The California Electricity Crisis: An Experimental Investigation of the Effects of Changing the Market Rules

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ABSTRACT

Motivated by the extremely high prices for wholesale electricity in California from May, 2000 to June, 2001, this paper presents the results from four economics experiments using both industry professionals and students who compete to sell electricity in a simulated market. The market structure in the first three experiments parallels the design of the California market over time: a uniform price last accepted offer auction, a soft-cap auction, and a soft-cap auction with price-responsive demand. The fourth experiment is a uniform price auction with price-responsive demand. Our design includes salient features of the California market: generation costs that vary to simulate high prices of natural gas, a high ratio of demand to available capacity, and a hard price cap. Participants were able to manipulate the uniform price auction and attain prices near the price cap. These high prices were sustained in the next two experiments using a soft-cap auction, even though load was price responsive. Prices were noticeably lower in the uniform price auction with price-responsive demand. Since this paper analyzes the effects of changing the market rules in California, our objectives are quite different from the numerous studies which have evaluated the importance of market power as the cause of the "California crisis."

1. 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 by the California Independent System Operation (CAISO) from \$750 MWh to \$250 MWh during the summer and the Federal Energy Regulatory Commission (FERC) declared that the spot market was dysfunctional, and introduced a new type of "soft-cap" auction in December, 2000, to replace the uniform price auction. The soft-cap auction combines a standard uniform price auction for offers below the soft cap with a discriminative auction for offers higher than the 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. Figure 1 shows the spot prices in Southern California and the hard and soft price caps that were enforced. As a result, FERC abandoned the soft-cap auction in June 2001 and imposed a hard cap of $92/MWh across the entire Western Electric Coordinating Council (WECC).

This paper presents results from four tests of markets 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 why price-responsive load is more effective in a uniform price auction. 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.

2. PREVIOUS FINDINGS FROM TESTING MARKET STRUCTURES

Existing deregulated electricity markets are comprised of several firms who can sell multiple units (blocks of capacity) and face an inelastic but stochastic demand. Equilibrium strategies in such complex settings are not well understood (Klemperer and Meyer, 1989) and the more recent advances in multi-unit auction theory, applicable to electricity markets or otherwise, are due to findings in a controlled laboratory setting (see Bernard, Schulze, and Mount, 2002).

The results of earlier tests of markets conducted with POWERWEB show that a uniform price auction, a pure discriminative auction, and a soft-cap auction can all 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. The daily spot prices and maximum load for PJM are shown in Figure 2 as an illustration. In a uniform price auction, generators 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 hockey stick, where the bulk of capacity is offered at prices near cost. An example of a typical offer curve in PJM is shown in Figure 3. 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.

Introducing price-responsiveness in load in a uniform price auction through contracts for interruptible load, Mount et al. find that prices are reduced by 13%. Price-responsive load was not tested in a discriminative or soft-cap auction. With a different experimental design, Rassenti, Smith, and Wilson (forthcoming) find that discriminative price auctions produce much higher prices than uniform price auctions in treatments with price-responsive load. They confirm our earlier results POWERWEB and with show that 1) price volatility is reduced in a discriminative auction, and 2) prices are considerably above competitive levels with both types of auction.

In a set of related experiments, Rassenti, Smith, and Wilson (2001) find that the introduction of demand-side bidding – where human participants submit bids to buy power, and thus make the market less dominated by sellers – effectively brings prices down to competitive levels. Chao and Plott (2000), Denton, Rassenti, and Smith (2001) and Nicolaisen, Petrov, and Tesfatsion (2001) describe and test two-sided auctions for electricity that produce competitive outcomes. Hence, there is a growing body of literature showing that wholesale markets for electricity would be more competitive using a uniform price auction if demand responded to price. In contrast, there is relatively little information about the relative performance of using a soft-cap auction instead of a uniform price auction in a wholesale market for electricity.

3. EXPERIMENTAL FRAMEWORK AND METHODOLOGY

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.[1] Participants were recruited via email and worked as traders, consultants, analysts, or regulators. Experiments were conducted remotely from the participant's own computer

[1] The experiments not presented here are a uniform price auction and a 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.

through the Netscape browser. Participants were separated into 3 groups of 6 competing firms. Each experiment consisted of 25 trading periods.

During the months of February and March, 2002, we conducted a series of four experiments in a designated computer laboratory using a class of 18 undergraduate business and economics students at SUNY-Binghamton. As with the professionals, experimental markets consisted of 3 groups of 6 individuals, but the members of each group varied from one experiment to the next, and each experiment consisted of 50 trading periods. In all of the experiments, 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 in the training sessions were exactly as they were in actual experiments. Participants were required to reach a minimum earnings goal in a training session and they had to repeat the exercise until this goal was met. The purpose of the training sessions 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 preliminary experiments with other individuals, particularly for discriminative auctions, is the most effective way to train participants.

Experimental Platform

The experiments were conducted using POWERWEB, an interactive, distributed, Internet-based simulation environment for testing various auction markets using human decision makers.[2] 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. However, for the experiments discussed in this paper, network constraints are not binding.

Each participant represents one of six firms in an electricity market.[3] Each firm owns five generating units and has 100MW of total capacity. The baseload generator is 50 MW and operates at a cost of $20 per MWh (2¢ per KWh). Costs for the other four generators are variable during the experiment, so only the baseline (minimum) costs are given here. The second generator is 20 MW with a marginal cost of $40/MWh. The last three generators are 10 MW each with marginal costs between $48/MWh and $52/MWh. 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. On average, demand is 82% of available capacity. Actual load in each period was equal to forecasted load plus a small stochastic error within the range +/- 20MW (about +/- 4%). For most periods, some of the marginal (expensive) generators were needed to meet load. With price-responsive

[2] The POWERWEB homepage is currently located at www.pserc.cornell.edu/powerweb/.
[3] The generators in California were owned by two utilities (Pacific Gas & Electric and Southern California Edison), five roughly equal-sized firms (AES-Williams, Duke, Dynegy, Reliant, and Thermo Ecotek), and a variety of small independent firms.

load, actual load can be up to 100MW lower, which corresponds in size to one additional generator.

In each dispatch period, the firm submits offers to sell capacity into an auction run by an ISO. A separate offer is made for the capacity of each generating unit submitted, and the maximum offer allowed (i.e., a hard price cap) is $100/MWh.[4] A stand-by cost of $5/MWh is incurred for all offered capacity, 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 firm can choose to withhold a generator to avoid the stand-by cost and this makes the participants consider the issue of withholding capacity.

The ISO selects the least expensive combination of offers to meet the system load. If insufficient capacity is submitted to meet load, the ISO randomly recalls generating units withheld from the auction. The firm is charged $10/MWh for each recalled generator and receives a price equal to the highest offer in the original auction. Once the results have been reviewed by the firms, the process is repeated until the end of the experiment when a predetermined number of periods have been completed.

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).

[4] Our price cap is relatively low in order to reduce the variability in participant earnings, and to keep the maximum possible payment to participants reasonably low.

2) A soft-cap auction, where the soft-cap is set at \$75. Offers less than \$75/MWh are submitted into a uniform price auction. Offers greater than \$75/MWh 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) with price-responsive load (professionals and students).
4) The same as (1) with price-responsive load (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 June 2001 FERC has imposed a hard price cap on the market is and the state purchases much of its power through long-term contracts negotiated by the California Department of Water Resources[5]. Discussions about a new structure for the market are ongoing. Our experience from earlier experiments suggests that a uniform price auction with price-responsive load (Experiment 4) can reduce average prices effectively, due to the hockey stick shape of the offer curve in multi-unit uniform price auctions. Our expectation for the experiments was that prices would be high in the first three experiments and low in the last experiment.

The costs for the four smallest generators (50% of capacity) varied during each experiment conducted with the students to reflect fluctuating natural gas prices. The costs of the three smallest blocks varied for the industry professionals. Approximately 50% of electric power generation comes from natural gas in California. Prices of natural gas on the spot market at Henry Hub began rising in May, 2000 and peaked in December, 2000. In addition, there was a

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[5] The legitimacy of these long-term contracts, signed during the winter of 2001 when prices were high, is currently being challenged in a series of hearings before FERC.

dramatic increase in the reported prices of natural gas delivered in California in December 2000 and January 2001. This was exactly when the soft-cap auction was implemented. In January, 2001, the spot price for natural gas in California may have been over ten times greater than it was at the same time in the previous winter.[6]

Instead of mimicking the exact pattern of California natural gas prices, our firms experienced a pattern of both high and low generation costs for the more expensive generators in each experiment. We implemented this to observe whether electricity prices declined with generation costs for each type of auction. The pattern of costs differed across experiments so that participants would have to 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 generating blocks were increased by $30/MWh. High costs persisted for 10 to 15 periods with students (5 to 10 with professionals), and then decreased by $5/MWh each dispatch period for five periods. After this, the baseline (lower) costs stayed in effect for the remainder of the experiment.

Experiments 3 and 4 involved price-responsive load introduced through contracts for interruptible load, and this type of contract was actually used in California when the soft-cap auction was used. Contracts were predetermined, did not vary, and details of the contracts were not given to the participants. 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,

[6] A staff report from FERC (2002) shows how these delivery prices may have been manipulated. The report recommended that the reported prices of natural gas should not be used for paying refunds in California.

the second contract will be partially or fully exercised (up to an additional 20MW). Additional contracts will be exercised as needed. At most load can be reduced by 100MW, equivalent to the total capacity of one firm.

4. RESULTS

Overview

Four different types of auction, described in the previous section, were tested by the professionals in November, 2001 with the costs of generation fixed for all periods. However, some of the results were surprising and not consistent with the results of earlier tests conducted during the spring of 2001 using students. The professionals did well exploiting the uniform price auction in Experiment 1, and were able to get a number of price spikes by speculating with marginal (high cost) generating units. Also, they found it much harder to get price spikes in a uniform price auction when the load was price responsive (Experiment 4). 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 the soft-cap (Experiments 2 and 3). In experiments conducted during the spring of 2001 (Mount et al. 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.

In order to understand 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 firms 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 above the soft-cap to sell marginal 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 may have helped firms 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 with students and professionals. 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.[7] 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

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

prices than we have seen with other groups in similar experiments, particularly when load was price inelastic. The professionals were more cautious. Figure 4 presents the average time series for the soft-cap auction experiments (Experiments 2 and 3) conducted with professionals. The soft-cap (Experiments 2 and 3) and uniform price auction (Experiments 1 and 4) results for students are presented in Figure 5 and Figure 6, respectively. As a point of reference, the figures show the minimum true marginal cost of producing the last MWh needed to meet demand, which can be thought of as the competitive price.[8] Actual prices for all groups and all experiments are in general substantially above these competitive levels, particularly in low cost periods.

For the professionals, the average prices across all groups in both high and low cost periods were \$77/MWh and \$73/MWh for the soft-cap auction with and without price-responsive load, respectively (Experiments 2 and 3). For the students, average prices were much higher in the soft-cap auction with inelastic demand (\$90/MWh), but were similar to the professionals when price-responsive load was introduced (\$75/MWh). For the uniform price auction with and without price-responsive load (Experiments 1 and 4), average prices for student subjects were \$90/MWh and \$78/MWh, respectively. Although there were minimal differences between the overall average prices in the uniform and soft-cap auctions, with either inelastic or price-responsive load, there were interesting differences in the prices in periods with high costs and low costs.

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 probably caused by the students learning how to exploit the soft-cap auction more effectively by adjusting their offer strategies from the ones they used in a uniform price auction in Experiment 1. A few individuals

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[8] For the uniform price auction experiments and the soft-cap experiments with costs below the soft-cap, this would have been the prevailing market price if everyone submitted offers equal to costs. In the soft-cap auction, if some accepted offers are above the soft-cap, the average market price would be lower than the "competitive" price.

in each group submitted very low offers for their baseload generator during the first few periods, as they had done in Experiment 1, but eventually they raised the offers for these blocks above the soft cap of $75/MWh (see Figure 5). 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 in this situation. 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.

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.

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 than average in the high cost periods, but only one experiment for the students the soft-cap auction with price responsive load (Experiment 3) had lower prices. The uniform price auction with inelastic load (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 the soft-cap auction with inelastic load (Experiment 2) ($6/MWh below average compared to $11/MWh above average). Figure 5 reveals that high prices increased throughout Experiment 2 from $80/MWh to over $90/MWh. Although prices started near $80/MWh in Experiment 3, prices fell gradually to about $70/MWh. The transition between the uniform price and soft-cap auctions, explains the price increase in Experiment 2. Students needed several periods to revise their offer strategy given the new type of auction. The argument does not hold for the transition from Experiment 2 to Experiment 3 (both soft-cap auctions). One possible explanation is that Experiment 3 started with low generation costs and, perhaps unfortunately, the (randomly generated) demand levels during the highest cost periods were 30MW below average.[9]

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 negative coefficients, and the reduction in the uniform price auction with price-responsive load (Experiment 4) 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 5 and 6 provide the best illustration of the differences in the soft-cap and the uniform price auction. Prices do eventually drop during the soft-cap auction experiment with price-responsive load (Experiment 3), but only

[9] This refers to the base load, before any interruptible contracts are exercised.

after periods in which load was unusually low (periods 34 and 43). In the uniform-price auction with price-responsive load (Experiment 4), prices begin to decline as soon as the costs for marginal generation units fall, and they continue doing so for the remainder of the experiment. It appears we needed additional periods to establish whether prices would further decline and reach some sort of equilibrium. In the introduction, we hypothesized that introducing price-responsive load in a uniform price auction would reduce prices and mitigate price spikes, due to the commonly observed hockey stick shape of the offer curve in uniform price markets. Prices did not drop to competitive levels because participants avoided getting low prices by withholding more capacity and speculating more with marginal generators. Compared to the professionals, some of the students were very aggressive speculators who were willing to lose a large part of their market share (and earnings). These students were clearly frustrated by how difficult it was to sustain high prices in Experiment 4 compared to the other three experiments.

5. CONCLUSIONS

Student subjects had great success exploiting the weaknesses of both the uniform price and the soft-cap auctions when demand was stochastic, but inelastic. This was 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 the market prices were high from the very beginning in all three groups. The soft-cap auction began with high generation costs. In lieu of the upward price trend observed for all three groups of students, we can't rule out the possibility that the high prices were due to the high costs. However, after looking at individual offer data we posit that there was a transition period between the uniform price and soft-cap auctions. Some conservative participants submitted very low offers for their baseload generator at the beginning of the experiment and then gradually raised these offers during the experiment. The basic question facing an individual in this type of auction is that if some capacity can be sold above the soft-cap, why not sell all capacity above the soft-cap. Additional evidence was provided in practice tests of a discriminative auction when students consistently got average prices above \$90/MWh even though costs were low all the time. In contrast to the students, it was necessary to have periods with high costs to induce the industry professionals to make offers above the soft-cap. In general, the students outperformed their professional counterparts in their ability to exploit the soft-cap auction.

In all experiments with soft-cap auctions, prices between high and low cost periods were very similar. The verdict is still out on the causes of the extremely high prices for electricity in California and other states in the WECC during the winter of 2001 – perhaps high prices for natural gas, perhaps exploiting market power. What is evident in a soft-cap auction is that when – for whatever reason – the prices go above the soft-cap they tend to stay there. No matter how factors change, participants realize that high prices are possible and they are able to sustain these high prices. Looking at individual offer data in our experiments, it is apparent that the prices paid in previous periods shape offers for the current period in a discriminative auction.

As in previous experiments, the offer curves in the soft-cap auctions tended to be relatively flat. As an example, in period 50 in Experiment 2 with inelastic load, the difference between the lowest and highest submitted offer was less than \$10 for all three groups of students. The corresponding difference could be \$80 in a uniform price auction (the price cap of \$100/MWh minus the lowest cost of generation). The flat offer curves make the market price relatively insensitive to reductions of load compared to the hockey stick shape in a uniform price auction. This may explain why load reductions were relatively ineffective in California when the soft-cap auction was in effect. Prices remained at high levels from January to May, 2001 in spite of major efforts to conserve power.

After the students' success of getting persistent high prices in the soft-cap auction with inelastic load in Experiment 2, where the vast majority of their offers were made above the soft-cap, it was surprising that the introduction of price-responsive demand in Experiment 3 decreased prices immediately. If individuals had simply submitted the same offers as they did at the end of Experiment 2, the prices would have been above $90/MWh instead of below $80/MWh. Students were not able to increase the price during Experiment 3 in the same way that they had done in Experiment 2. We hope to conduct more experiments using a soft-cap auction to determine the reasons for this result. For example, it is possible that introducing price-responsive load in the middle of an experiment would lead to a better understanding of how the offer strategies of individuals change when load respond to price.

Our most important result is for a uniform price auction with price-responsive load (Experiment 4) because the price decrease from the high cost to the low cost periods was the largest compared to the analogous soft-cap auction (Experiment 3). Prices were on a definite downward trend from the moment generation costs were lowered in Experiment 4, with some infrequent upward jumps, and prices continued to decline throughout the remainder of the experiment. We believe this type of market with price-responsive load can lead to more competitive prices. This conclusion follows from the typical hockey stick shape of the aggregate offer curve in a uniform price auction, and this shape of supply curve exists with and without price-responsive load. When there are only a few speculative offers, a small load response can have a big effect and price spikes will be smaller and occur less frequently. As such, introducing price-responsive load into existing markets that use a uniform price auction (e.g., by implementing conservation programs during periods of high demand) is an effective way to reduce average electricity prices. When high prices are paid in a discriminative auction (or prices above the soft-cap), it is likely that there will be much more speculation than there would be in a uniform price auction, making supply curves flatter and making price-responsive load less effective for price mitigation. The evidence from other experimental studies supports our main conclusion that the development of a two-sided, uniform price auction is the best way to reach the goal of competitive wholesale markets for electricity. The soft-cap auction in California was a failure as a way to mitigate high prices.

REFERENCES

Bernard, J.C., W. Schulze, and T. Mount (2002). "Comparing Multi-Unit Vickrey and Uniform Price Auctions in a Repeated Procurement Setting." Working Paper, Department of Applied Economics and Management, Cornell University, Ithaca, New York.

Chao, H-p. and C.R. Plott (2000). "A Competitive Mechanism for the Distribution of Electric Power through a Network and the Determination of Network Capabilities." Working Paper, Department of Management Science and Engineering, Stanford University, Stanford, California.

Denton, M.J., S.J. Rassenti, and V.L. Smith (2001). "Spot Market Mechanism Design and Competitivity Issues in Electric Power." Journal of Economic Behavior and Organization 44(4): 435-453.

Federal Energy Regulatory Commission Staff (2002). "Initial Report on Company-Specific Separate Proceedings and Generic Reevaluations: Published Natural Gas Price Data' and Enron Trading Strategies," Fact-Finding Investigation of Potential Manipulation of Electric and Natural Gas Prices, Docket No. PA02-2-000.

Mount, T.D., W.D. Schulze, R.J. Thomas, and R.D. Zimmerman (2001). "Testing the Performance of Uniform Price and Discriminative Auctions." Working paper, Department of Applied Economics and Management, Cornell University.

Nicholaison, J., V. Petrov, and L. Tesfatsion (2001). "Market Power and Efficiency in a Computational Electricity Auction with Discriminatory Double Auction Pricing. Working Paper, Department of Economics, Iowa State University, Ames, Iowa.

Rassenti, S.J., V.L. Smith, and B.J. Wilson (2001). "Controlling Market Power and Price Spikes in Electricity Networks: Demand-Side Bidding." Working Paper, Interdisciplinary Center for Economic Science, George Mason University, Fairfax, Virginia.

Rassenti, S.J., V.L. Smith, and B.J. Wilson. (2003) "Discriminatory Price Auctions in Electricity Markets: Low Volatility at the Expense of High Price Levels." Journal of Regulatory Economics, forthcoming.

Table 1: Average Prices for Uniform and Soft-Cap Auctions, with and without Price-Responsive Load, in Periods with High and Low Costs

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**

Table 2: Estimated Price Changes for Uniform and Soft-Cap Auctions, with and without Price-Responsive Load, in Periods with High and Low Costs

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 for a single t test.*

Figure 1: Spot Prices of Electricity in Southern California and Price Caps

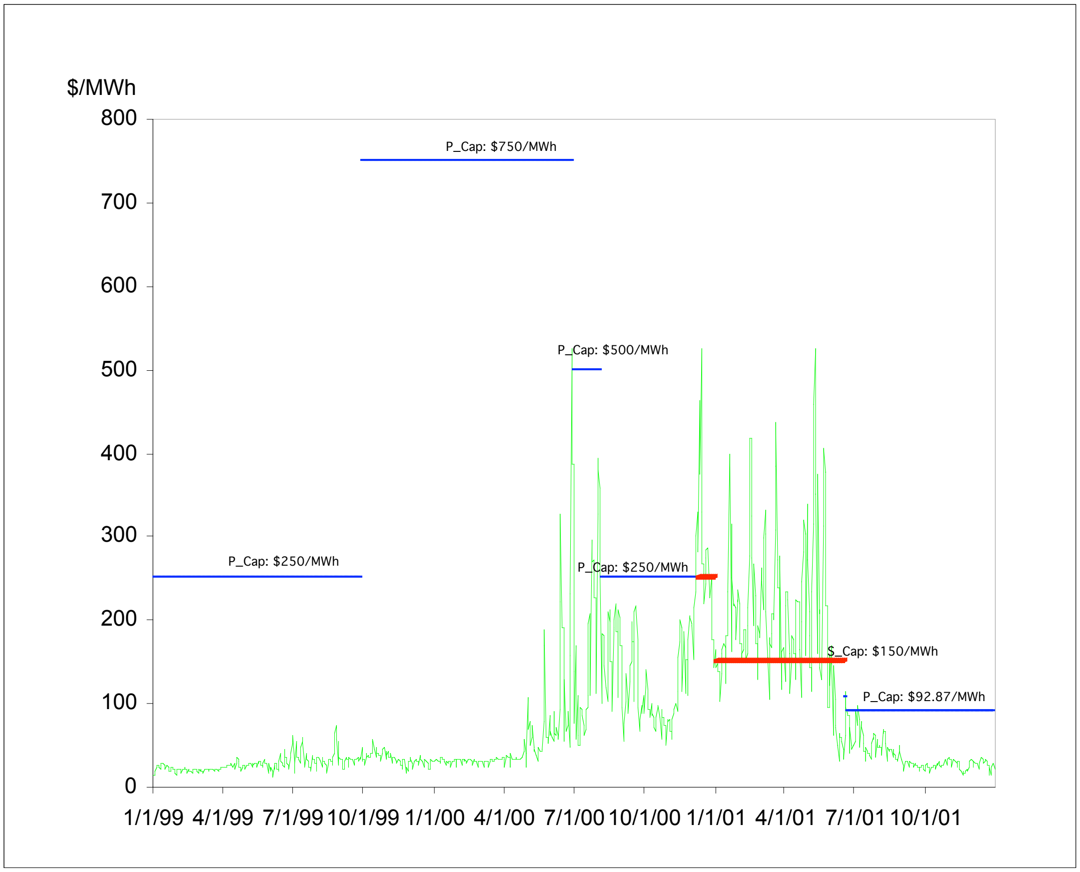


Figure 2: Daily Maximum Load and On-Peak Price in PJM

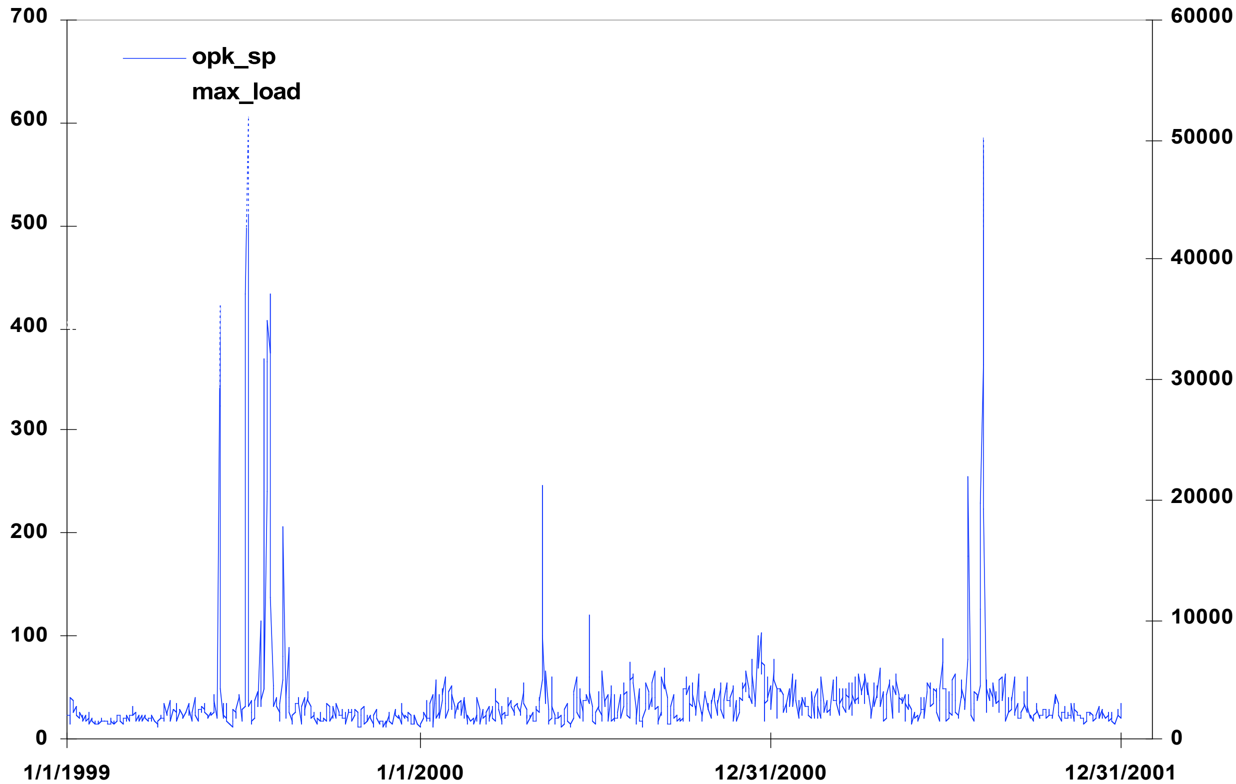


Figure 3: A Typical Aggregate Offer (Supply) Curve in PJM (all offers submitted on July 27, 1999 at 5pm)

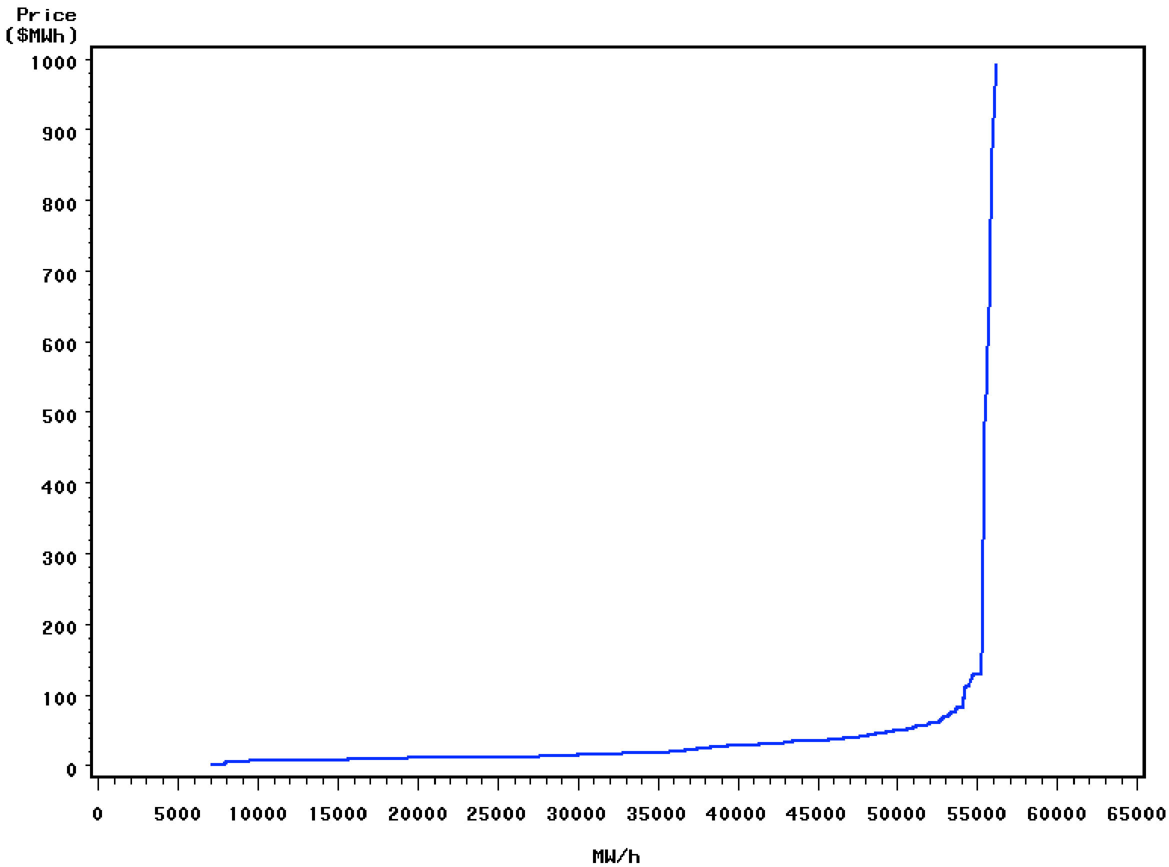
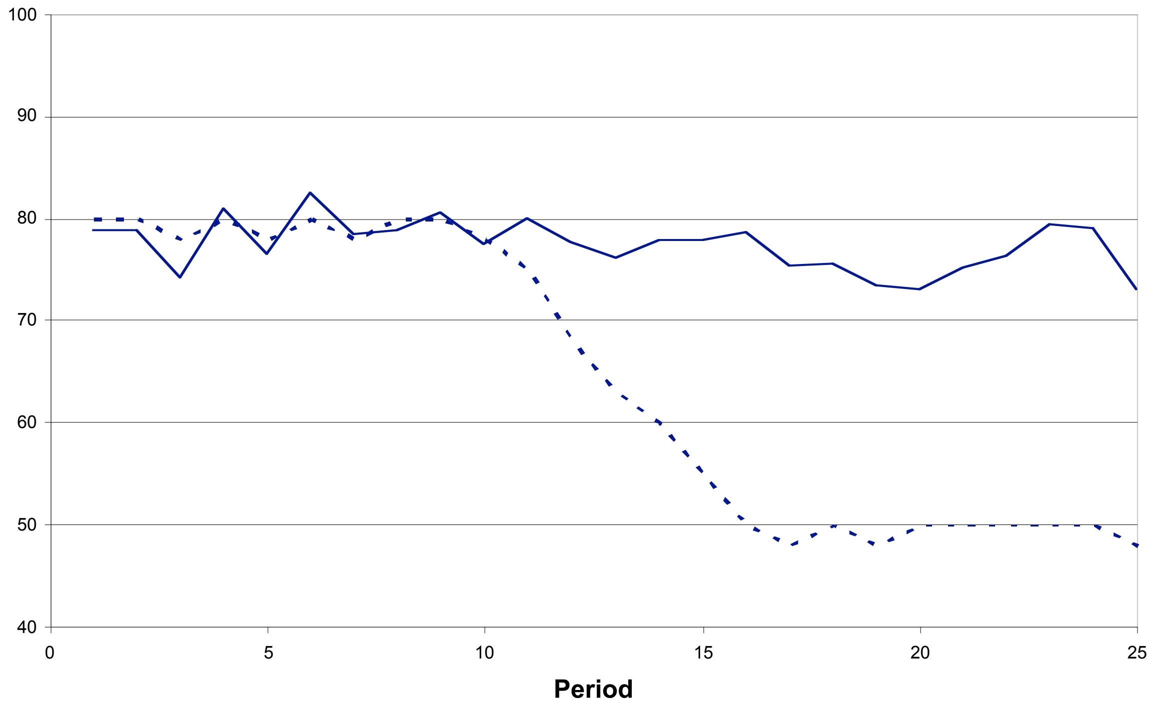
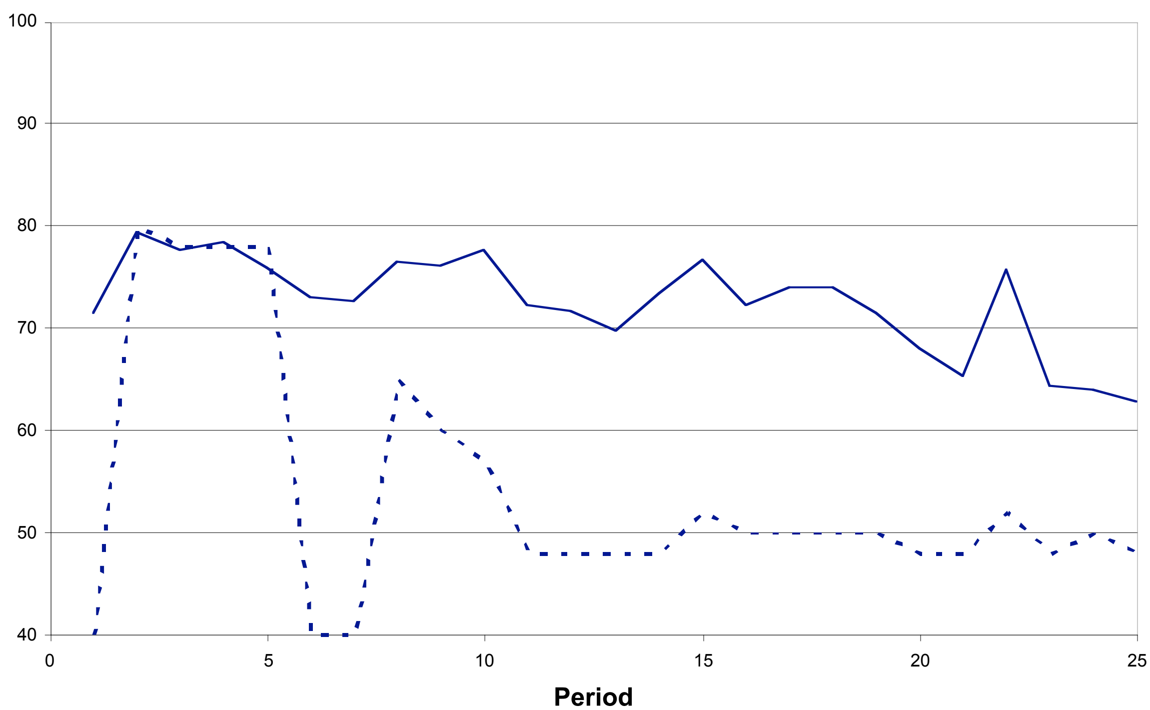


Figure 4: Average Market Price per Period (Professional Subjects)
Soft-Cap Auction with (bottom) and without (top) Price-Responsive Load

Experiment 2



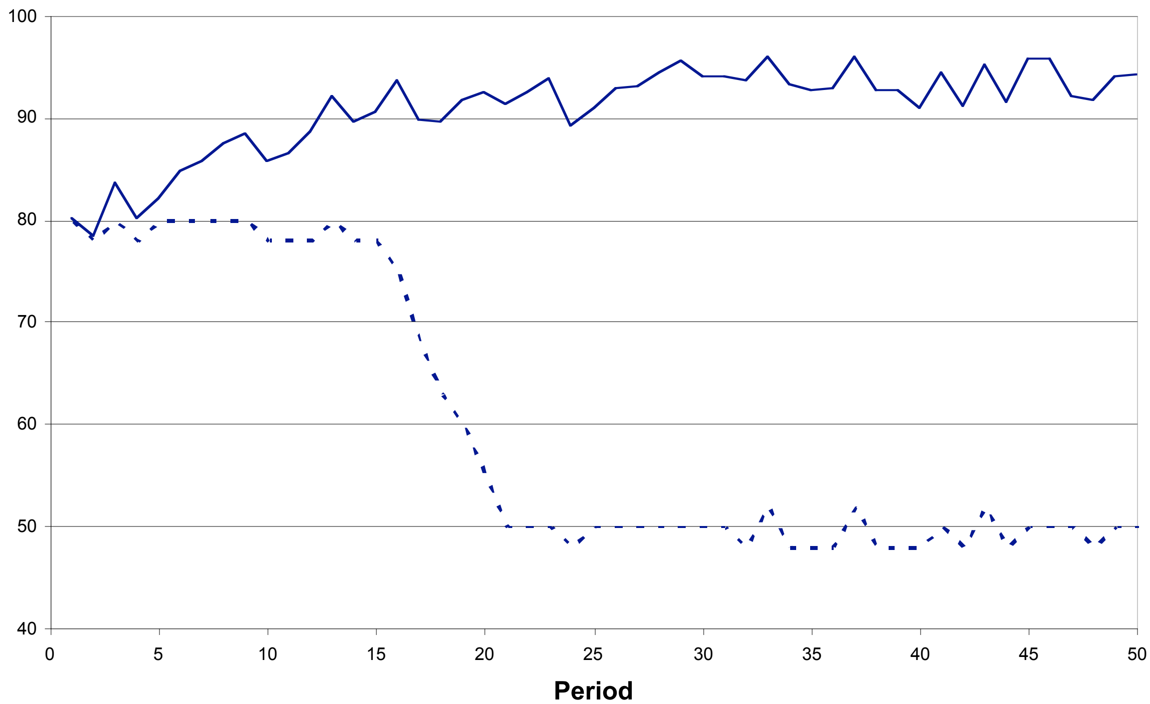
Experiment 3



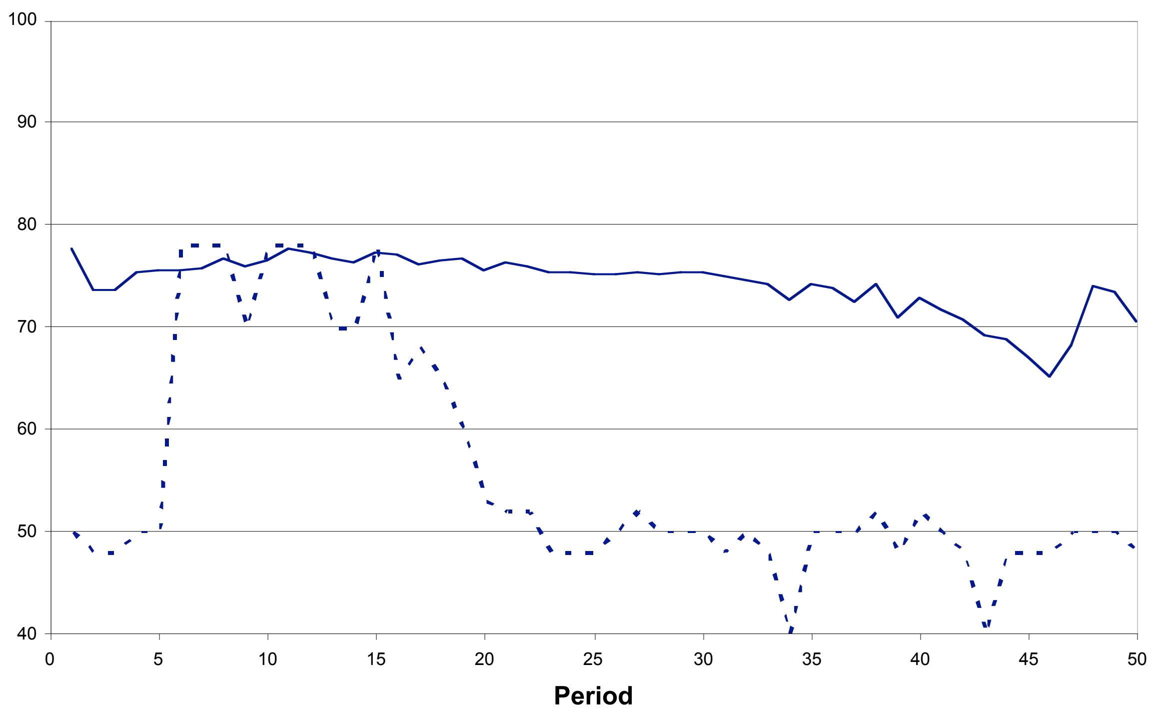
Note: Dotted line denotes the quasi-competitive price: the cost of generating the last MWh needed to meet demand when offers equal marginal cost.

Figure 5: Average Market Price per Period (Student Subjects)
Soft-Cap Auction with (bottom) and without (top) Price-Responsive Load.

Experiment 2



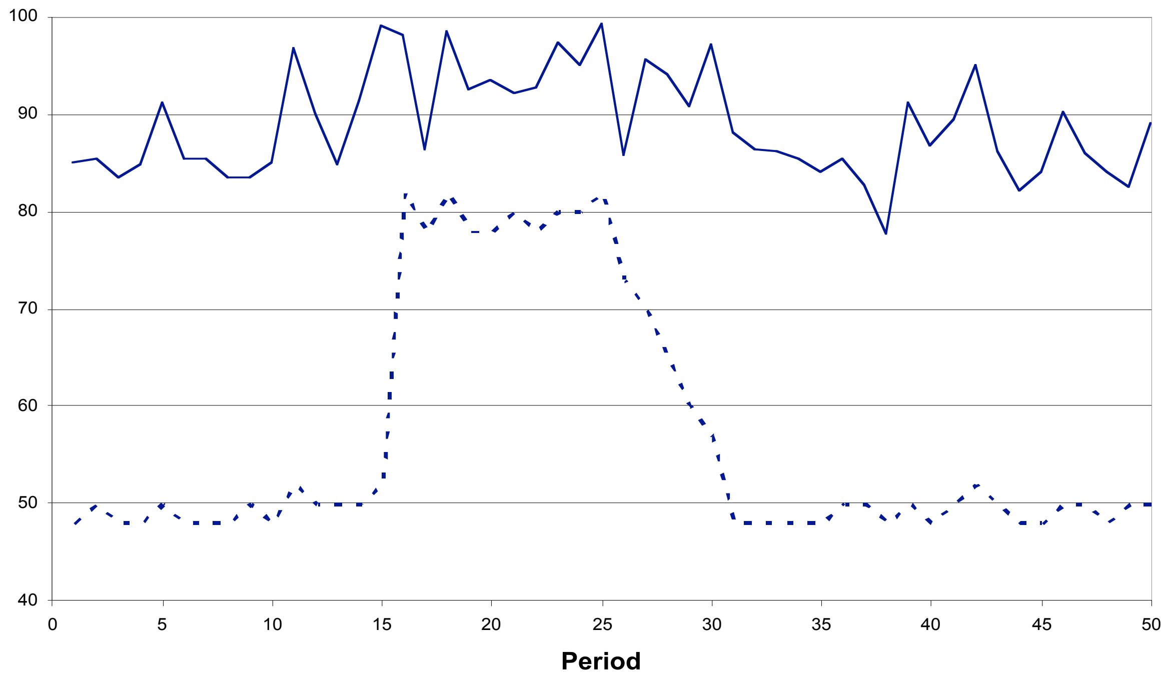
Experiment 3



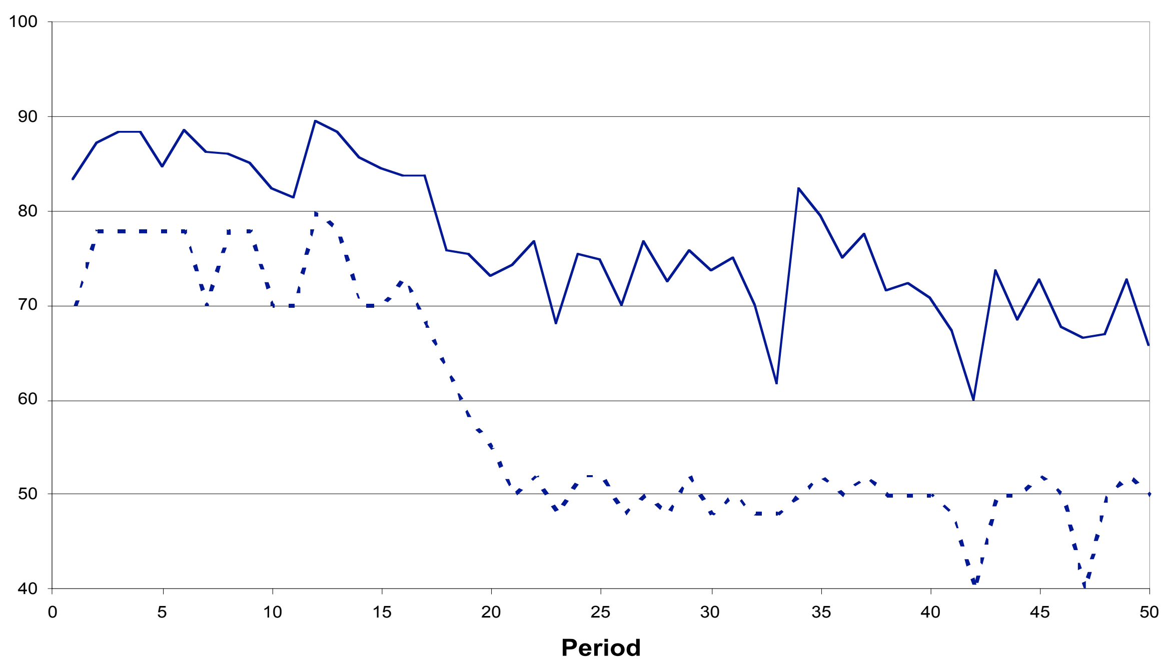
Note: Dotted line denotes the quasi-competitive price: the cost of generating the last MWh needed to meet demand when offers equal marginal cost.

Figure 6: Average Market Price per Period (Student Subjects)
Uniform Price Auction with (bottom) and without (top) Price-Responsive Load.

Experiment 1



Experiment 4



Note: Dotted line denotes the quasi-competitive price: the cost of generating the last MWh needed to meet demand when offers equal marginal cost.