Experimental Evidence about the Persistence of High Prices in a Soft-Cap Auction for Electricity[1]

Timothy D. Mount*
Department of Applied Economics and Management
Cornell University

Robert J. Thomas
Department of Electrical and Computer Engineering
Cornell University

Christian A. Vossler
Department of Applied Economics and Management
Cornell University

Ray D. Zimmerman
Department of Applied Economics and Management
Cornell University

I. Introduction

The high prices for electricity in California during the summer of 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 be adopted to replace the uniform price auction. This auction combines a standard uniform price auction with a discriminative auction for offers higher than a specified soft-cap ($150/MWh). All offers to sell generating capacity below the soft-cap are submitted in a uniform price auction and paid a clearing price set to the last (highest) accepted offer. Any capacity offered above the soft-cap needed to meet the load is paid the actual offer in a discriminative price auction. With this structure, high offers above the soft-cap can not set the clearing price for all capacity sold. Nevertheless, high prices persisted during the winter of 2001. As a result, FERC abandoned the soft-cap auction in May, 2001. This paper presents results from four experiments using uniform and soft-cap auctions, with and without price-responsive load. The objective of this paper is to show that it is hard to mitigate high prices in a soft-cap auction when prices are driven above the soft-cap and to demonstrate how price-responsive load is a more effective strategy in uniform price auctions. Both industry professionals and students are used as participants who represent generators in a "smart" market, POWERWEB, which replicates the physical constraints of meeting loads on an electrical grid.

The results of earlier experiments conducted with POWERWEB show that both a uniform price auction and a pure discriminative auction can produce average prices fifty percent above competitive levels (Mount et al. 2001). However, the prices for the uniform price auction are more volatile with many price spikes. This is because generators in a uniform price auction tend to submit low offers for large, lower cost units and speculate with or withhold their marginal, high cost units. The resulting offer curve takes the shape of a

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[1] The Power System Engineering Research Consortium (PSERC) is a multi-university group of researchers established by the National Science Foundation to encourage collaboration between industry, government and universities on power system research. The PSERC group at Cornell University includes economists and engineers, and testing the performance of different forms of market for electricity and ancillary services is a central focus of this group. The current research is supported by the U.S. Department of Energy through the program on markets and reliability in the Consortium for Electric Reliability Technology Solutions (CERTS). An earlier version of the paper will appear in the Proceedings of the 25th Annual International Conference, International Association of Energy Economics, Aberdeen, Scotland, June 26-29, 2002.

*Correspondence should be directed to Timothy D. Mount, Department of Applied Economics and Management, 214 Warren Hall, Cornell University, Ithaca, New York 14853-7801. Email: tdm2@cornell.edu. Phone: 607-255-4512. Fax: 607-255-9984.

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hockey stick (the aggregate offer curve in the Pennsylvania-New Jersey-Maryland (PJM) market has this general shape). Small fluctuations in load can result in large price changes as the last accepted offer sets the price for everyone. In contrast, for a discriminative auction – where generators are paid their offers – the offer curves are relatively flat. When prices are above the cap in a soft-cap auction, offers have the same characteristics as a pure discriminative auction. This flat shape is the reason for lower price volatility and is likely to undermine the effectiveness of demand conservation as a way of mitigating high prices.[2]

II. Experimental Framework and Methodology

A. Participants

During the months of November and December, 2001, we conducted a series of six experiments using 18 individuals from the electric power industry. The last two experiments are reported here.[3] Participants were recruited via email and worked as traders, consultants, analysts, or regulators. Experiments were conducted remotely from the participant's own computer through the Netscape browser. Participants were separated into 3 groups of 6 competitors. Each experiment consisted of 25 trading periods.

During the months of February and March, 2002, we conducted a series of four experiments using a class of 18 undergraduate business and economics students at SUNY-Binghamton. Experiments were conducted in a designated computer laboratory on campus. As with the professionals, experimental markets consisted of 3 groups of 6 competitors. However, the members of each group varied from one experiment to the next. Each experiment consisted of 50 trading periods. Each participant was paid in direct proportion to her generator's earnings and told the main objective was to earn as much money as possible. On average, industry professionals were paid $150 for each experiment and students were paid $25 for each experiment.

Prior to the experiments, participants went through two training sessions where they competed against five adaptive computer agents in both a uniform price and a discriminative price auction. The user interface and many of the design parameters were exactly as they were in actual experiments. Participants were required to reach a minimum earnings goal in each exercise and were asked to repeat the exercise until the goal was met. The purpose of the training exercises was to allow participants to develop and test various offer strategies as well as minimize confusion and careless behavior during actual experiments. In addition, the students were given direct experience in class with actual experiments using a uniform price and a discriminative auction (15 periods for each auction). Our experience with testing auctions suggests that running actual experiments, particularly for discriminative auctions, is the most effective way to train participants.

B. Experimental Platform

Our experiments were conducted using POWERWEB, an interactive, distributed, Internet-based simulation environment for testing various auction markets using human decision makers.[4] POWERWEB assumes the presence of a central agent acting as an independent system operator (ISO) to assure the reliable operation of the physical power system. The POWERWEB environment is designed to run unit commitment and optimal power flow routines to provide generation schedules that minimize the cost of meeting load subject to the physical constraints of an AC network.

Each participant represents one of six suppliers in an electricity market. Each supplier owns 100MW of capacity, divided into five blocks. The first block is 50 megawatts (MW) and operates at a cost of $20 per MW. Costs for the other four blocks are variable during the experiment, so only the baseline costs are given here. The second block is 20 MW with a marginal cost of $40/MW. The last three blocks are 10 MW each with marginal costs between $48/MW and $52/MW. In each trading period, the generator incurs a fixed interest charge of $1200 (to make earnings roughly equal to profits in excess of competitive levels) and is given a forecast of the system load. The forecasted load in each period was randomly generated using a uniform distribution within a band of 430 MW to 550 MW. Actual load in each period was equal to forecasted load plus a stochastic error within the range +/- 20MW. For most periods, some of the marginal

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[2] Unfortunately, due to an uncontrolled disruption by a participant that greatly contaminated the results, Experiment 4 had to be redone. The results of the repeated experiment are reported here.

[3] The experiments not presented here are uniform price auction and soft-cap auction, with and without price-responsive load. Unlike the experiments discussed in this paper, the omitted experiments did not involve periods with substantially higher generation costs.

[4] The POWERWEB homepage is currently located at www.pserc.cornell.edu/powerweb/.

(expensive) blocks were needed to meet load. With price-responsive load, actual load can be up to 100MW lower.

In each period, the generator submits offers to sell capacity into an auction run by an ISO. A separate offer is made for each block of capacity submitted and the maximum offer allowed (i.e., a hard price cap) is $100/MW. A stand-by cost of $5/MW is incurred for each block offered, regardless of whether an offer is accepted. This stand-by cost is included to represent the opportunity cost of being available for a time period, foregoing sales in other markets or delaying maintenance activities. The generator can choose to withhold the block and avoid the stand-by cost.

The ISO selects the least expensive combination of offers to meet the system load. If not enough capacity is submitted to meet load, the ISO randomly recalls blocks withdrawn from the auction. The generator is charged $10/MW for each recalled block and receives a price equal to the highest offer in the original auction. Once the results have been reviewed by the generators, the process is repeated until the end of the experiment when a predetermined number of periods have been completed.

C. Experimental Design

The four auctions tested were (participants in parenthesis):

1) A uniform price auction using the last accepted offer 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. (students)
2) A soft-cap auction, where the soft-cap is set at $75. Offers less than $75/MW are submitted into a uniform price auction. Offers greater than $75/MW are submitted into a discriminative auction, and they do not set the market price for other capacity. Load is price inelastic. (professionals and students)
3) The same as (2) except that load is price-responsive. (professionals and students)
4) The same as (1) except that load is price-responsive. (students)

The rationale for the order of experiments is that they follow the sequence of events in California. A uniform price auction (Experiment 1) was replaced by a soft-cap auction in December, 2000 (Experiment 2). Efforts to reduce prices by reducing demand were relatively ineffective (Experiment 3). Since May 2001 the market has essentially been regulated. Discussions about a new structure for the market are ongoing. Our experience from earlier experiments shows that a uniform price auction with price responsive load (Experiment 4) reduces average prices effectively. Our expectation for the experiments was that prices would be high in the first three experiments and low in the last experiment.

The generation costs for the four smallest blocks varied during each experiment conducted with the students. The three smallest blocks varied for the industry professionals. The pattern of costs differed across experiments so that participants would pay attention to their costs before submitting offers in any period. The pattern was similar, however. At or near the beginning of each experiment, costs for the relevant blocks were increased by $30/MW. High costs persisted for 10 to 15 periods with students (5 to 10 with professionals), then decreased by $5 each round for five rounds. Then, the baseline (lower) costs were in effect for the remainder of the experiment. Starting the experiments with high costs for marginal units mimics the conditions when the soft-cap auction was introduced in California (the spot prices for natural gas were unusually high in January, 2001).

Experiments 3 and 4 involved price-responsive load introduced through contracts for interruptible load. Contracts were predetermined, did not vary, and details of the contracts were not given to respondents. Contracts existed at $60, $70, $80, and $90 for 10MW, 20MW, 30MW, and 40MW of interruptible load, respectively. As an example, suppose there are not enough offers below $60/MWh to meet the load. The ISO exercises the contract and the effective load is now up to 10MW less, depending on whether the load can be met using the contract. If the contract is fully exercised and offers below $70 are not sufficient to meet the modified load, the second contract will be partially or fully exercised. Additional contracts will be exercised as needed. At most load can be reduced by 100MW, equivalent to the total capacity of one generator.

III. Results

A. Overview

The four experiments were run with professionals earlier in November 2001 with the costs of generation fixed for all periods. However, some of the results were surprising and not consistent with our expectations. The professionals did well exploiting the uniform price auction in Experiments 1, and were able to get a number of price spikes by speculating with marginal (high cost) units. Also, they found it much harder to get price spikes in Experiment 4 when the load was price responsive. In contrast, they were not successful in exploiting the discriminative part of the soft-cap auction and they were satisfied to sell most of their capacity in the uniform price auction below in soft-cap. In experiments that we conducted during the spring of 2001, students were able to get high prices in a soft-cap auction by selling most capacity above the soft-cap. These students had participated in earlier experiments to test both a uniform price and a discriminative auction.

To explain the conflicting experimental results for the soft-cap auction obtained by the professionals and the students, we asked the professionals to repeat Experiments 2 and 3 under a new set of conditions. The challenge to us was to design experiments so that participation in the market provided the needed experience for the professionals to exploit the discriminative part of the soft-cap auction. At the same time, we hoped to duplicate the situation that was faced by suppliers in California when the soft-cap auction was introduced - namely, high prices for natural gas. These high prices were represented as high costs of generation for marginal capacity in the new experiments. Given these high costs, it was rational to submit high offers to sell capacity, and by doing so, get experience selling in the discriminative part of the auction. The professionals found that they could sustain high prices when the generation costs returned to normal levels. Consequently, we demonstrated that the high costs of natural gas in California probably helped suppliers learn how to exploit the soft-cap auction. The primary objectives of running the experiments with students at SUNY Binghamton were: (1) to replicate the results obtained by the professionals in Experiments 2 and 3 using a soft-cap auction; (2) to determine the effect of introducing high generation costs in the uniform price auction, with and without price-responsive load; and (3) to improve the scientific credibility of our results by having others (not the authors) supervise the experiments. In addition, each experiment was run for 50 periods (compared to 25 periods with the professionals).

Table 1 presents results from the experiments. Load-weighted average prices for high and low cost periods are given separately along with the average of the high and low cost prices for each group and each experiment.[5] Here, high cost periods are those with generation costs anywhere above the baseline (lowest cost) levels. The low cost price corresponds to the average for the periods after costs have returned to the baseline levels. Overall, the students were very aggressive about speculating and generally got higher prices than we have seen with other groups in similar experiments, particularly when load was price inelastic. The professionals were more cautious. Figures 1.1 through 1.6 present price plots for Group 1 for all experiments and both subject pools. As a point of reference, the figures show the quasi-competitive price that would occur if all generators submitted cost-based offers. It is clear that actual prices for all groups and all experiments are substantially above these competitive levels, particularly in low cost periods.

For the professionals, the average prices across all groups and costs were \$77.22 and \$73.18 for the soft-cap auction with and without price-responsive load, respectively. For the students, average prices were much higher in the soft-cap auction with inelastic demand (\$90.23), but were similar to the professionals when price-responsive load was introduced (\$74.64). For the uniform price auction with and without price-responsive load, average prices for student subjects were \$90.15 and \$77.94, respectively. As such there were minimal differences between the average prices in the uniform and soft-cap auctions with inelastic and with price-responsive load. Overall, results across groups for any given experiment are similar and consistent within each level of cost.

In all experiments average prices are consistently higher in high cost versus low cost periods, except for Experiment 2 with the students. This latter result is likely the result of the students learning how to exploit a soft-cap auction after a uniform auction in Experiment 1. A few individuals in each group submitted very low offers for 50MW during the first few periods, as they had done in the uniform auction, and then raised the offers for these blocks above the soft cap of \$75/MWh (see Figure 1.4). Since the competitive price is high when the costs of the marginal generating units are high, it is not surprising that the prices obtained in the experiments are also high when costs are high. The primary issue of interest for the analysis that follows is whether the high prices seen during the initial periods with high costs can be sustained when the costs fall. In this respect, the soft-cap auction with price inelastic load (Experiment 2) with the students represents one extreme, with higher prices when costs are low. The uniform price auction with price responsive load (Experiment 4) is the other extreme, with much lower prices when costs are low.

[5] Load-weighted prices are displayed mostly for convenience since the software computes these by default. Simple averages differ negligibly.

Table 1. Results for Uniform and Soft-Cap Auctions, with and without Price-Responsive Load.

Average Prices ($/MWh)		**Experiment 1:** Uniform price auction	**Experiment 2:** Soft-Cap auction	**Experiment 3:** Soft-Cap auction with price-responsive load	**Experiment 4:** Uniform price auction with price-responsive load
Industry Professionals 25 Trading Periods					
Group 1	**High Costs**		**79.89**	**76.28**	
	Low Costs		**77.14**	**71.27**	
	Average		**78.52**	**73.77**	
Group 2	**High Costs**		**78.83**	**79.12**	
	Low Costs		**76.70**	**74.97**	
	Average		**77.77**	**77.05**	
Group 3	**High Costs**		**76.76**	**72.51**	
	Low Costs		**74.01**	**64.93**	
	Average		**75.39**	**68.72**	
All Groups	**High Costs**		**78.50**	**75.97**	
	Low Costs		**75.95**	**70.39**	
	Average		**77.22**	**73.18**	
SUNY-Binghamton Students 50 Trading Periods					
Group 1	**High Costs**	**96.80**	**91.78**	**76.36**	**84.89**
	Low Costs	**87.16**	**96.97**	**71.64**	**73.58**
	Average	**91.98**	**94.38**	**74.00**	**79.23**
Group 2	**High Costs**	**96.15**	**83.68**	**76.41**	**79.66**
	Low Costs	**92.91**	**90.34**	**73.96**	**69.01**
	Average	**94.53**	**87.00**	**75.19**	**74.34**
Group 3	**High Costs**	**89.38**	**85.90**	**76.42**	**87.60**
	Low Costs	**78.54**	**92.70**	**73.04**	**73.11**
	Average	**83.96**	**89.30**	**74.73**	**80.36**
All Groups	**High Costs**	**94.11**	**87.12**	**76.40**	**83.99**
	Low Costs	**86.20**	**93.34**	**72.88**	**71.90**
	Average	**90.15**	**90.23**	**74.64**	**77.94**

Figure 1.1: Soft-Cap Auction; Industry Professionals (Experiment 2)

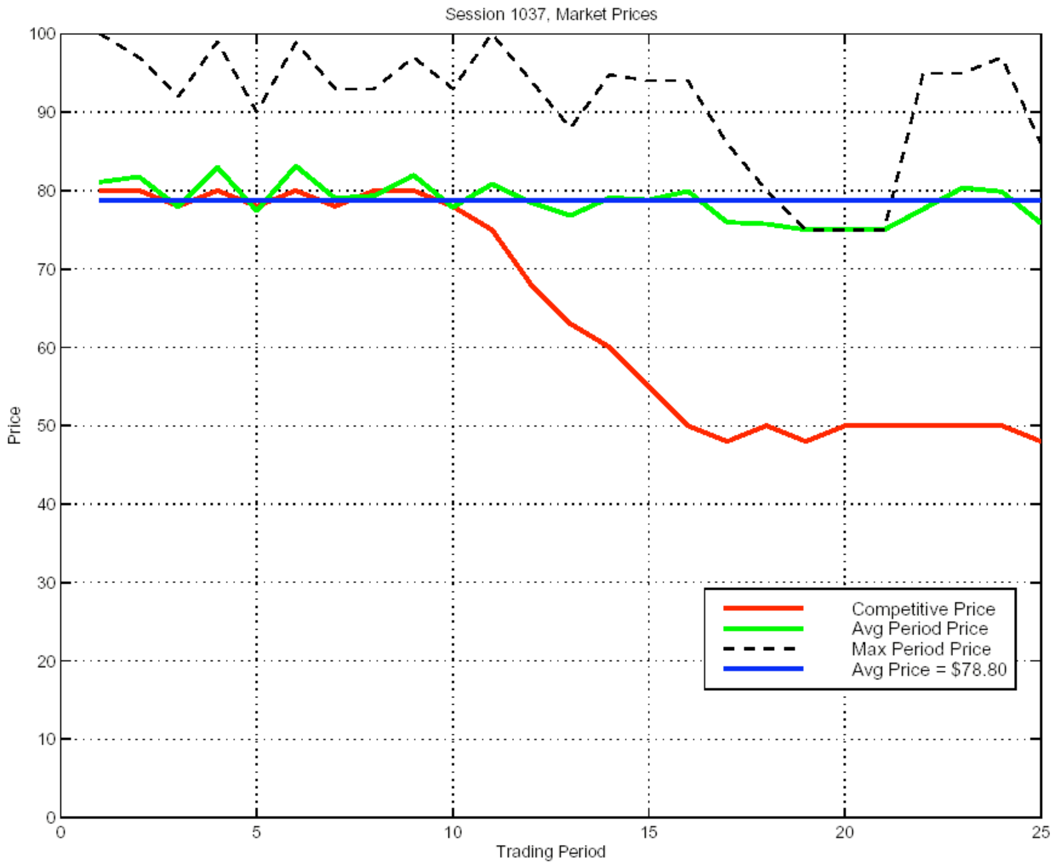


Figure 1.2: Soft-Cap Auction with Price-Responsive Load; Industry Professionals (Exp. 3)

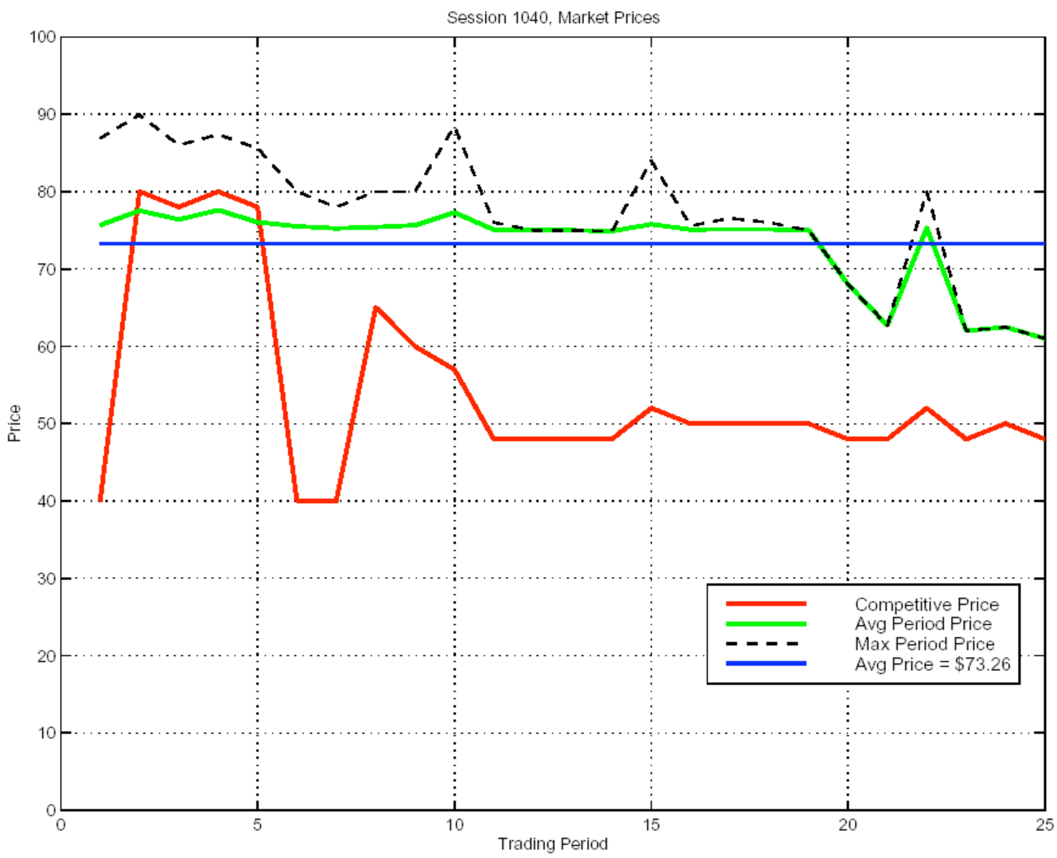


Figure 1.3: Uniform Price Auction; Students (Experiment 1)

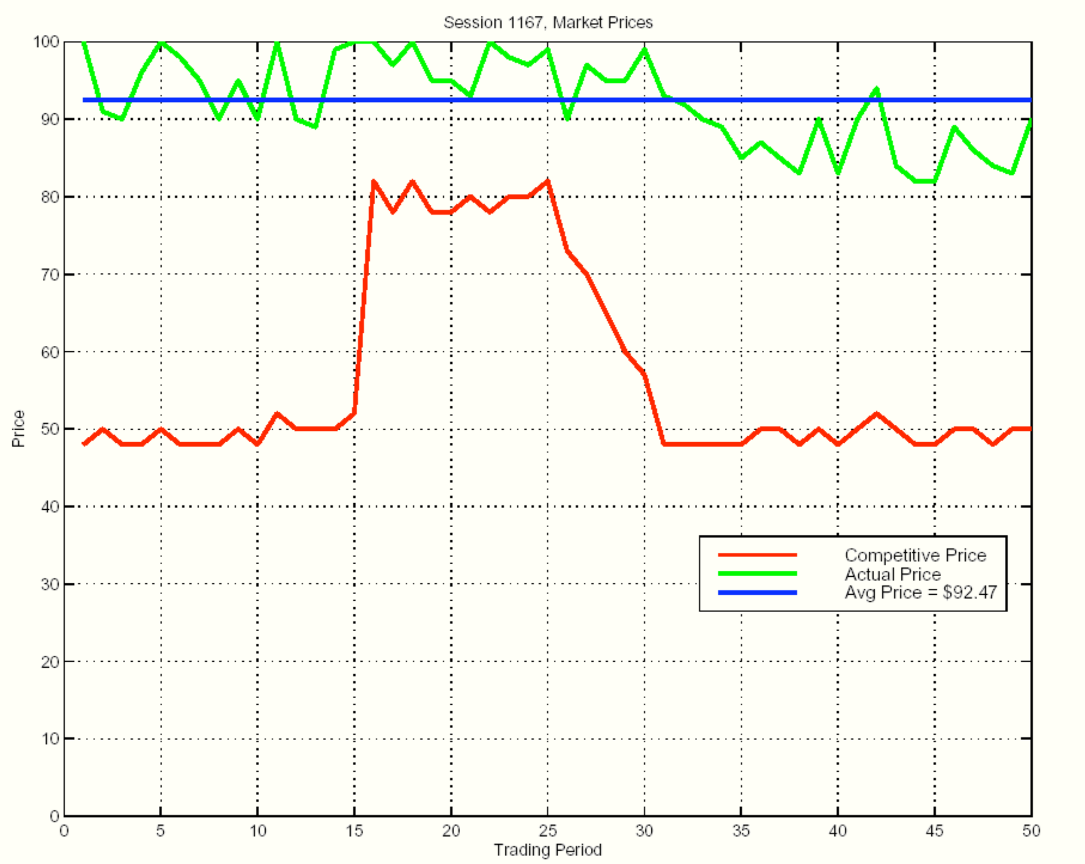


Figure 1.4: Soft-Cap Auction; Students (Experiment 2)

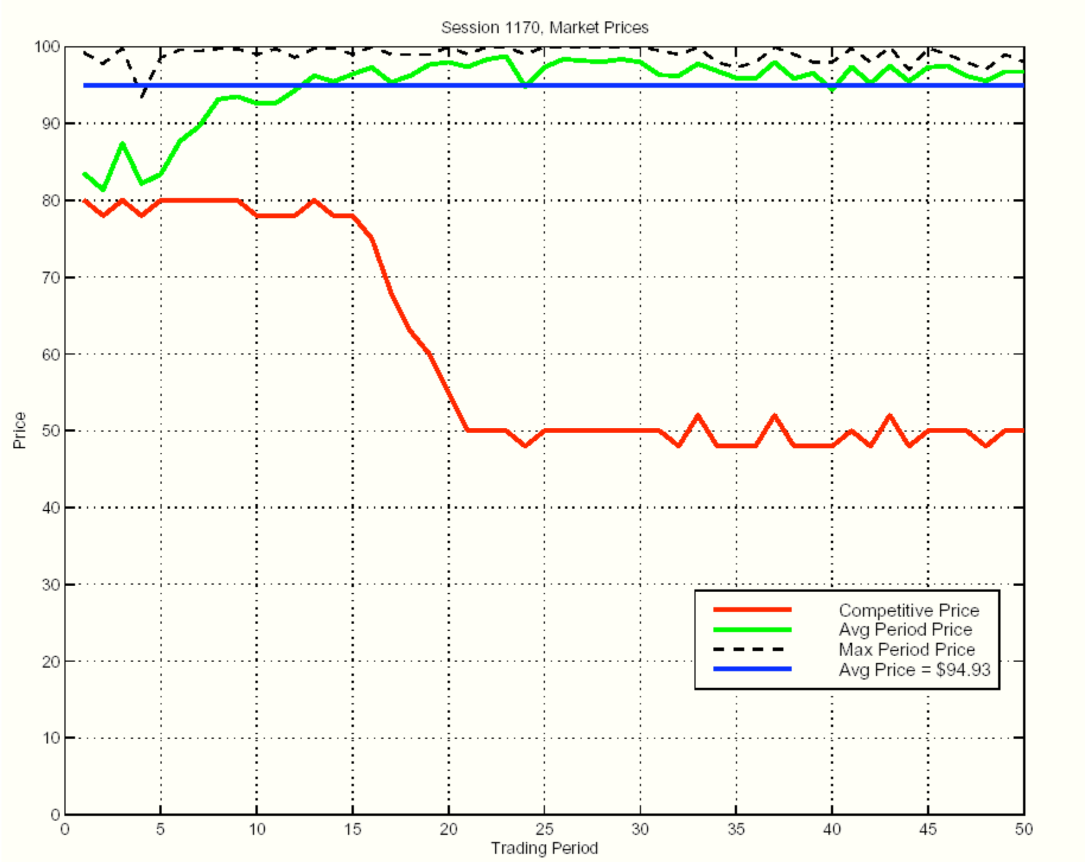


Figure 1.5: Soft-Cap Auction with Price-Responsive Load; Students (Experiment 3)

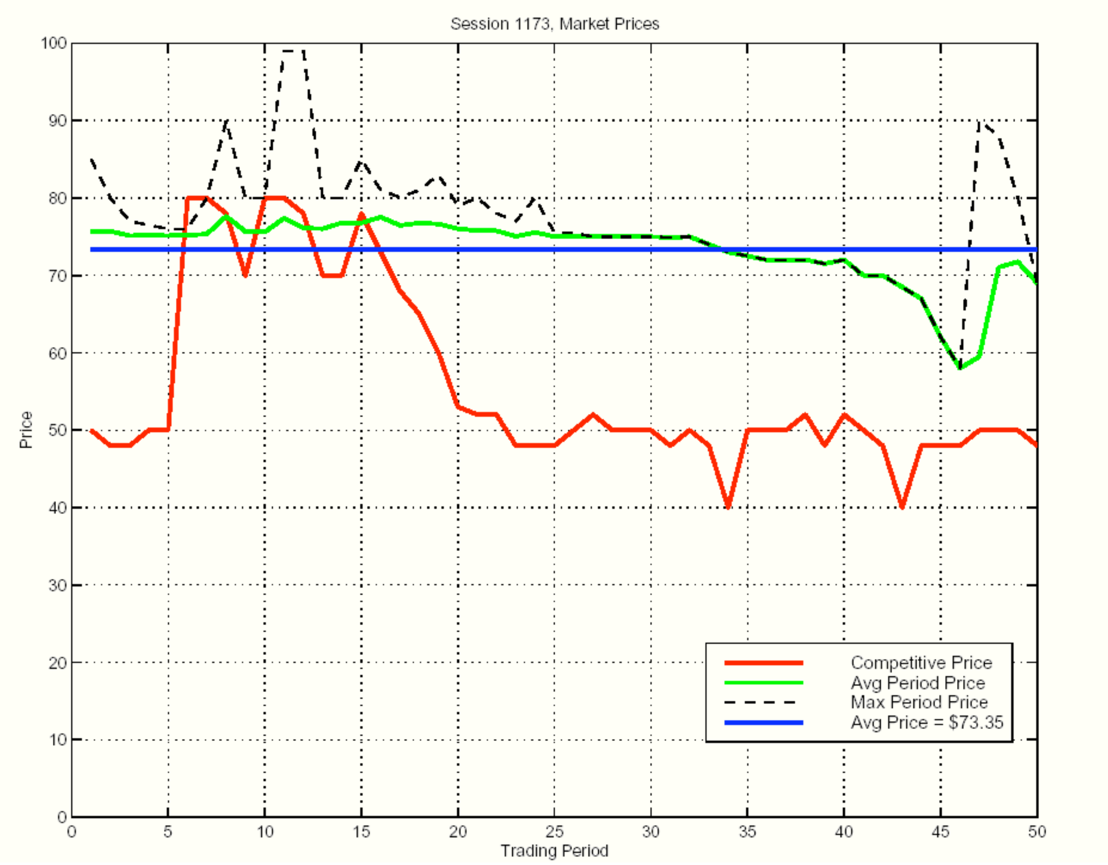
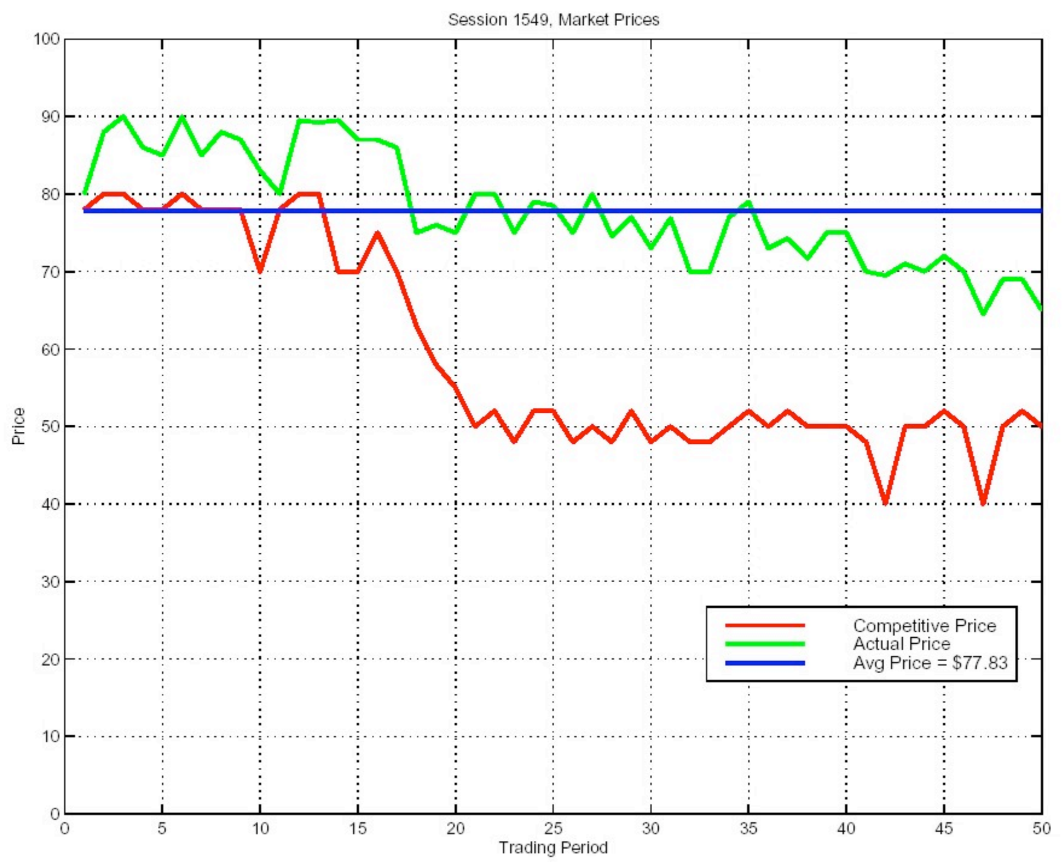


Figure 1.6: Uniform Price Auction with Price-Responsive Load; Students (Experiment 4)



B. Analytical Results

The data in Table 1 were used to estimate a regression model that identified the six different experiments in the high cost and low cost periods. The three groups for each experiment were treated as replications. The results are summarized in Table 2 and the fit is relatively good (R^2 = 87%). The intercept measures the overall average price in the high cost periods for all experiments ($82.69/MWh). The first column of coefficients measures the differences in the average prices for high cost periods among experiments, and the second column of coefficients measures the changes in the average price from the high cost to the low cost periods by experiment. For example, the average price for Experiment 1 is 82.69 + 11.42 = $94.11/MWh in the high cost periods and 82.69 + 11.42 – 7.91 = $ 86.20/MWh in the low cost periods.

Table 2. Regression Results

Intercept[1]	**82.69**	**(94.8)***		
Experiment[2]	**Difference from the average price in high cost periods[3]**		**Changes in price from high cost to low cost periods[3]**	
1 – S	**+ 11.42**	**(5.9)***	**- 7.91**	**(2.6)***
2 – S	**+ 4.43**	**(2.3)***	**+ 6.22**	**(2.1)**
2 – P	**- 4.19**	**(2.2)***	**- 2.54**	**(0.8)**
3 – S	**- 6.29**	**(3.3)***	**- 3.52**	**(1.2)**
3 – P	**- 6.72**	**(3.5)***	**- 5.58**	**(1.8)**
4 – S	**+ 1.36**	**(0.7)**	**- 12.15**	**(4.0)***

[1] *Average price ($/MWh) in high cost periods with* $|t\ ratio|$ *in parentheses.*

[2] *1 Uniform price auction with inelastic load*
2 Soft-cap auction with inelastic load
3 Soft-cap auction with price responsive load
4 Uniform price auction with price responsive load
S Students
P Professionals

[3] *Estimated price change ($/MWh) with* $|t\ ratio|$ *in parentheses.*

* *Denotes statistical significance at the 5% level.*

The differences of prices among experiments in the high cost periods were larger than expected. Both of the experiments with professionals had significantly lower prices in the high cost periods, but only one experiment for the students (Experiment 3) had lower prices. Experiment 1 with students had by far the highest price. One major surprise was that the initial prices in Experiment 3 with the students were much lower than the final prices in Experiment 2 ($6/MWh below average compared to $4/MWh above average). Figure 1.4 shows prices staying well above the soft-cap price until the end of Experiment 2, but the prices at the beginning of Experiment 3 in Figure 1.5 were immediately close to the soft-cap. The behavior in all three groups was roughly the same, and the students anticipated the effects of introducing price responsive load in Experiment 3 by reducing offers substantially from Experiment 2.

All of the changes of price from the high cost to low cost periods were negative except for Experiment 2 with students (due to the effects of learning mentioned above). Only Experiments 1 and 4 had statistically significant differences, and the reduction in Experiment 4 with price-responsive load was by far the largest. For the students, the smallest reduction occurred in Experiment 3 using a soft-cap auction even though the load was price responsive. The comparison between Figures 1.5 and 1.6 provide the best illustration of the differences in the soft-cap and the uniform price auction. Prices do eventually drop in Experiment 3 (soft-cap auction with price responsive load) but only after periods in which load was unusually low (periods 34 and 43). Prices in Experiment 4 begin to decline as soon as competitive prices fall and continue doing so for the remainder of the experiment. From Figure 1.6, it appears we needed additional periods to establish whether prices would further decline and whether some sort of equilibrium would be reached in the soft-cap auction with price response.

IV. Conclusions

Student subjects had great success exploiting the weaknesses of both uniform price and soft-cap auctions when demand was stochastic, but inelastic. This is not solely due to the introduction of high generation costs. Higher costs were not introduced until period 16 of the uniform price experiment

(Experiment 1) and prices were high from the start in all three groups. The soft-cap auction began with high generation costs. In lieu of the upward price trend observed in all experiments we can't rule out that the persistence of high prices was due to the high costs. However, from looking at individual offer data we posit that there was a transition period between uniform price and soft-cap auctions as some habitual or very conservative participants submitted very low offers for their 50MW block at the beginning of the experiment. Also, during an unpaid practice experiment conducted before these experiments, students consistently got average prices above $90/MWh in a discriminative auction. On the other hand, the introduction of high costs was necessary to induce industry professionals to make offers above the soft-cap. In general, students outperformed their professional counterparts.

In all experiments with the exception of the uniform auctions, prices between high and low cost periods were very similar. The verdict is still out on what really caused the prices in California to dramatically increase in January 2001 when a soft-cap auction was implemented – perhaps increases in natural gas prices, perhaps market power. What is evident in these markets is that when – for whatever reason – the prices go above the soft-cap they tend to stay there. No matter whether other factors change, generators realize that high prices are possible and are persistent about maintaining these prices. Looking at individual offer data, it is apparent that the prices from previous periods shape offers for the current period in a discriminative auction.

After observing the persistent high prices in the soft-cap auction where the vast majority of offers were above the soft-cap, it was surprising that the introduction of price-responsive demand in Experiment 3 decreased prices with the students. As in previous experiments, the offers tended to be relatively flat. As an example, in period 50 for the experiment with inelastic load the difference between the lowest and highest submitted offer was less than $10 for all three groups. From the very beginning of the price-responsive demand experiment offers were systematically lower, although offers were still generally flat. If subjects had simply submitted the same offers as before, the prices would not have changed. We hope to conduct more experiments of this type to determine whether this result is general and the reasons for it. Perhaps if price-responsive load is introduced in the middle of an experiment we would see different results.

Our strongest result is for the uniform price auction with price-responsive load (Experiment 4) where prices reached the lowest levels compared with the analogous soft-cap experiment. Prices were on a definite downward trend from the moment generation costs were lowered and continued declining throughout the remainder of the experiment. We believe this type of market can lead to more competitive prices. Such a result is due to the hockey stick shape of the aggregate offer curves which persist during experiments with and without price-responsive load. When the ISO has the ability to avoid using the few really high offers, price spikes are smaller and occur less frequently (or not at all). As such, introducing price-responsive demand in existing markets that currently use a uniform price auction, may serve to substantially reduce average electricity prices substantially.

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