Von der Fehr and Harbord (1993) have shown why being essential is an important determinant of behavior in an electricity market. In our experiments, if a generator submits all capacity at the reservation price of $100/MWh when the forecasted load is >520MW, some of the capacity must be dispatched. (This illustrates why it is important to have a hard cap on prices in an electricity auction and thus avoid excessively high prices when firms are essential.)

EXPERIMENTAL RESULTS FOR UNIFORM AND DISCRIMINATIVE AUCTIONS PowerWeb,Six Generators April/May 2001								
Average Clearing Price $/MWh	**Experiment 1** Uniform price auction with stochastic load: Inelastic load		**Experiment 2** Uniform price auction with stochastic load: Price responsive load		**Experiment 3** Discriminative price auction with stochastic load: Inelastic load		**Experiment 4** Hybrid uniform/discriminative auction with stochastic load: Inelastic load	
	Forecasted Load		Forecasted Load		Forecasted Load		Forecasted Load	
University of Illinois: Last 40 Trading Periods	<480MW	>520MW	<480MW	>520MW	<480MW	>520MW	<480MW	>520MW
Group 1	55.57	82.66	59.65	78.46	85.01	93.73	67.91	86.81
Group 2	66.08	88.44	67.57	75.14	81.07	93.60	74.90	83.98
Average Price	60.83	85.55	63.61	76.80	83.04	93.67	71.41	85.40
Cornell University Last 15 Trading Periods								
Group 1	58.89	90.00	56.57	69.10	81.35	85.47	77.30	83.11
Group 2	72.38	89.90	61.00	68.57	57.77	62.39	58.83	74.49
Group 3	83.33	100.00	55.07	64.64	78.24	93.73	78.64	93.03
Average Price	71.53	93.30	57.55	67.44	72.45	80.53	71.59	83.54
NYSDPS Last 20 Trading Periods								
Group 1	63.42	100.00			68.75	95.27		
Group 2	60.33	74.03			91.41	96.30		
Group 3	65.25	99.00			83.63	95.94		
Group 4	59.33	80.00			85.36	92.76		
Average Price	62.08	88.26			82.29	95.07		
Overall Average Price	64.95	89.34	59.97	71.18	79.18	89.91	71.52	84.28
Competitive Price*	47.37	50.67	49.91	51.81	48.35	50.55	47.13	51.25
*For Last 40 Trading Periods								

Table 4.2: Average Prices for High and Low Loads

The trading periods in Table 4.2 are divided into “essential” (Forecasted load >520 MW) and “non-essential” (Forecasted Load <480 MW) to represent high and low loads. In addition, the prices for the first ten trading periods are not included in the analysis to allow for a learning period (especially for the discriminative auction in Experiment 3). The corresponding average prices for high and low loads are reported in Table 4.2. It should be noted that the competitive prices differ very little for the high and low loads ($4/MWh or less). In contrast, the uniform auction in Experiment 1 has an overall range of $24/MWh from $65/MWh to $89/MWh. When load is price responsive in

Experiment 2, it is harder to produce price spikes and the range of prices is only $11/MWh (from $60/MWh to $71/MWh). The discriminative auction in Experiment 3 also has a relatively small range of $11/MWh, but at very high prices from $79/MWh to $90/MWh. For the soft-cap auction in Experiment 4, the range is $12/MWh from $77/MWh to $84/MWh. The average prices for the high and low load periods are summarized in Figure 4.10. The uniform price auction in Experiment 1 shows that high prices occur in high load periods. The discriminative auction (Experiment 3) has a substantially higher low price and roughly the same high price. (Eliminating the first ten trading periods has the effect of increasing the average prices in the discriminative auctions.) The soft cap auction (Experiment 4) does trim the high price compared to the uniform price auction (Experiment 1), but the corresponding low price is higher. In contrast, with price responsive load in Experiment 2, both prices are lower than Experiment 1, particularly for the high load periods. In other words, price responsive load is an effective way to reduce price spikes in a uniform price auction. However, the most important result from the experiments is to show that the discriminative and soft-cap auctions both exhibit relatively high prices and do not deal with market power effectively. Given the additional feature of having flat offer curves, these two auctions undermine the effectiveness of one of the most powerful ways to reduce prices, which is to make the load responsive to price.

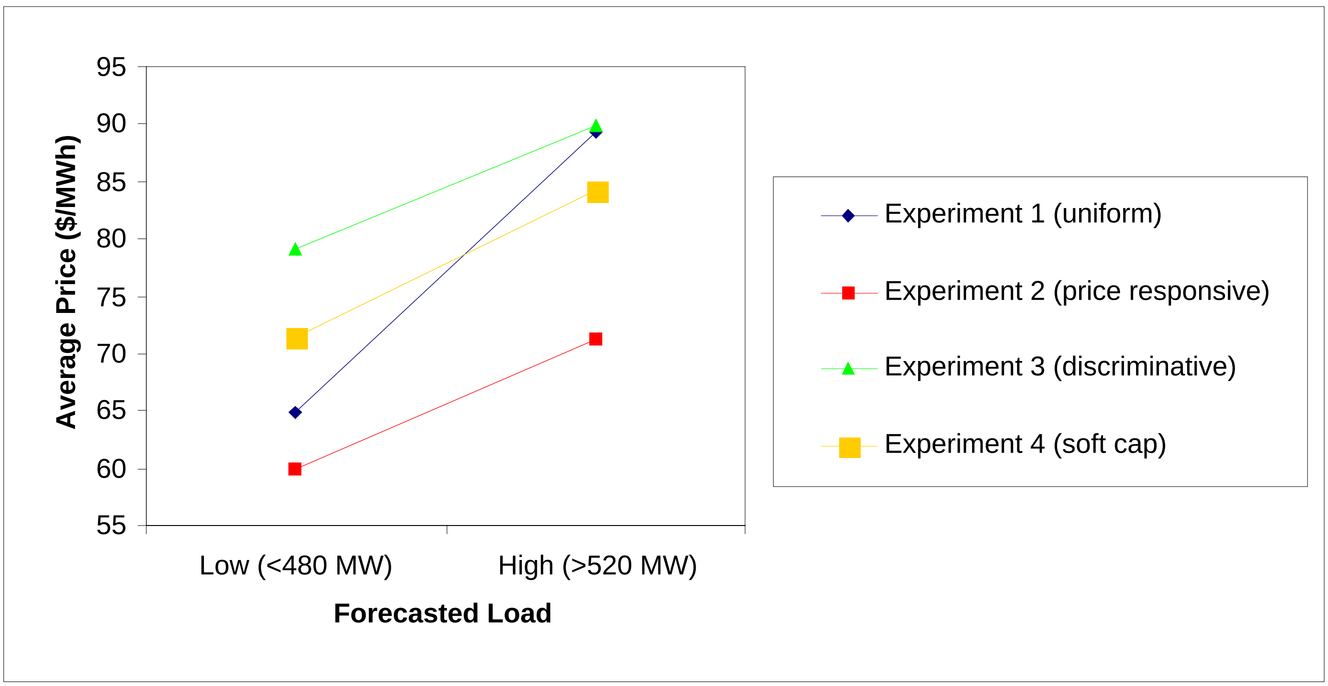


Figure 4.10: Average Prices for High and Low Loads

5 Conclusions

The primary objective of this paper was to test the performance of different uniform and discriminative auctions using experimental economics. For this purpose, a smart market, POWERWEB, was used to represent an electrical supply system with six generators. For each experiment, individuals act as the owners of the six generators and submit offers into an auction, given information about the operating costs of their own generating capacity, the number of competitors, the total installed capacity and a forecast of the load for the next trading period. The equivalent of an Independent System Operator (1S0) determines the optimal pattern of dispatch to minimize the cost of meeting load, subject to meeting system constraints. In addition, the ISO determines the price paid for each block of capacity that is dispatched for any given type of auction. After reviewing the results of the auction, the participants receive information about the next trading period (i.e., the forecasted load) and submit a new set of offers. In this way, an experiment proceeds through a predetermined number of trading periods.

An important characteristic of the experiments is that the participants are paid money based on the profits they earn in the auction. These profits correspond to the excess profits above competitive levels. In a typical experiment, which may take two hours to complete, the average earnings for a student are about $25. Paying the participants in an experiment is important for replicating the behavior observed in real markets and improving the statistical accuracy of the results.

A sequence of four different auctions were tested by two groups of graduate students in engineering at the University of Illinois, Urbana-Champaign, and by three groups of graduate students in economics and engineering at Cornell University. In addition, four groups from the staff of the New York State Department of Public Service (NYSDPS) tested two of the auctions. In all cases, the participants were given an initial briefing and told they represented traders in a new market for electricity. The price spikes that occurred in the PJM market during the summer of 1999 were used to illustrate what other traders had accomplished. The generators were told that their objective was to maximize their own profits. For these experiments, there were no network constraints, and each generator owned 100 MW of capacity divided into five blocks. All six generators had similar operating costs.

For all groups, the first auction tested was a uniform price auction with price inelastic load, using the last accepted offer to set the market clearing price. In earlier experiments with the same fixed level of load for every trading period, this type of auction with six generators produced relatively stable market prices that were close to competitive levels. There were no price spikes. However, making load stochastic from period to period, with a forecasting error for the next period, and charging a standby cost for all units submitted into the auction were sufficient to produce volatile price behavior. When the actual load is uncertain, there is more incentive for speculation with some generating capacity (i.e., submitting high offers for these units). In addition, standby costs give the participants an incentive to withhold some capacity from the auction. A procedure for recalling some of the withheld capacity was implemented if the total capacity offered into the auction was insufficient to meet the actual load.

The results for the first experiment (to test a uniform price auction with price inelastic load) were consistent across groups. All nine groups were able to produce price spikes in some periods, and the overall average price was 50% above the competitive price. The important implication is that six identical generators are not sufficient to make the market competitive. This result confirms the conclusions of other studies. It is clearly inconsistent with the standard used by federal agencies. The conventional rule assumes that four competitors are needed to make a market workably competitive. However, when load is price inelastic, more than six generators are needed in an electricity market to drive prices down to competitive levels.

Having replicated the type of price volatility seen in real markets for electricity in Experiment 1, the additional experiments can be viewed as different approaches for making prices more competitive. Hence, the sequence of experiments mimics the way that actual markets could evolve. In Experiment 2, the uniform price auction is maintained but load is made responsive to price by introducing blocks of interruptible load, equivalent in size to adding an extra generator. This experiment is consistent with the approach used in the PJM market to deal with price spikes.

When high market prices occur in a uniform price auction, these prices are very sensitive to small reductions of load. As a result, price-responsive load is an effective way to reduce the number of price spikes and lower average prices. This is confirmed by the results of Experiment 2. The overall average price is about 30% above competitive levels in Experiment 2 compared to 50% above in Experiment 1. This auction is still not fully competitive, but it does represent an effective way to reduce high market prices. In Experiment 2, a small block of interruptible load was specified at 20% above the competitive price, and another small block at 40% above. Hence, the load was still completely price inelastic at the competitive price. Additional price responsiveness at lower prices would make the market work even better. The specifications in Experiment 2 represent the conventional type of interruptible load, and more elaborate ways to reduce load, such as shifting load from peak periods to off-peak periods, are likely to be effective in real markets.

An alternative approach to mitigating price volatility and reducing average prices is to use a discriminative auction. In Experiment 3, costs are still minimized in the auction, but the generators are paid their actual offers for capacity that is dispatched. The overall average price for this auction was actually 16% higher than the corresponding price for the uniform price auction in Experiment 1. This is reasonably consistent with the concept of revenue neutrality between uniform price and discriminative auctions. There is no evidence from our experiments to show that a discriminative auction is more competitive than a uniform price auction. It is interesting to note that, the new electricity market in the UK has adopted a discriminative auction.

Experiment 4 represents a hybrid between a uniform price auction, for offers below $75/MWh, and a discriminative auction for high offers. This structure is similar to the “soft-cap” market adopted in January 2001 in California, based on an order issued by the FERC. If generators used the same strategy for submitting offers as they do for a uniform price auction, the soft-cap market would work quite well. Unfortunately, this is not how the generators behave. When high prices are anticipated, the generators behave as though they are in a discriminative auction and try to set a high price for all of their capacity. Most capacity is offered into the auction at roughly the same price. The overall average price in Experiment 4 is slightly lower than the average price for the discriminative auction, but it is still higher than the price in the uniform price auction (Experiment 1). Our conclusion is that the soft-cap market does not represent an effective way to make an electricity market more competitive.

Using revenue neutrality as a guide, one could argue that the differences between the uniform price (with price inelastic load), the discriminative and the soft-cap auctions are unimportant. This is not the case because the shapes of the typical offer curves are different. In particular, the flat offer curves for the discriminative and soft-cap auctions make the average market price much less responsive to reductions of load than a uniform price auction. Hence, the effectiveness of making load responsive to price is undermined. It is important to test this assertion in new experiments, but our results do provide one explanation of why it was so difficult to reduce prices in California after the soft-cap auction was adopted. In fact, it is possible that the introduction of a soft-cap auction in California in January, 2001 is partly responsible for the stability of the spot prices at levels well above $200/MWh over the following four months until more drastic restrictions on prices were adopted. To quote a report by the California ISO, "… the soft cap unfortunately has produced little discipline on the exercise of market power… [and] the bulk of non-utility supply has been offered above the single price auction threshold…" (i.e. the soft cap), (Sheffrin, 2001).

In real markets, regulators should assume that traders will eventually identify and exploit any deficiencies in the structure of a market. It is difficult, and may be impossible, to have competitive prices in a market unless there are an adequate number of competitors (on both sides of the market). Reinforcing the importance of this obvious principle may be one of the most useful implications of our experiments, particularly for regulators who are searching for a clever form of auction to deal with market power.

A great deal of regulatory scrutiny is being directed to high offers in real markets. For example, one regulatory solution to high market prices is to make generators justify high offers. This encourages generators to submit very expensive units into the auction (and possibly withhold less expensive capacity). Instead of placing greater regulatory pressure on high offers, a better way to lower market prices is to increase the price responsiveness of load and to increase the number of competing generators (firms) in the market. At the present time, there is too much concern by regulators about high offers and not enough about the patterns of ownership of capacity. As our experiments show, six firms are not enough to ensure that prices are competitive in electricity markets.

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7 Appendices

7.1 Experiment 1: Uniform Price Auction with Stochastic Load (No Price Response)

You are one of six suppliers in an electricity market. Each supplier owns 100 MW of capacity, divided into five blocks. Offers to sell these blocks can be submitted into an auction. An ISO selects the least expensive combination of offers to meet the system load and determines the market clearing price (last accepted offer) paid to all successful offers. For each period, you will be given a forecast of the system load. The actual load is uncertain but it falls into the range of **Forecast ± 20 MW**. When actual load is above 500 MW, some of your capacity is essential to meet load. However, the chances of load being above or below the forecast are the same.

The operating costs of your capacity have two components. The first is the operating cost/MWh for a capacity that is dispatched. The second is a fixed standby charge of **$5/MW** for submitting an offer. Hence, standby costs are paid when a block is offered into the market even if it is not dispatched. Withholding blocks from the auction is the only way to avoid standby charges for those blocks (the "submit offers" screen for POWERWEB has buttons for withholding blocks). If the total capacity offered into the auction is less than the actual load, the ISO recalls enough additional capacity to meet load. Recalled capacity is selected at random from the blocks that were withheld from the auction. A recall charge of **$10/MW** must be paid if a block is recalled, as well as the operating cost for the capacity purchased.

Your objective in the experiment is to maximize your profits over a series of 50 periods.

Summary

Auction:	Uniform – Last accepted offer
Periods:	50
Load:	Forecast = 490MW ± 60MW, Actual = Forecast ± 20 MW
Price Response:	Load is price inelastic
Standby Charges:	$5/MW for each block
Shortfall Mechanism:	Random recall with price set to the highest offer
Recall Charge:	$10/MW for each block
Fixed Interest Charge:	$1200/period
Exchange Rate:	1/6000

7.2 Experiment 2: Uniform Price Auction with Stochastic Load (with Price Response)

You are one of six suppliers in an electricity market. Each supplier owns 100 MW of capacity, divided into five blocks. Offers to sell these blocks can be submitted into an auction. An ISO selects the least expensive combination of offers to meet the system load and determines the market clearing price (last accepted offer) paid to all successful offers. For each period, you will be given a forecast of the system load. The actual load is uncertain but it falls into the range of **Forecast ± 20 MW**. The change from Experiment 1 is that **Contracts for Interruptible Load** exist that are automatically exercised at specified prices. The details of these contracts are not public information.

The operating costs of your capacity have two components. The first is the operating cost/MWh for a capacity that is dispatched. The second is a fixed standby charge of **$5/MW** for submitting an offer. Hence, standby costs are paid when a block is offered into the market even if it is not dispatched. Withholding blocks from the auction is the only way to avoid standby charges for those blocks (the "submit offers" screen for POWERWEB has buttons for withholding blocks). If the total capacity offered into the auction is less than the actual load, the ISO recalls enough additional capacity to meet load. Recalled capacity is selected at random from the blocks that were withheld from the auction. A recall charge of **$10/MW** must be paid if a block is recalled, as well as the operating cost for the capacity purchased.

Your objective in the experiment is to maximize your profits over a series of 50 periods.

Summary

Auction:	Uniform – Last accepted offer
Periods:	50
Load:	Forecast = 490MW ± 60MW, Actual = Forecast ± 20 MW
Price Response:	Contracts for interruptible load
Standby Charges:	$5/MW for each block
Shortfall Mechanism:	Random recall with price set to the highest offer
Recall Charge:	$10/MW for each block
Fixed Interest Charge:	$1200/period
Exchange Rate:	1/6000

7.3 Experiment 3: Discriminative Price Auction with Stochastic Load (No Price Response)

You are one of six suppliers in an electricity market. Each supplier owns 100 MW of capacity, divided into five blocks. Offers to sell these blocks can be submitted into an auction. An ISO selects the least expensive combination of offers to meet the system load, and pays the **actual offer for every purchased block in a discriminative auction.** You will be told the average market price as well as the average price you receive. For each period, you will be given a forecast of the system load. The actual load is uncertain but it falls into the range of **Forecast ± 20 MW**. Another change from Experiment 2 is that load is no longer responsive to price (i.e. the characteristics of load are exactly the same as they were in Experiment 1).

The operating costs of your capacity have two components. The first is the operating cost/MWh for a capacity that is dispatched. The second is a fixed standby charge of **$5/MW** for submitting an offer. Hence, standby costs are paid when a block is offered into the market even if it is not dispatched. Withholding blocks from the auction is the only way to avoid standby charges for those blocks (the "submit offers" screen for POWERWEB has buttons for withholding blocks). If the total capacity offered into the auction is less than the actual load, the ISO recalls enough additional capacity to meet load. Recalled capacity is selected at random from the blocks that were withheld from the auction. A recall charge of **$10/MW** must be paid if a block is recalled, as well as the operating cost for the capacity purchased.

Your objective in the experiment is to maximize your profits over a series of 50 periods.

Summary

Auction:	Discriminative – Pay actual offer
Periods:	50
Load:	Forecast = 490MW ± 60MW, Actual = Forecast ± 20 MW
Price Response:	Load is price inelastic
Standby Charges:	$5/MW for each block
Shortfall Mechanism:	Random recall with price set to the highest offer
Recall Charge:	$10/MW for each block
Fixed Interest Charge:	$1200/period
Exchange Rate:	1/6000

7.4 Experiment 4: Hybrid Price Auction with Stochastic Load (No Price Response)

You are one of six suppliers in an electricity market. Each supplier owns 100 MW of capacity, divided into five blocks. Offers to sell these blocks can be submitted into an auction. An ISO selects the least expensive combination of offers to meet the system load. The auction is divided into two parts. A clearing price for all **offers below $75/MWh** is determined in a **uniform price auction** (last accepted offer ≤ $75/MWh). If **offers above $75/MWh** are needed to meet load, the purchased blocks are paid the actual offers > $75/MWh in a **discriminative auction**. For each period, you will be given a forecast of the system load. The actual load is uncertain but it falls into the range of **Forecast ± 20 MW**. Load is not responsive to price.

The operating costs of your capacity have two components. The first is the operating cost/MWh for a capacity that is dispatched. The second is a fixed standby charge of **$5/MW** for submitting an offer. Hence, standby costs are paid when a block is offered into the market even if it is not dispatched. Withholding blocks from the auction is the only way to avoid standby charges for those blocks (the "submit offers" screen for POWERWEB has buttons for withholding blocks). If the total capacity offered into the auction is less than the actual load, the ISO recalls enough additional capacity to meet load. Recalled capacity is selected at random from the blocks that were withheld from the auction. A recall charge of **$10/MW** must be paid if a block is recalled, as well as the operating cost for the capacity purchased.

Your objective in the experiment is to maximize your profits over a series of 50 periods.

Summary

Auction:	Uniform ≤ $75/MW, Discriminative > $75/ MW
Periods:	50
Load:	Forecast = 490MW ± 60MW, Actual = Forecast ± 20 MW
Price Response:	Load is price inelastic
Standby Charges:	$5/MW for each block
Shortfall Mechanism:	Random recall with price set to the highest offer
Recall Charge:	$10/MW for each block
Fixed Interest Charge:	$1200/period
Exchange Rate:	1/6000