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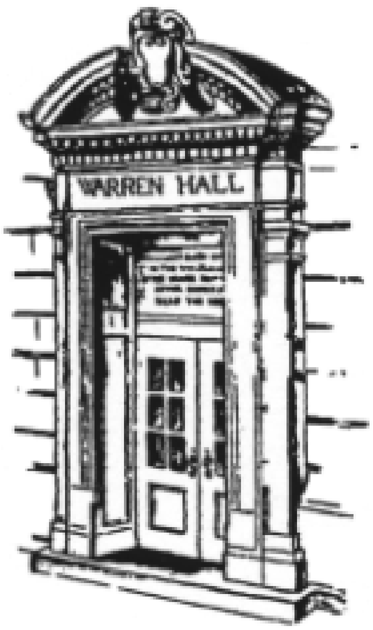

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Market Efficiency, Competition, and Communication in Electric Power Markets: Experimental Results

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ABSTRACT

Economic theory gives no clear indication of the minimum number of producers necessary for a market to define competitive price-quantity equilibria which approximate price equal to marginal cost. Previous work and FERC Guidelines generally suggest that 6 to 10 generators may be workably competitive. Our experiments with PowerWeb suggest that a higher number of suppliers may be necessary to approximate competitive market solutions, this in the absence of any communication among producers. As communications rules are altered to parallel differing types of antitrust enforcement, market results with 24 participants approach pure monopoly values.

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1. INTRODUCTION

The early experience in the restructured power markets of California and PJM raised several issues. (PJM as a system includes Pennsylvania, New Jersey, Maryland, Virginia, the District of Colombia, and Delaware.) Issues of interest include price spikes, generator outages, periodic unavailable capacity, brownouts, and the overall relationship of market clearing prices to marginal costs. Implicit in these subjects is the possible exercise of market power by generators and merchant suppliers. In restructured markets, generators submit offers to sell specific quantities of electricity at specific prices. The least-cost combination of offers[1] is selected by an ISO (Independent System Operator). The price paid to the supplier depends upon the type of auction system used.

Figure 1 shows an offer supply curve for July 6, 1999, for PJM.[2] This system used a last-accepted-offer auction, where the price (the lowest necessary to meet actual load) is uniformly paid to all suppliers. The $1,000/MWh price cap, a ceiling price, the maximum price allowed, was nearly attained 49 times in the summer of 1999.[3]

In general, average (not marginal) production costs are substantially less than $100/MWh. This value includes both variable running cost, and fixed costs with a normal return on investment.

In California, similar market results occurred in 2000 and early 2001 as shown in Figure 2. Average prices in the summer of 2000 were nearly 500% higher than during the same months one and two years earlier.[4] From January to April 2001, spot prices were around $300/Mwh, ten times higher than year earlier values.[5] Unexpected heat and lowered hydropower capacity contributed to abnormally higher demand and lower supply in the summer of 2000. Still, market

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[1] Some ISOs use the term "bid" to refer to the supply offer described here.

[2] From work by Hyungna Oh, *Three Essays on Modeling Offer Behavior in Electricity Spot Markets*, Ph.D. dissertation, Cornell University, forthcoming 2002.

[3] For 49 hours in 14 different days, the price exceeded $908/MWh. For 14 of those hours on July 29 and 30, the price exceeded $998/MWh. Hyungna Oh, ibid., personal communication, March 26, 2002. Note: $100/MWh is equivalent to 10c/kWh.

[4] P. Joskow and E. Kahn, "A Quantitative Analysis of Pricing Behavior in California's Wholesale Electricity Market During Summer 2000: The Final Word," February 4, 2002. Figure 1 shows market clearing prices for CAISO (California Independent System Operator).

[5] R.J. Thomas, T.D. Mount, R. Zimmerman, W.D. Schulze, R.E. Schuler, and L.D. Chapman, "Testing the Effects of Price Responsive Demand on Uniform Price and Soft-Cap Electricity Auctions," presented at the 35th Annual Hawaii International Conference on Systems Sciences, Kona, January 2002.

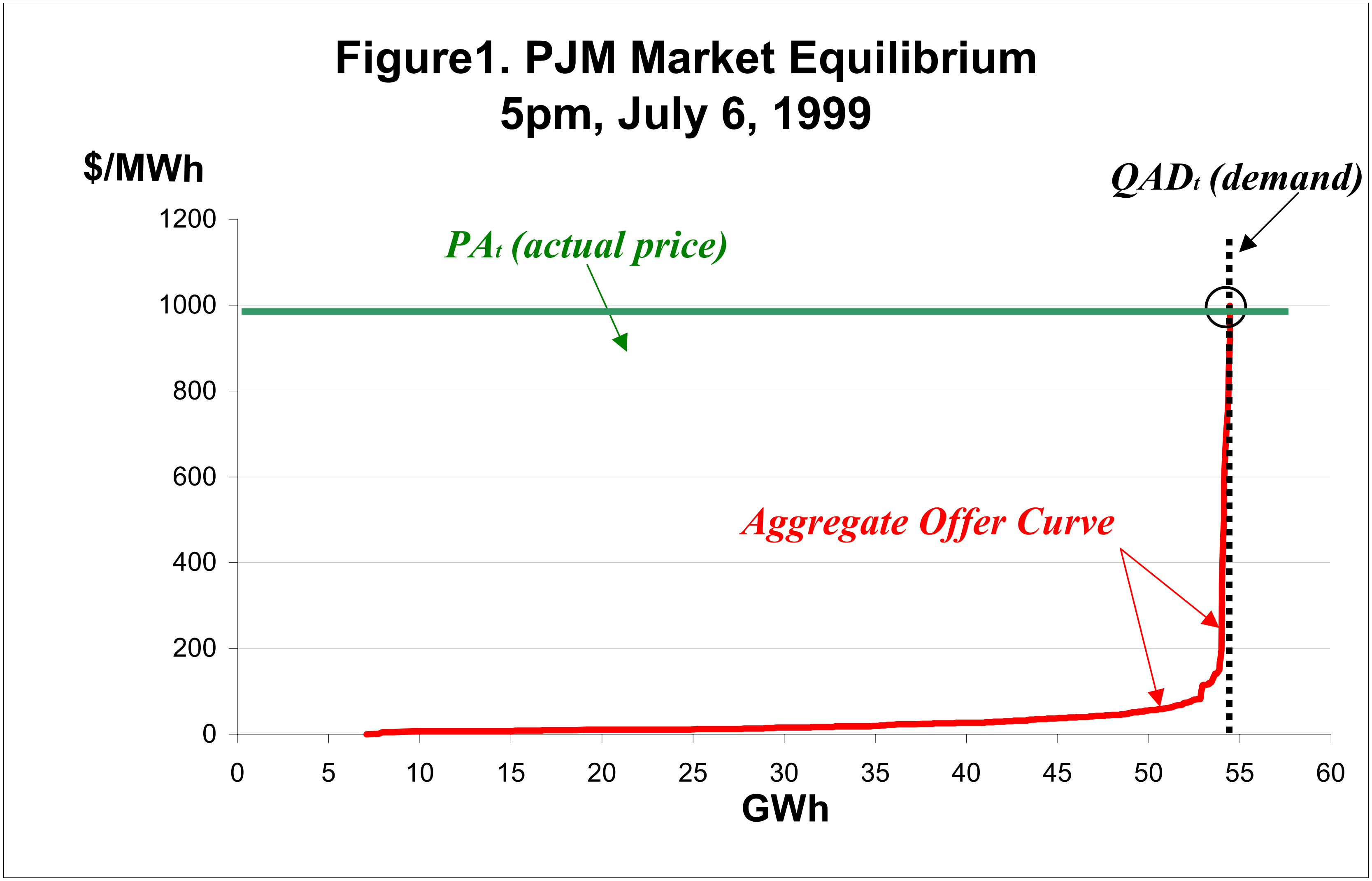

Figure1. PJM Market Equilibrium
5pm, July 6, 1999
$/MWh
QADt (demand)
PAt (actual price)
Aggregate Offer Curve
1200
1000
800
600
400
200
0
0
5
10
15
20
25
30
35
40
45
50
55
60
GWh

Figure 2. California ISO Prices ($/MWh)

Source: *New York Times*, March 24, 2001, p. C1 power was discussed as a possible factor.[6] In a general way, economic thinking about market-clearing prices in power auctions is reflected in Equation 1:

(1) P = p(QOF, QAC, QFD, QAD, CQ, HHI, ANTI).

P is the market clearing-price in an auction system managed by an ISO. QOF is the quantity offered; accepted offers from suppliers are typically a convex function of quantity, as in the "hockey stick" shape of Figure 1. (They are generally parallel to marginal cost curves, with an increasing difference at the right side of the offer curve.) QAC, QFD, and QAD are available capacity, forecast demand, and actual load demand quantities. CQ is the cost for quantity supplied; it represents either or both variable running costs and long run fixed costs, depending upon the context.

HHI is the Herfindahl Hirschman Index, the sum of squares of market shares for power suppliers in a market. ANTI represents antitrust policy: industry behavior in communications about offers and the framework for this communication as determined by antitrust policy.

Throughout the 1990s and into the beginning of this decade both experimentalists and policy makers generally believed that six to ten comparably sized suppliers defined a workably competitive market. The FERC (Federal Energy Regulatory Commission) guidelines held this to be so,[7] as well as the findings of Bernard, Mount, Green and Newberry, Joskow, and Andersson and Bergman.[8]

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[6] New York Times, February 11, 2001. Eight companies, mostly outside of California, generate most of the power for CAISO. A significant proportion of the capacity used to generate power may be from facilities purchased from California load serving entities during the restructuring process.

[7] The FERC position has been congruent with Department of Justice and Federal Trade Commission guidelines. See U.S. Federal Energy Regulatory Commission, "Inquiry Concerning the Commission's Merger Policy Under the Federal Power Act: Policy Statement," Docket No. RM 96-6-000; Order No. 592, 18 December 1996. Also U.S. Dept. of Justice and U.S. Federal Trade Commission, "Horizontal Merger Guidelines," Sec. 1.5, 1992. Both the FERC and DOJ/FTC references are from A. Rudkevitch, M. Duckworth, and R. Rosen, "Modeling Electricity in a

However, Rudkevich et al. used a model adapted from Kemperer and Meyer to suggest that 30 equal-sized market participants bring equilibrium price to an acceptable level of 5% above marginal cost at the equilibrium.[9]

The HHI can be defined as

$$(2) \quad HHI = \Sigma_i (100 * f_i)^2$$

The term f_i represents the decimal fraction of the total market supplied by any i participant. (The definition of share in a power market is usually based upon capacity.) In a perfectly competitive market, HHI approaches zero. In a pure monopoly, the index is at its maximum at 10,000. Note that the HHI gives a higher value for a market with one firm at 50% and 20 at 2.5% each than it does with 21 firms of equal size; it increases as some firms dominate with total number of firms unchanged.

The Department of Justice considers a value of 1,000 to be analogous to a benchmark. As values pass below the benchmark, they suggest a greater likelihood of a market being workably competitive.[10] With even-sized firms, 10 would define an HHI of this value of 1,000.

In the economic literature on power markets, antitrust policy is not discussed. It is implicitly assumed that antitrust law prevents direct communication and cooperation among suppliers. In the United States, explicit agreements to support prices or restrict output are

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Deregulated Generation Industry," September 1998 *Electricity Journal,* 19(3): 19-48. The FERC Guidelines held that 10 suppliers with equal market share were likely to result in a satisfactorily competitive market.

[8] See Bernard et al. 1998 (referenced in Mount et al., "Testing the Performance of Uniform Price and Discriminative Auctions," draft, July 16, 2001, pp. 5, 11). Also J. Bernard, "Performance Comparisons of Single Sided Auction Mechanisms Across Different Market Sizes in a Multiple Unit Setting," Ph.D. Dissertation, 1999. Also R. Green and D. Newberry, "Competition in the British Electricity Spot Market," 1992, *Journal of Political Economy,* 100(5): 929-953; and P. Joskow, "Horizontal Market Power in Wholesale Power Markets, Appendix A," 1995, cited in Rudkevitch et al. p. 48. B. Andersson and L. Bergman, "Market Structure and the Price of Electricity," 1995 *Energy Journal* 16(2): 97-109.

[9] Rudkevitch et al., *op cit.* footnote #7.

[10] See W.K. Viscusi, J.M. Vernon, and J.E. Harrington, Jr., *Economics of Regulation and Antitrust*, 3rd edition. Cambridge, MA: MIT Press, 2000, p. 148.

prohibited by the Sherman Act.[11] It is informal behavior that traditionally has been difficult to interpret.[12] Parallelism by different firms in setting offer curves for price and capacity offered to an ISO could be acceptable in the absence of any communication between firms.

However, it is well known to energy economists and the antitrust bar that strong incentives exist to undermine informal parallel systems as well as explicit agreements. Assume a system which initially results in withheld capacity by suppliers, and offer curves significantly above marginal cost curves. An individual supplier can engage in strategic behavior: even if earning rent considerably above competitive outcomes, he can earn a still higher level of rent by a minor downward adjustment in his offer curve, and an increase in his offered capacity. As each individual supplier seeks maximum profit, the market equilibrium thereby produced moves closer to the competitive market solution. It is workably competitive. This logic supports the belief noted above that six to ten suppliers will be sufficient for a workably competitive market.

According to one perspective, price caps (also known as reservation prices or price ceilings) can encourage parallel offers.[13]

We define four categories of allowable communication among power market participants:

Category One Behavior: No communication of any kind is allowable between suppliers participating in an ISO-administered market.

Category Two Behavior: General discussion of policies, strategies, and philosophies is possible, but there can be no mention or discussion orally or in writing of any specific prices or capacity quantities to be offered or withheld.

Category Three Behavior: Prices, price offer curves, capacity offered and withheld can be explicitly discussed. However, no binding agreements or contracts may be made, nor can any redistribution of profit occur.

Category Four Behavior: Similar to Category Three, but binding enforceable agreements are allowed.

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[11] Ibid., pp. 127-131.

[12] Viscusi, op.cit., pp. 131-135. Also see F.M. Scherer, *Industrial Market Structure and Economic Performance*. Chicago: Rand McNally, 1980, pp. 169-196.

[13] Scherer, op. cit., p. 191.

Category One is not applicable in any actual restructured market; but, as will be seen below, it is of experimental interest. However, Category Two has traditionally been the flexible boundary of antitrust law. Power traders can legally attend trade, professional, and academic meetings, and may use such phrases as "Generator income would be enhanced if offers were higher for higher cost units." But an actual $/MWh price cannot be named. Someone may say "Withholding capacity increases revenue to cover everyone's long-run capital costs," but they may not name a MW figure to offer or withhold.

Category Three communications are currently "just over the fence;" they are not generally allowable under antitrust law.[14] Category Four is an illustration of actions that might be allowable in the presence of the reinterpretation of antitrust law. Taken together, the four categories define locations on a continuum of antitrust concern.

Our experimental work sought to illuminate these two questions: how many suppliers are necessary for competitive equilibria to be approximated, and how does antitrust policy affect outcomes?

[14] In real markets, Categories Two and Three are not as neatly differentiated with respect to antitrust law. Example: two suppliers discuss and compare old offers, and these two are not major participants. This behavior would be difficult to place in either category.

2. HYPOTHESES AND EXPERIMENTAL DESIGN

From previous research, we developed the following hypotheses.

H1: Six generators in a market are sufficient to give results comparable to a competitive market.

H2: A market with 12 suppliers[15] will be competitive.

H3: With 24 generators, a market will be competitive.

H4: A competitive market with 24 suppliers will remain competitive when allowable communication moves into the Category Two type, from Category One. Restated, the existing antitrust framework is sufficient to maintain competition with a large number of suppliers.[16]

H5: Introducing Category Three communication with 24 generators will have cartel-like results; lower prices than pure monopoly, but higher prices than in competition.

H6: With Category Four communication, market results approximate the prices expected from a pure monopoly.

In the fall of 2001, we conducted six experiments to examine and test these hypotheses. We used a class of 24 Cornell University engineering and economics graduate students. Subjects were paid in direct proportion to the profits of their simulated firms and earned $110 on average for eight hours of participation. Before the experiments took place, each participant went through a training exercise where they competed against five smart computer agents in a uniform price auction for 25 trading periods.

Our experiments were conducted using PowerWeb,[17] a web-based platform for performing economic experiments on electricity markets. Users interact with the platform through the Netscape browser; sample offer and results screens are included as an Appendix.

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[15] Suppliers are both generators and power merchants that buy and resell energy. In discussing the experiments, all participants are generators; the words are synonymous.

[16] In each case for hypotheses H1 – H4, the alternate hypothesis is that the results are not comparable to those in a competitive market.

[17] Available at www.pserc.cornell.edu/powerweb.

Each participant plays the role of an electricity generator who owns five blocks of capacity. The first block is 50 megawatts (MW) and operates at a cost of $20 per MW. The second block is 20 MW with a marginal cost of $40/MW. The last three blocks are 10 MW each with marginal costs of $48/MW, $50/MW, and $52/MW. In each trading period, the generator incurs a fixed interest charge of $1200. At the beginning of each period, the generators see a forecast of the system load (i.e., QFD in Equation [1]). Forecast load in each period was randomly generated using a uniform distribution within a band of 430 MW to 550 MW. Actual demand in each period (QAD) was equal to forecast demand, plus a stochastic term within $\pm$ 20MW. (These parameters are for a group of six participants. Values are scaled proportionally for the other group sizes.)

In each period, the generator submits offers to sell blocks of capacity at prices designated by the generator. This offer curve (p[QOF]) is entered into a uniform price auction run by an ISO. The ceiling price (i.e., price cap) is $100/MW. A stand-by charge of $5/MW is incurred for each block offered, regardless of whether an offer is accepted. This stand-by charge is included to represent the opportunity cost of being available for a time period, foregoing sales in other markets, and delaying maintenance activities. The generator can choose to shut down one or more of his generating unit blocks and avoid the associated stand-by cost.

The ISO selects the least expensive combination of offers to meet the system load. The market clearing price is equal to the last accepted offer and is paid to all successful offers. The uniform price auction is currently used in the PJM, New York, New England, and Australian wholesale markets and was used in the California market. 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 the market-clearing price for all recalled capacity. A similar recall procedure has been used in the PJM market.

The six experiments are divided into two series. In the first series the number of generators in a market is varied; in the second series, different levels of information exchange are allowed in stages comparable to Categories One through Four. In the first series of three experiments, no communication was allowed between participants; Category One rules were enforced. Initially, four groups of six each (sessions denoted as 6A, 6B, 6C, and 6D) participated in 40 trading periods. In the second experiment, the 24 participants were divided into two groups of 12 each (12A and 12B). Finally, as the third experiment, all 24 subjects participated in a single market (24A). The second and third experiments consisted of 25 periods each.

This first sequence could be seen as representing a policy of separation of larger firms into smaller firms. It must be considered possible that prices with 24 generators could be lower if they had no prior experience with the successful exercise of market power.

In the second series of three experiments, all 24 subjects participated in the same market for 20 periods and each experiment began with a group discussion led by an experiment participant. The discussion was intended to be analogous to legal Category Two communication: a professional conference session moderated by an industry professional.[15] The purpose of the discussion was to increase industry profits. In this fourth experiment (24C), the discussion was overseen by the lead author, who played the role of an antitrust consultant. No discussion was allowed that violated Category Two rules, which represent current U.S. antitrust law. In particular, no direct reference could be made to specific offer prices or specific quantities submitted into the market.

The next two experiments represent cases in which antitrust policy becomes increasingly less restrictive. In the fifth experiment (24D), any discussion was allowed even if in violation of antitrust law. This reflects Category Three communication. However, participants were allowed to make verbal agreements, but without consequences for those who did not follow the agreements. The sixth experiment (24E) was identical to the fifth except an explicit binding agreement was allowed; this is Category Four, the suspension of antitrust policy.

The timing of the experiments was such that there was a gap of one and a half months between the two series of experiments. During this time the class of subjects participated in other electricity market experiments which potentially affected the comparability between the two series of experiments discussed here. Therefore, to initiate the second series of experiments on communication, we conducted another session with 24 participants (24B) and Category One rules: no information exchange. As this experiment and our third experiment are identical in all respects except for timing, we consider both sessions with 24 participants and Category One rules to be the third experiment.

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[15] Professor Fred Aman (Indiana University School of Law) reports that in his early career in antitrust in the private sector, he performed just this kind of role. Personal communication, March 4, 2002.

3. EXPERIMENTAL RESULTS

Figure 3 displays the mean market prices for the experiments. Since the number of periods differed among experiments, we used data from the last 20 periods of each experiment only. This truncation eliminates "learning" effects observed in one of the initial sessions with 6 suppliers. Table 1 shows the variability of realized prices within each group as well as the HHI. For the four groups each with six suppliers, under Category One rules prohibiting any communication, the mean market price is $75/MWh. Our results with 6 participants are comparable to the results of Mount et al. (2001),[18] who conducted these same experiments with regulators in the New York State Department of Public Service (mean price = $71.50), engineering and economics graduate students at the University of Illinois ($72.25), and a previous class of engineering and economics graduate students at Cornell University ($79.00).[19] For comparison, the competitive price is the market clearing price if all generators submitted offers p(QOF) equal to the marginal operating cost plus stand-by cost for each block of generation. For all experiments the competitive price is approximately $54, and is represented by the blue bar in Figure 3. In Experiment 2, there are now two groups of 12 each. Doubling the size of groups results in a lower mean price, a reduction of $7/MWh. Doubling the size again to 24 generators (Experiment 3) further reduces the mean price to roughly $66.

Table 2 presents results of a regression of group mean price – over and above competitive levels – on a set of dummy variables corresponding to group size. The coefficients thus measure the difference between the observed price and the competitive price for each experiment. The t-ratios are the test statistics corresponding to hypotheses H1, H2, and H3. For Experiments 1, 2, and 3, we reject the null hypothesis that the experimental price is the same as the competitive price.[20]

[18] T.D. Mount, R.J. Thomas, and R.D. Zimmerman, "Testing the Performance of Uniform Price and Discriminatory Auctions," presented at the Rutger's Advanced Workshop, San Diego, California, June 2001.
[19] These mean values are rounded to nearest 25¢.
[20] Throughout the paper we use a 10% significance level.

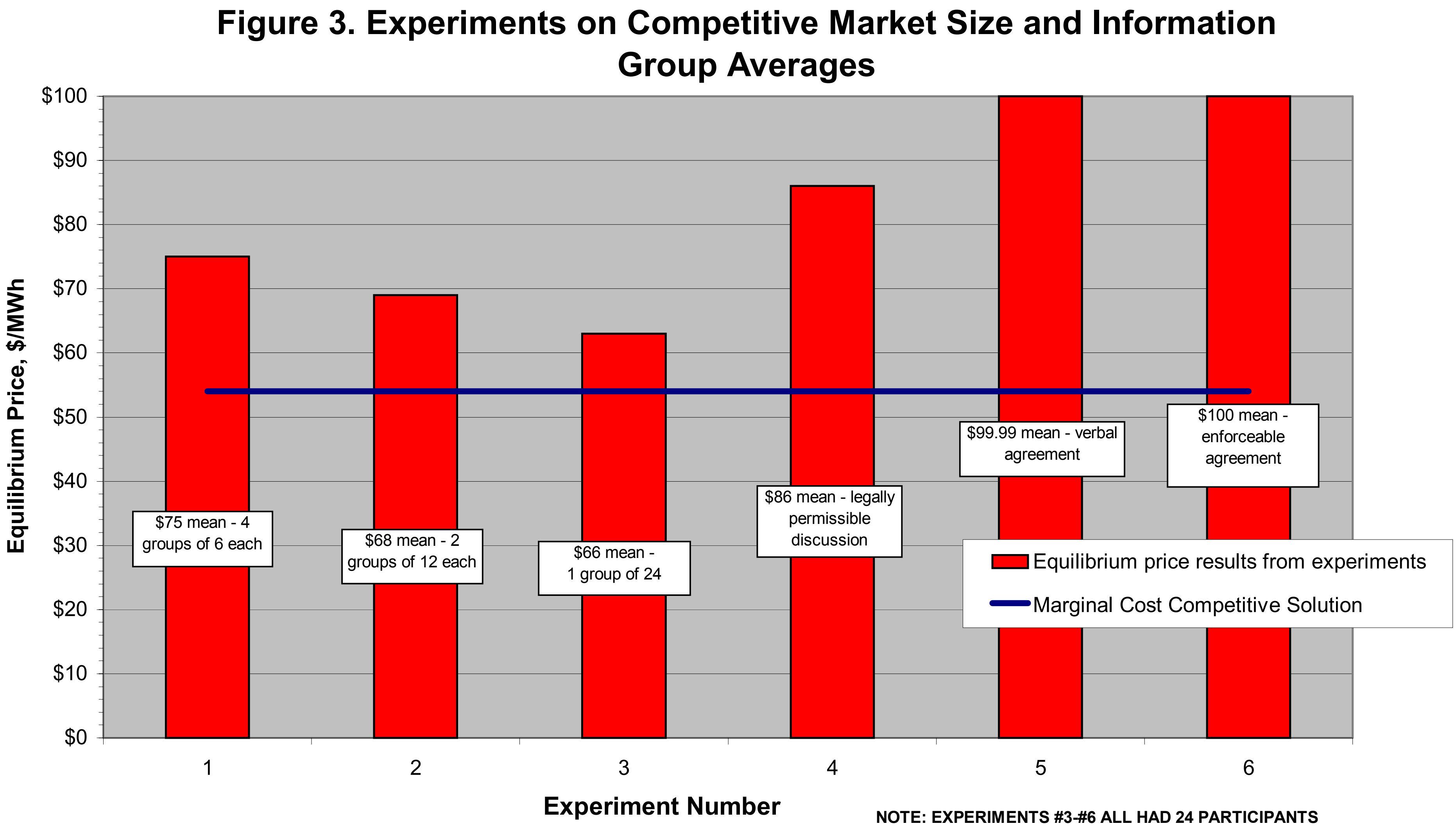
Figure 3. Experiments on Competitive Market Size and Information
Group Averages
Equilibrium Price, $/MWh
$100
$90
$80
$70
$60
$50
$40
$30
$20
$10
$0
$75 mean - 4 groups of 6 each
$68 mean - 2 groups of 12 each
$66 mean - 1 group of 24
$86 mean - legally permissible discussion
$99.99 mean - verbal agreement
$100 mean - enforceable agreement
Equilibrium price results from experiments
Marginal Cost Competitive Solution
1
2
3
4
5
6
Experiment Number
NOTE: EXPERIMENTS #3-#6 ALL HAD 24 PARTICIPANTS

If we make use of a representation of workable competition resulting in a price within 10% of the competitive price, this would give a benchmark of approximately $59.40/MWh.[21] Experiment 1 and Experiment 2 prices are statistically higher than this benchmark (t_{exp1}=4.97, p=0.00; t_{exp2}=1.89, p=0.06). Experiment 3 prices are higher but not significantly so (t_{exp3}=1.36, p=0.12).

The group discussions that took place in Experiments 4, 5, and 6 were very engaging and fruitful. In Experiment 4, when participants were allowed only Category Two legally permissible discussion, participants used clever analogies to encourage others to make high price offers.[22] In reality, executives from competing energy companies do interact personally and professionally and have the opportunity to discuss non-binding price strategies that could be tacitly exercised in the interest of higher long-run profits. The results in this experiment: a mean price of $86/MWh.

Experiment 5 passes into Category Three behavior, now prohibited by antitrust law. Participants were allowed to discuss anything, including specific prices in $/MWh and capacity withholding in MW, but were only allowed to make a verbal, nonbinding agreement. Specific offer and quantity submission strategies were the basis of an agreement. All participants agreed to submit offers of $50, $99.97, $99.98, $99.99, and $100 for blocks 1 through 5, respectively. Guidelines were established on how much capacity to submit given the load forecast.[23] The offer strategy was generally adhered to although as expected (see above) some participants undercut suggested offer prices by a few cents and submitted all capacity into the market. This plan resulted in a mean price of $99.99.

In Experiment 6, with Category Four rules, participants were allowed to and did organize an enforceable agreement. The offer and quantity strategy was similar to that used in the previous experiment, although now the last offer submitted was set to $100, the next highest offer set to $99.99, the next highest offer (if applicable) set to $99.98, and the first block offered for $50. Block 5 was always withheld from the market and the first three blocks were always offered into the market. It was agreed that if the range of earnings among the 24 participants

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[21] Apparently the Department of Justice and the Federal Trade Commission used a 5% margin in the early 1990s in their analyses of mergers. Rudkevich et al., op. cit., pages 22-23.

[22] One participant: "On our fishing trip we found we should just catch a couple of fish, but make sure that we keep the big fish and throw the little fish back."

[23] All participants seemed enthusiastic about the new rules. A comment: "All right! It sounds like we can make lots of money."

(actual cash payouts) was greater than 75 cents, total earnings would be divided equally among participants. The range of earnings was only 27 cents and so no action was taken to equalize earnings. The price for each period in the experiment was at the $100 cap.

Corresponding with hypotheses H4, H5, and H6, we tested whether the mean price under Category Two, Three, and Four rules is statistically different than under Category One rules with the same group size. From the regression results, we estimated a 90% confidence interval around the mean price for 24 participants under Category One Behavior, resulting in an upper bound of $81.24.[24] Prices under Category Two, Three, and Four rules are all noticeably greater than this cut-off. As such, we reject H4 and fail to reject H5 and H6. Contrary to expectations for H4, allowing legally admissible discussion did result in a statistically higher market price. As hypothesized (H5 and H6), allowing Category Three and Four communication did result in a statistically higher market price. The pure monopoly outcome was reached under Category Four rules.

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[24] In constructing this interval, the standard error (se) is $[\text{MSE} + \text{se (Group Size} = 24)]^{1/2} = 7.798$, where MSE is the mean squared error from the regression. The critical value from the t distribution with 5 degrees of freedom is 2.015.

Table 1. Price Summary

Experimental Group	Mean	Std. Dev.	Range	% ≥ $70	% ≥ $80	% ≥ $90
6 Participants (Experiment 1), HHI = 1,667 (Category #1)						
6A	$85.00	13.39	59 – 99	80	70	55
6B	$73.88	21.32	50 – 100	45	35	35
6C	$71.18	15.53	54-100	50	15	15
6D	$70.86	13.74	48 – 95	60	30	15
12 Participants (Experiment 2), HHI = 833, (Category #1)						
12A	$62.85	14.65	50 – 100	20	15	10
12B	$73.00	19.40	51 – 100	45	40	35
24 Participants (Experiment 3), HHI = 417, (Category #1)						
24A	$62.48	14.11	52 – 100	20	20	10
24B	$68.56	19.36	49 – 99	35	30	25
24 Participants (Experiments 4, 5, 6), HHI = 417, (Categories #2, #3, #4)						
24C permissible discussion	$85.81	8.02	74 – 99	100	65	35
24D verbal agreement	$99.99	0.01	99.98-100	100	100	100
24E binding agreement	$100	0.00	100-100	100	100	100

Table 2. Regression Results

Dependent Variable: Group Mean Price – Competitive Price ($54)			
Variable	**Coefficient**	**Standard Error**	**t-ratio**
Group Size = 6	21.229	3.184	6.668
Group Size = 12	13.923	4.502	3.093
Group Size = 24	11.522	4.502	2.559
R^2	0.426		
N	8		

4. INTERPRETATION

The first three hypotheses are rejected. Neither the market size of 6 generators, nor 12, nor 24, give market results which approximate the results of a purely competitive market. Considering the benchmark of 10% above the competitive market price as an illustration of workably competitive markets, the first three experiments result in mean prices above the benchmark.[25]

The fourth hypothesis assumed that, with 24 suppliers, moving from Category One behavior (no communications) to Category Two rules (representing current antitrust policy), the market would remain competitive. However, the resulting average of $86 is significantly different from the competitive price of $54 as shown in Table 2. It is also significantly higher than the workable competition benchmark of $59.40.

Hypothesis 5 held that reducing antitrust enforcement or changing policy from Category Two to Category Three would raise equilibrium prices above competitive levels, but below the pure monopoly price. Technically, this hypothesis is supported. The result of $99.99 for 24

[25] Recall the prices with 6 and 12 participants are significantly higher than the workable competition benchmark. The result with 24 participants is higher than that benchmark, but the difference is not significant.

participants is significantly above the purely competitive price ($54), and also below (by one cent) the pure monopoly price cap of $100.

The last hypothesis (H6) correctly anticipated that with a Category Four framework and 24 generators, results would be at the pure monopoly price, at the price cap of $100.

5. CONCLUSION

The unusually high market equilibrium prices in power markets in the summers of 1999-2001 in California and PJM created new interest in the market structure necessary for efficient competitive results. Previous research had generally considered 6-10 suppliers sufficient for market results to approximate a workably competitive market, although Rudkevitch et al. had argued that 30 participants is necessary. All prior work had implicitly assumed that antitrust policy would continue to provide the behavioral framework for power markets.

We used PowerWeb as an experimental platform to examine six hypotheses structured around concepts of market size, and antitrust policy. Broadly stated, the experimental results illuminate the importance of the antitrust framework. The results also suggest that the number of participants necessary for a market to approximate competitive results is important; that number may be higher than 6-10 suppliers. Perhaps much higher.

Two observations qualify the extension of these research findings to policy for actual power markets. First, a different sequence of experiments might lead to different market outcomes for each experiment. For example, if the market size experiments had been sequenced in the reverse order, proceeding from 24 to 12 to 6 participants, the mean prices may have been lower in all three experiments. Second: actual power markets experience scheduled and unscheduled outages, variable load pockets, demand response to price variability, reserve requirements and markets, and offer supply curves which may at times be intentionally lower than those which generators believe would create maximum profit. These real market conditions[26] may tend to result in lower market prices than observed in these experiments.

[26] New work with PowerWebII is addressing some of these issues.

Nevertheless, these experimental results would seem to give emphasis to the importance of market structure and antitrust policy as factors affecting price outcomes in restructured power markets.

Appendix. Sample Offer Instructions, Submission, and Results Pages in PowerWeb

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. The chances of load being above or below the forecast are the same.

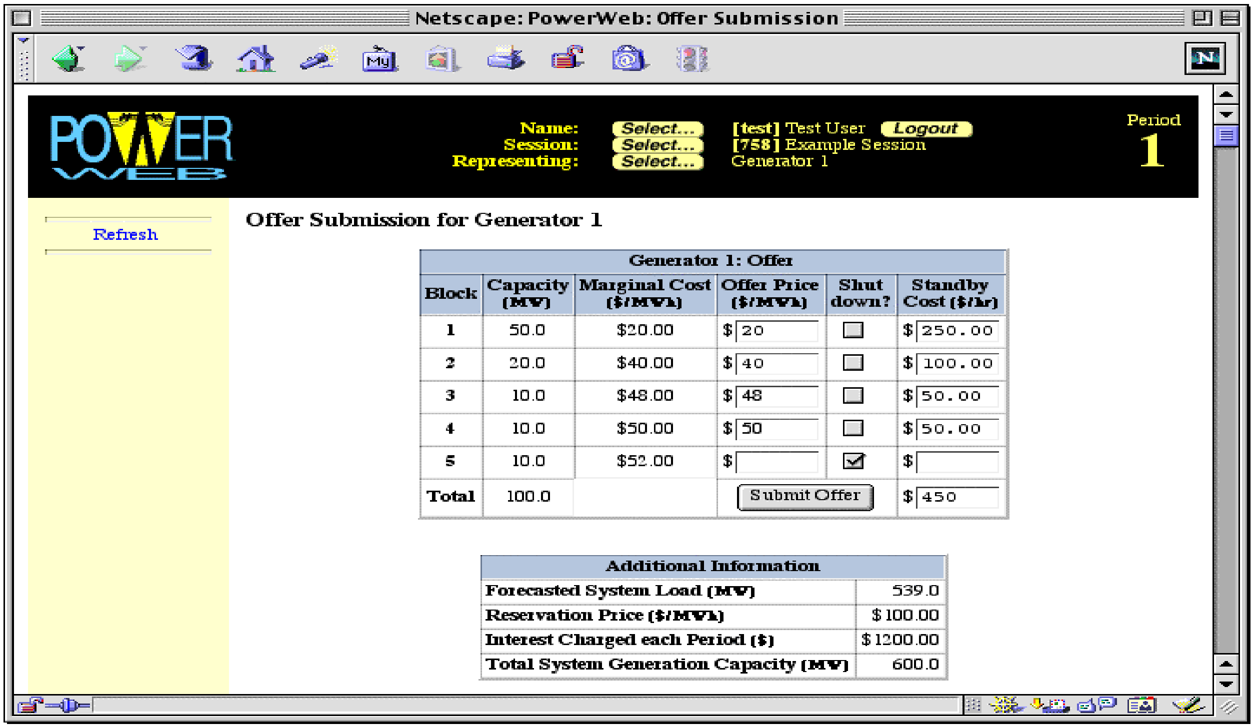
The operating costs of your capacity have two components. The first is the operating cost/MWh for a capacity that is dispatched. The second is a fixed standby cost of **$5/MWh** for submitting an offer. Hence, standby costs are paid when a block is offered into the market even if it is not dispatched. Withholding blocks from the auction is the only way to avoid standby costs for those blocks (the offer submission page for POWERWEB has check boxes 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 cost of **$10/MWh** must be paid for the entire capacity of any block recalled, as well as the operating cost for the actual recalled quantity purchased.

The amount of time you have to review the results from the previous period and make your offer is limited as shown below. If you do not submit your offer within the allotted time, your offer from the previous period will be automatically submitted for you.

Your objective is to maximize your earnings over a series of 40 periods.

Summary

Auction:	Uniform – Last Accepted Offer
Number of Suppliers:	6
Periods:	40
Load:	Forecast = 490MW ± 60MW, Actual = Forecast ± 20 MW
Price Response:	Load is price inelastic
Standby Costs:	$5/MWh for each block
Shortfall Mechanism:	Random recall with price set to the highest offer
Recall Cost:	$10/MWh for each block
Fixed Interest Charge:	$1200/period
Exchange Rate:	1/3500
Time Allowed per Period:	periods 1-5: unlimited periods 6-10: 3 minutes periods 11-40: 1 minute 30 seconds



Netscape: PowerWeb: Offer Submission

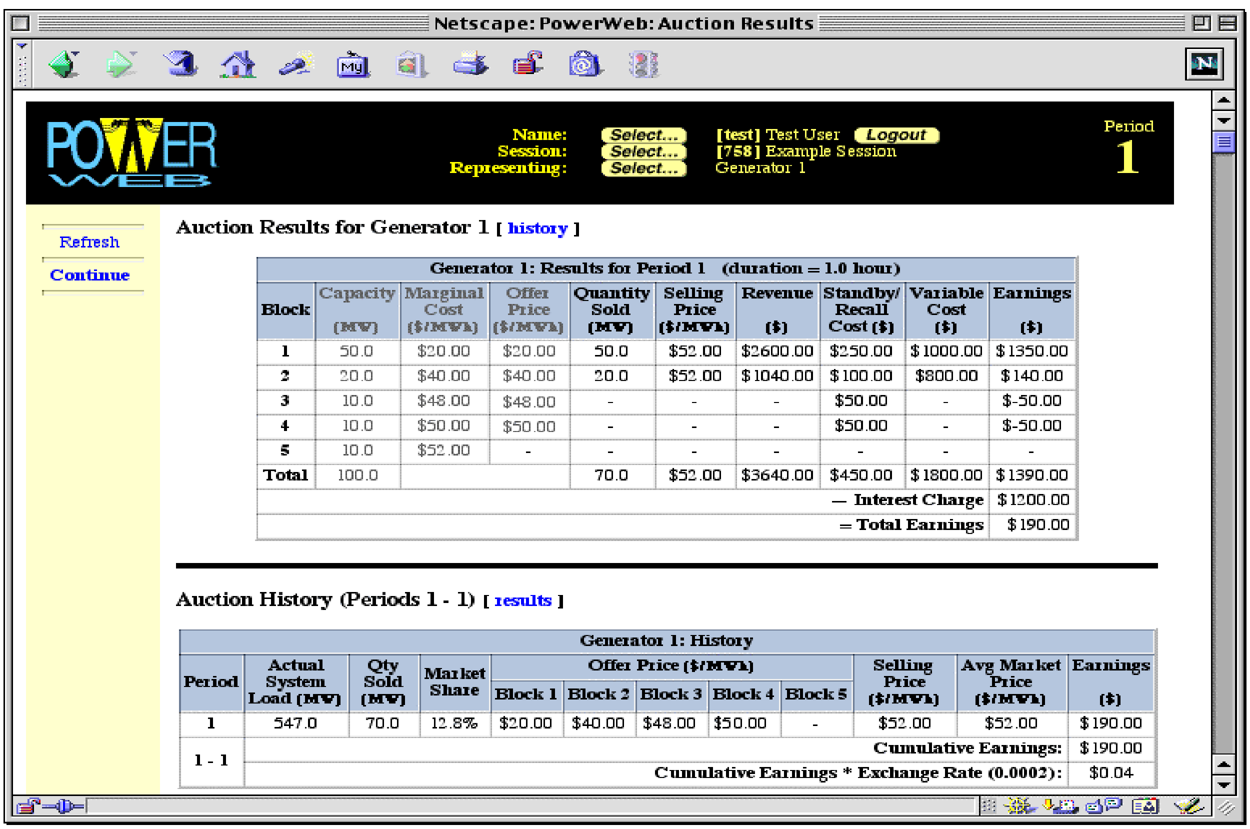
Name: Select... [test] Test User Logout
Session: Select... [758] Example Session
Representing: Select... Generator 1
Period 1

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	☐	$ 250.00
2	20.0	$40.00	$ 40	☐	$ 100.00
3	10.0	$48.00	$ 48	☐	$ 50.00
4	10.0	$50.00	$ 50	☐	$ 50.00
5	10.0	$52.00	$	☑	$
Total	100.0		Submit Offer		$ 450

Additional Information	
Forecasted System Load (MW)	539.0
Reservation Price ($/MWh)	$100.00
Interest Charged each Period ($)	$1200.00
Total System Generation Capacity (MW)	600.0



Netscape: PowerWeb: Auction Results

Name: Select... [test] Test User Logout
Session: Select... [758] 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	$52.00	$2600.00	$250.00	$1000.00	$1350.00
2	20.0	$40.00	$40.00	20.0	$52.00	$1040.00	$100.00	$800.00	$140.00
3	10.0	$48.00	$48.00	-	-	-	$50.00	-	$-50.00
4	10.0	$50.00	$50.00	-	-	-	$50.00	-	$-50.00
5	10.0	$52.00	-	-	-	-	-	-	-
Total	100.0			70.0	$52.00	$3640.00	$450.00	$1800.00	$1390.00
								— Interest Charge	$1200.00
								= Total Earnings	$190.00

Auction History (Periods 1 - 1) [results]

Generator 1: History											
Period	Actual System Load (MW)	Qty Sold (MW)	Market Share	Offer Price ($/MWh)					Selling Price ($/MWh)	Avg Market Price ($/MWh)	Earnings ($)
				Block 1	Block 2	Block 3	Block 4	Block 5			
1	547.0	70.0	12.8%	$20.00	$40.00	$48.00	$50.00	-	$52.00	$52.00	$190.00
1 - 1										Cumulative Earnings:	$190.00
										Cumulative Earnings * Exchange Rate (0.0002):	$0.04

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