Are Price Spikes Predictable, Reproducible and Avoidable?

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Objectives

1) To understand the causes of price volatility in spot markets

2) To determine how to make spot markets less vulnerable to strategic behavior by traders

Outline

1) A statistical model of price behavior
2) Analyzing actual offer curves for power
3) Properties of optimum offer curves
4) Testing market structures with PowerWeb
5) Replicating price spikes in experiments
6) Conclusions

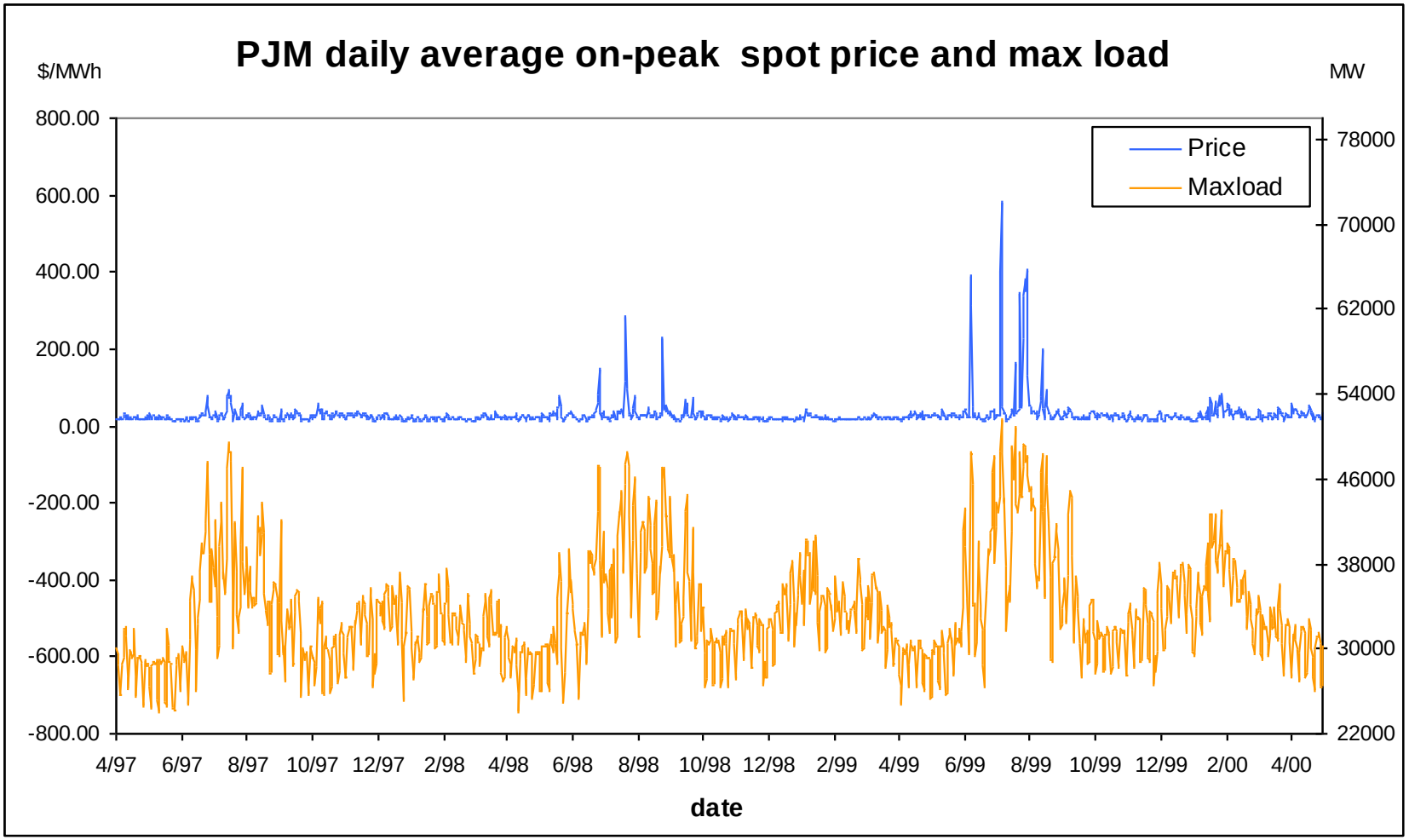
The Data are from the PJM (Pennsylvania, New Jersey, Maryland) Market East

(http://www.pjm.com/market_system_data/market_data_index.html)

- Hourly and on-peak daily prices from 4/1/97 to 8/31/00
- Hourly offer curves by company from 4/1/99 to 8/31/99

Two Important Disclaimers

1) The PJM market was chosen because offer data are available to the public.
2) The PJM market is working relatively well compared to other markets.
   - Take one step at a time
   - Respect commercial obligations


PJM daily average on-peak spot price and max load
$/MWh
MW
800.00
600.00
400.00
200.00
0.00
-200.00
-400.00
-600.00
-800.00
78000
70000
62000
54000
46000
38000
30000
22000
Price
Maxload
4/97
6/97
8/97
10/97
12/97
2/98
4/98
6/98
8/98
10/98
12/98
2/99
4/99
6/99
8/99
10/99
12/99
2/00
4/00
date

PJM Market Rules

1. Day-ahead offers with hourly settlements
   - Cost-based offers 4/97 to 3/99
   - Market-based offers 4/99 to 5/00
2. Day-ahead market plus an hourly balancing market 5/00 to current
   - Market-based offers 6/00 to current

Statistical Model

Markov Regime Switching

Conditional Distributions

y_t is $N(\mu_{1t}, \sigma_1^2)$ if $S_t = 1$ (high price regime)

y_t is $N(\mu_{2t}, \sigma_2^2)$ if $S_t = 2$ (low price regime)

where y_t is the logarithm of price

$\mu_{it} = \alpha_i + \phi_i y_{t-1} + \gamma_i x_t$ is the conditional mean

x_t is the logarithm of forecasted load

σ_i^2 is the variance

α_i, ϕ_i and γ_i are parameters

Transition Probabilities

$$\Pr[S_t = 1 \mid S_{t-1} = 1] = P_{1t}$$

$$\Pr[S_t = 2 \mid S_{t-1} = 1] = 1 - P_{1t}$$

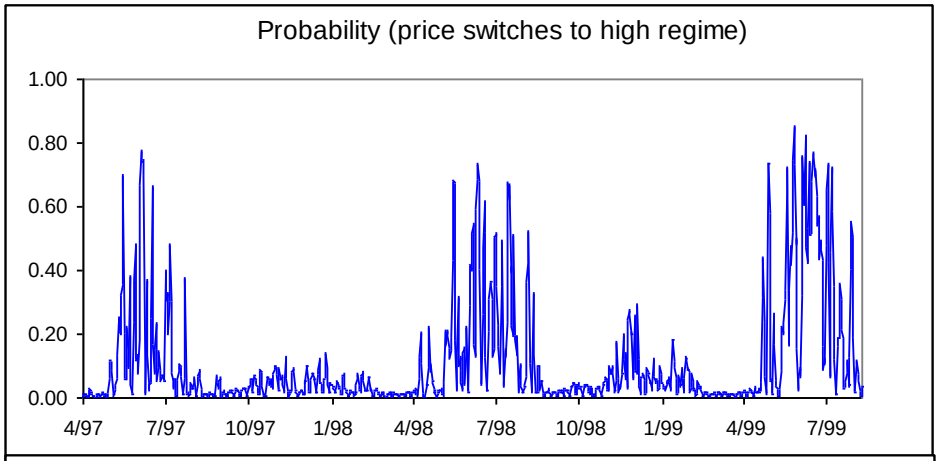
$$\Pr[S_t = 2 \mid S_{t-1} = 2] = P_{2t}$$

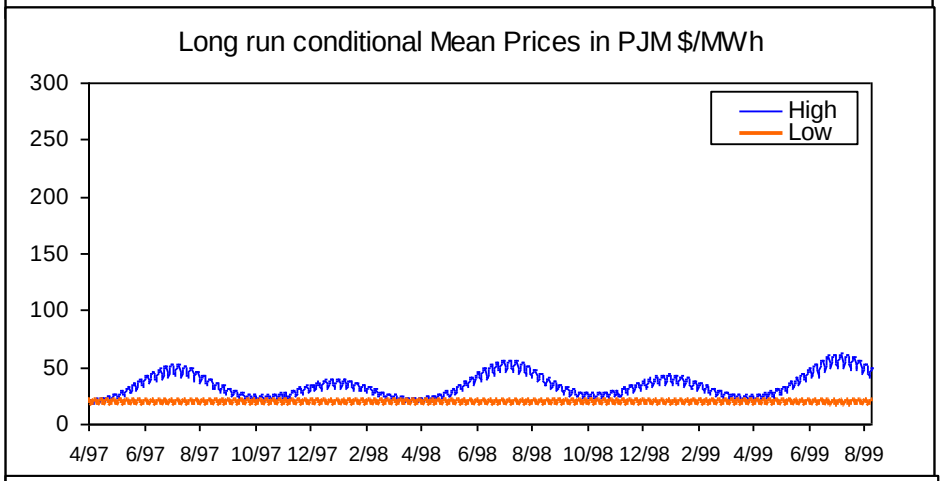
$$\Pr[S_t = 1 \mid S_{t-1} = 2] = 1 - P_{2t}$$

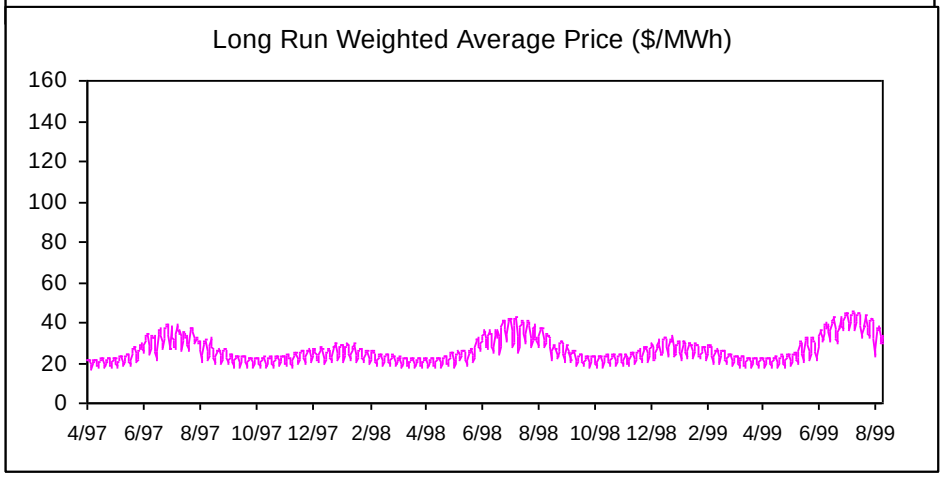
$$P_{it} = \frac{\exp(c_i + d_i z_t)}{1 + \exp(c_i + d_i z_t)} \quad \text{for } i = 1,2$$

where z_t is the logarithm of actual load

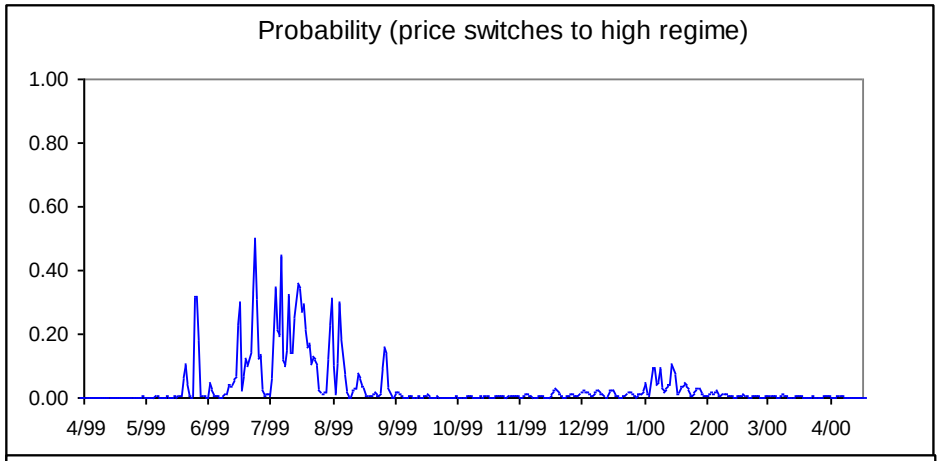
c_i and d_i are parameters

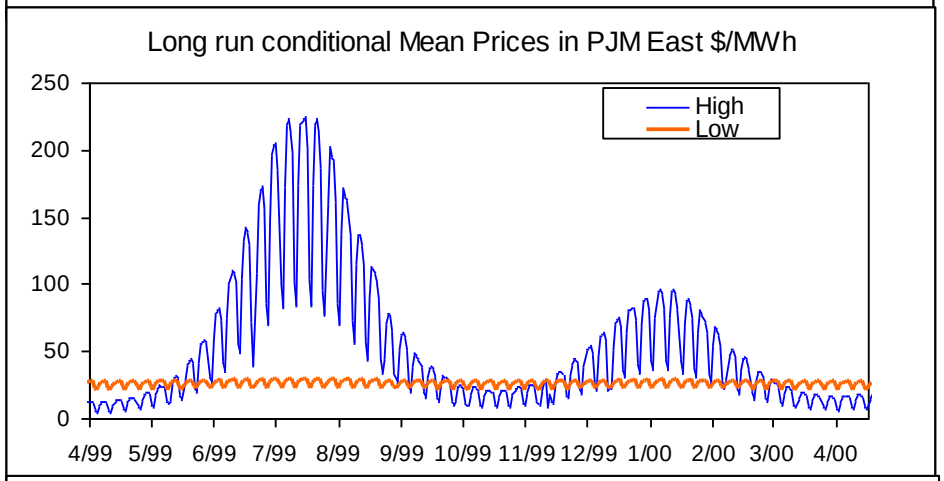


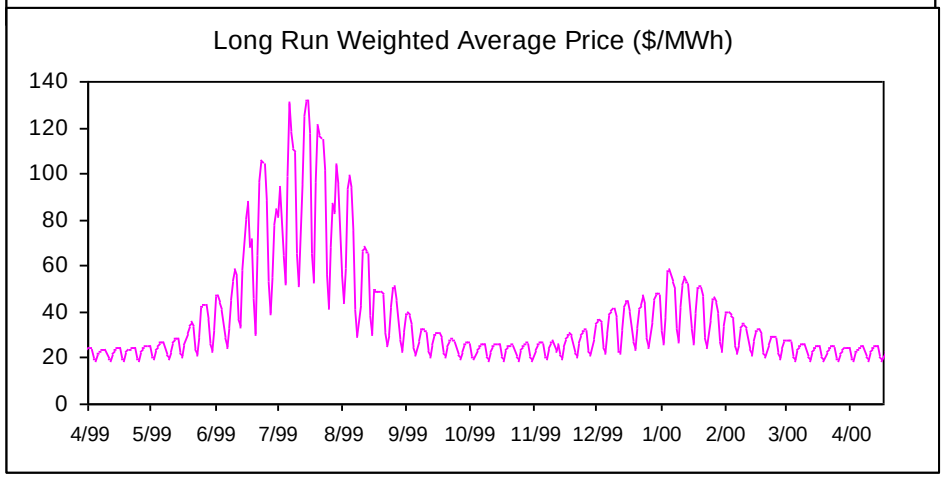




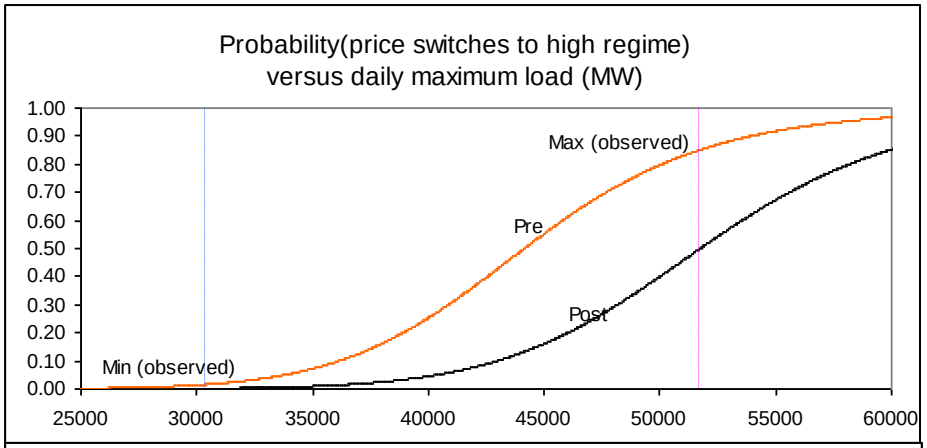
Estimated with Pre - 4/99 Data

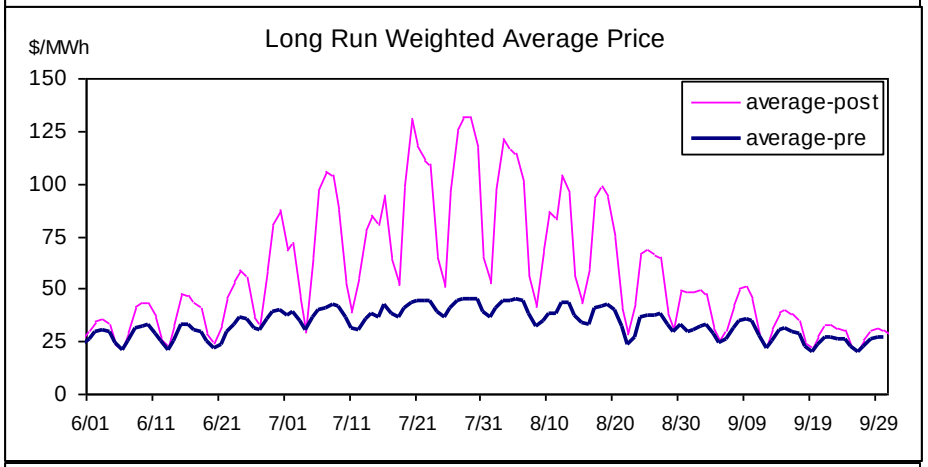


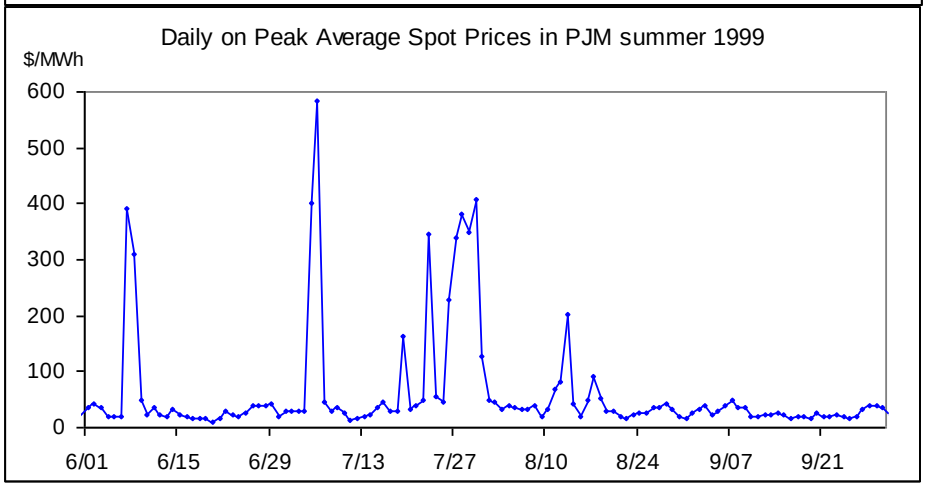




Estimated with Post - 4/99 Data

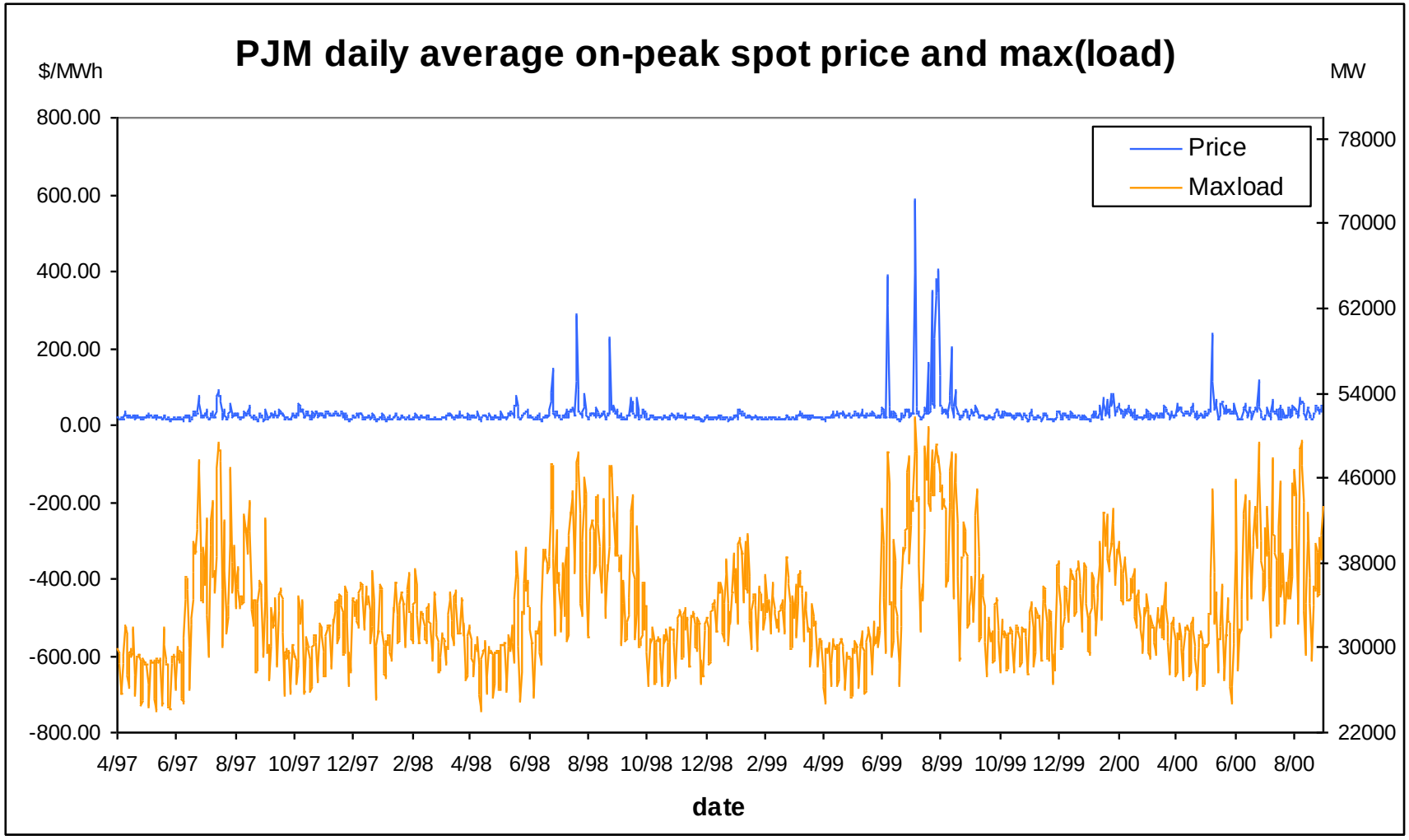

Probability(price switches to high regime)
versus daily maximum load (MW)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Max (observed)
Pre
Post
Min (observed)
25000
30000
35000
40000
45000
50000
55000
60000


Long Run Weighted Average Price
$/MWh
150
125
100
75
50
25
0
average-post
average-pre
6/01
6/11
6/21
7/01
7/11
7/21
7/31
8/10
8/20
8/30
9/09
9/19
9/29


Daily on Peak Average Spot Prices in PJM summer 1999
$/MWh
600
500
400
300
200
100
0
6/01
6/15
6/29
7/13
7/27
8/10
8/24
9/07
9/21

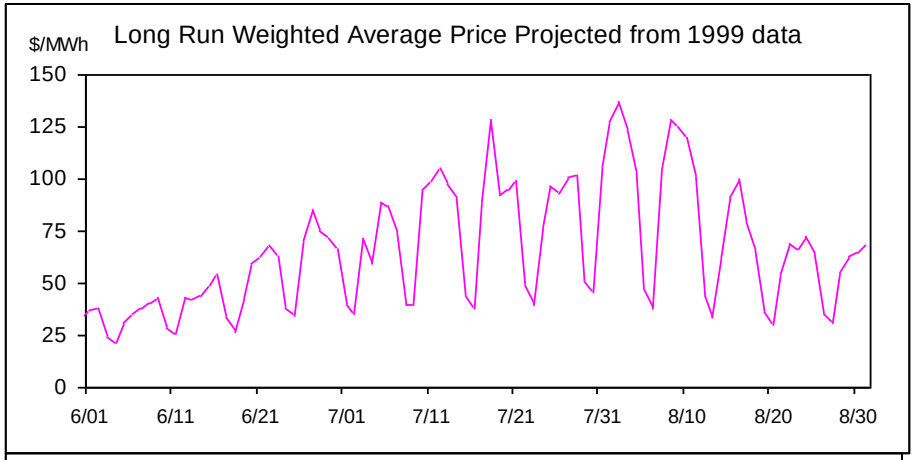
Conclusions about switching from cost-based to market-based offers in 1999

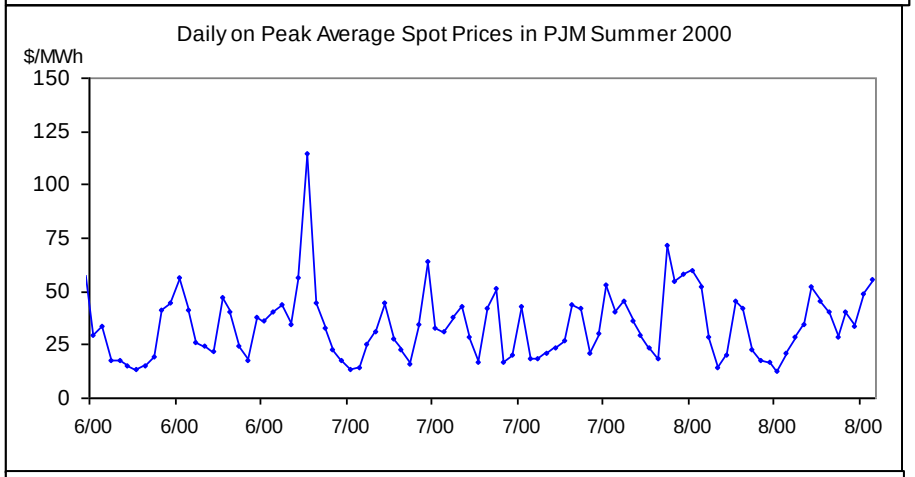
1) Probability of switching to the high-price regime is lower for a given load with market-based offers.
2) Average price in the high-price regime is much higher and more sensitive to load with market based offers.


PJM daily average on-peak spot price and max(load)
$/MWh
MW
800.00
600.00
400.00
200.00
0.00
-200.00
-400.00
-600.00
-800.00
78000
70000
62000
54000
46000
38000
30000
22000
Price
Maxload
4/97
6/97
8/97
10/97
12/97
2/98
4/98
6/98
8/98
10/98
12/98
2/99
4/99
6/99
8/99
10/99
12/99
2/00
4/00
6/00
8/00
date

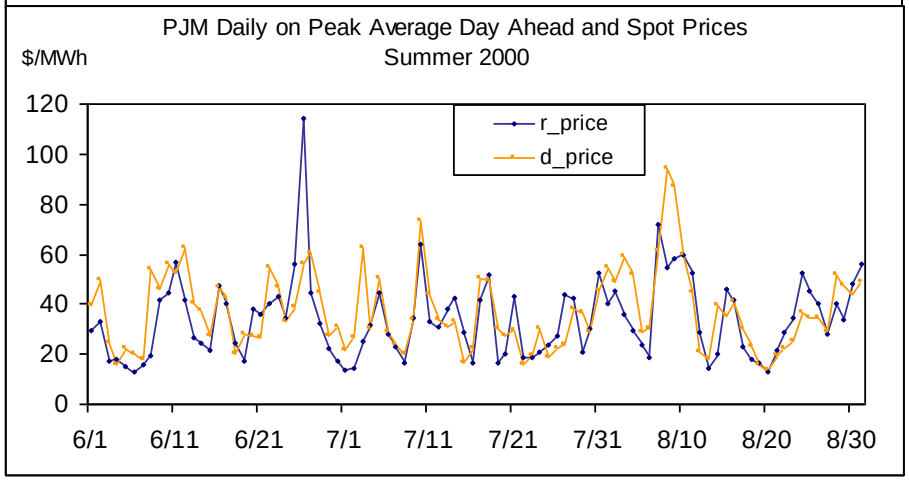
Estimated with data from 4/99 to 4/00

Predicted average price $66/MWh



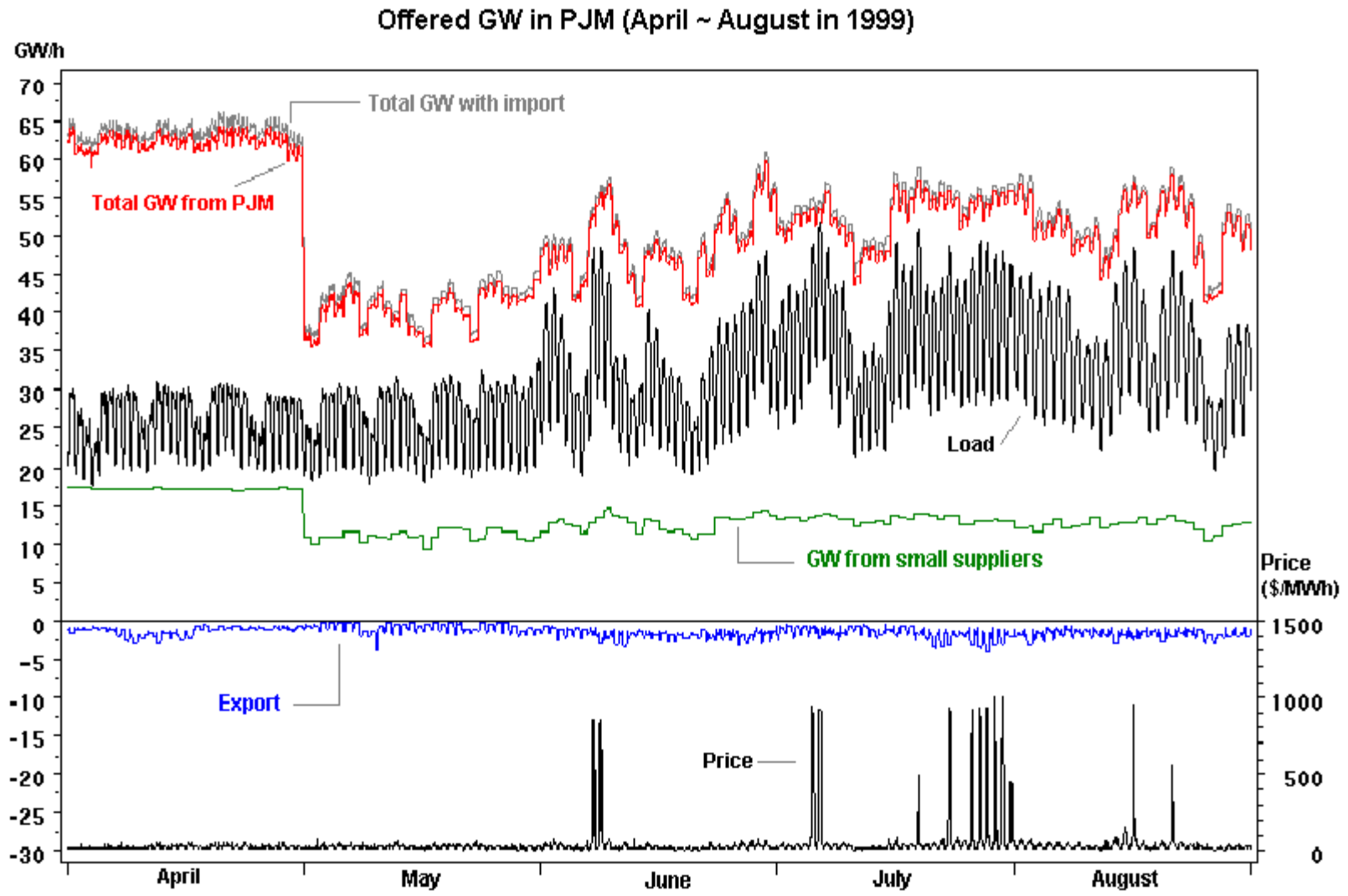


Observed average price $34/MWh

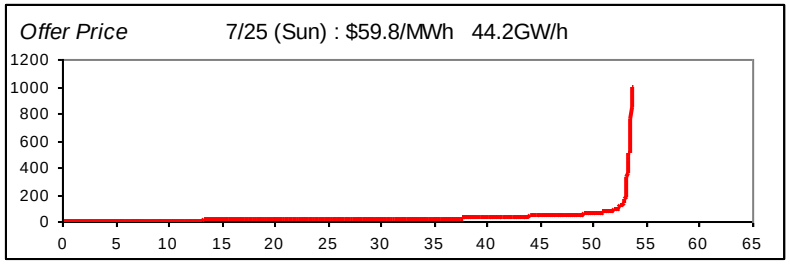


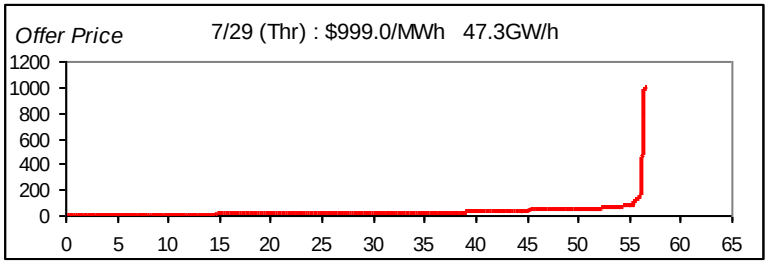
Conclusions about switching from hourly settlements to a two stage market

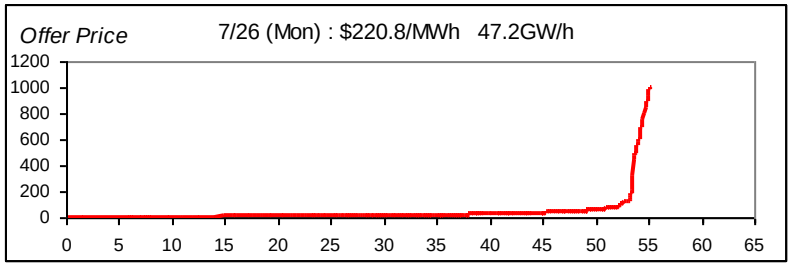
1) Prices predicted by the 1999 model for Summer 2000 are higher than the actual prices
2) Two-Stage markets may be effective in reducing susceptibility to price spikes.
3) Not enough data to estimate model for Summer 2000.

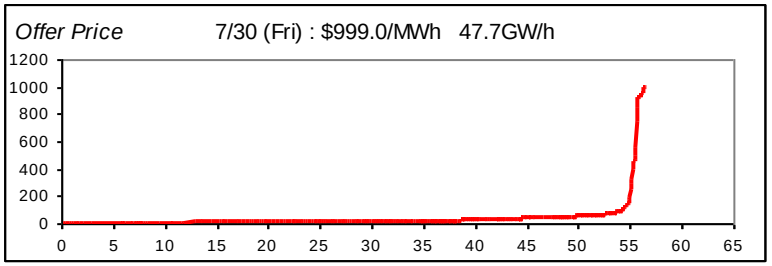

Offered GW in PJM (April ~ August in 1999)
GW/h
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
Total GW with import
Total GW from PJM
Load
GW from small suppliers
Export
Price
Price ($/MWh)
1500
1000
500
0
April
May
June
July
August

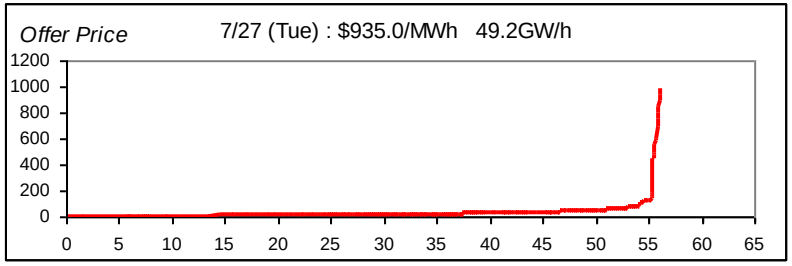
PJM Offer Curves at 5pm from 7/25/99(Sun) to 8/01/99 (Sun)

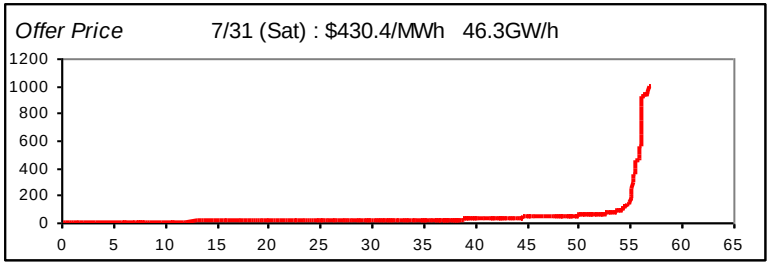


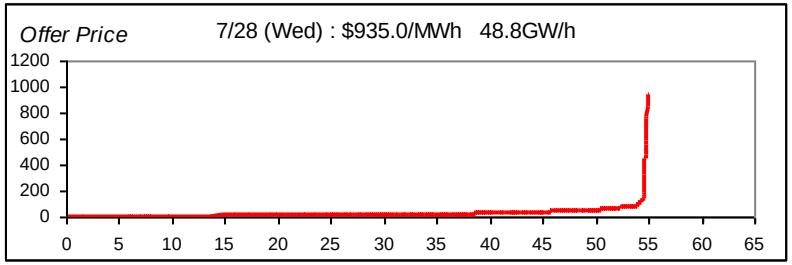


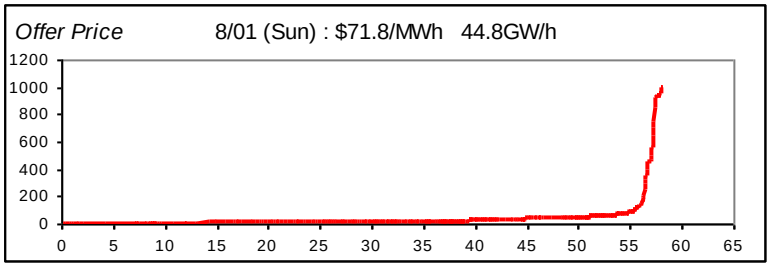




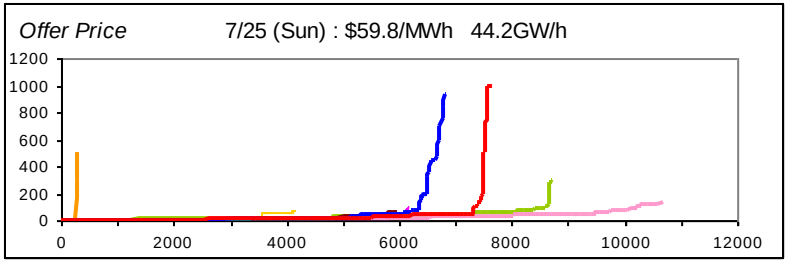


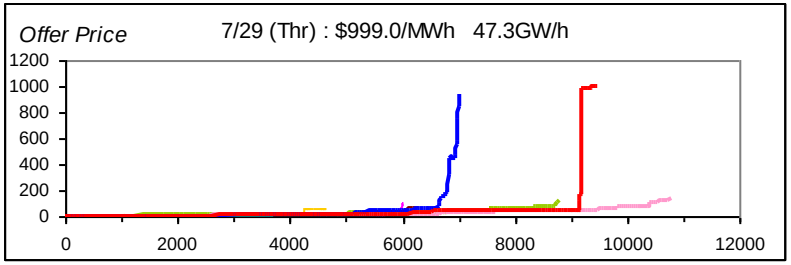


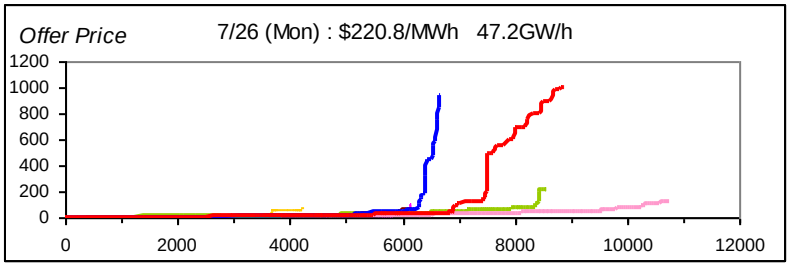


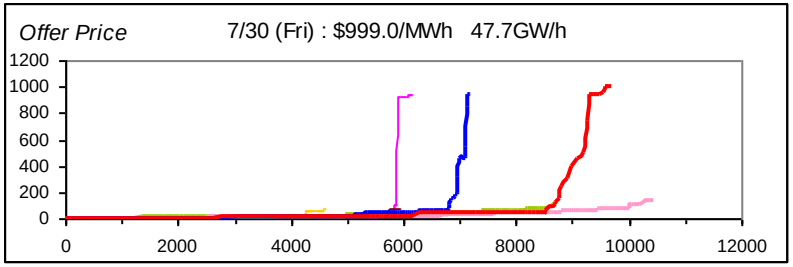


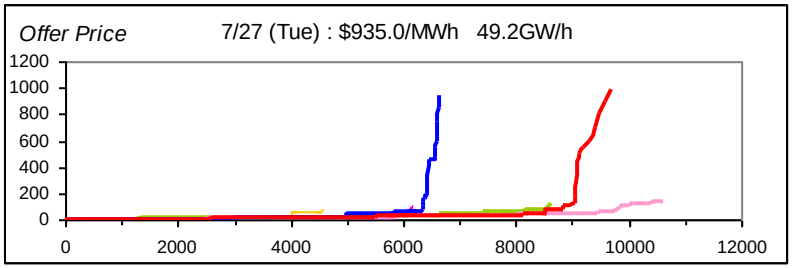
PJM Offer Curves at 5pm from 7/25/99(Sun) to 8/01/99(Sun)

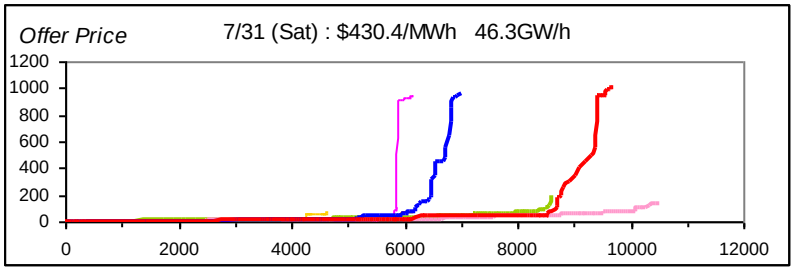


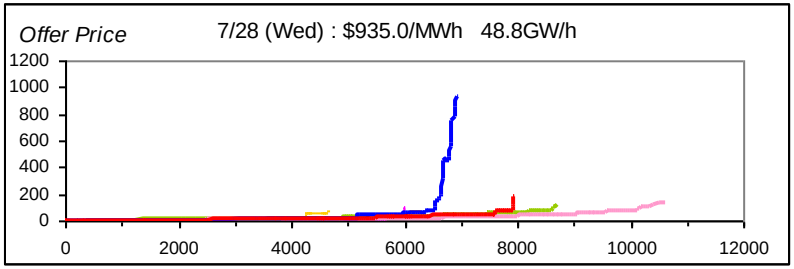


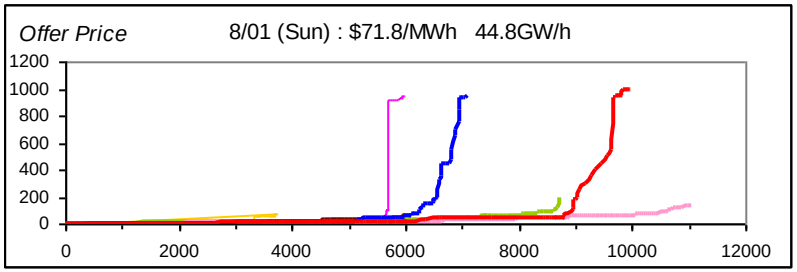




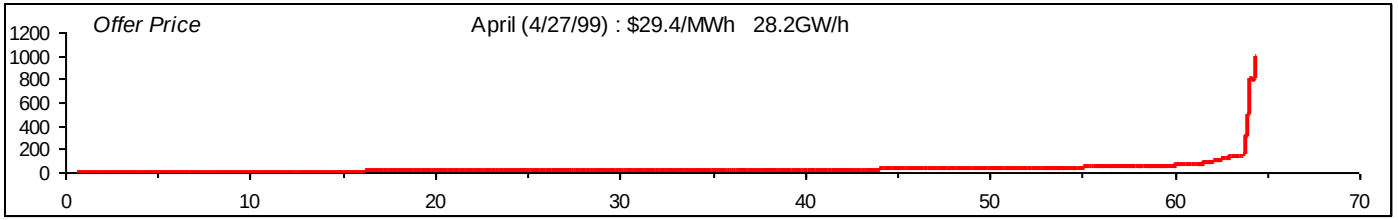


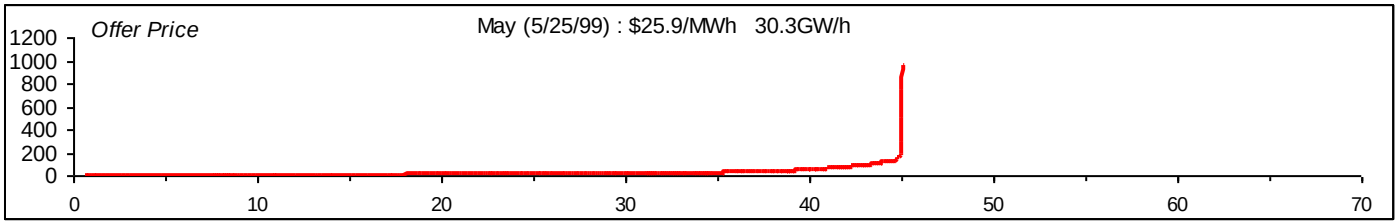


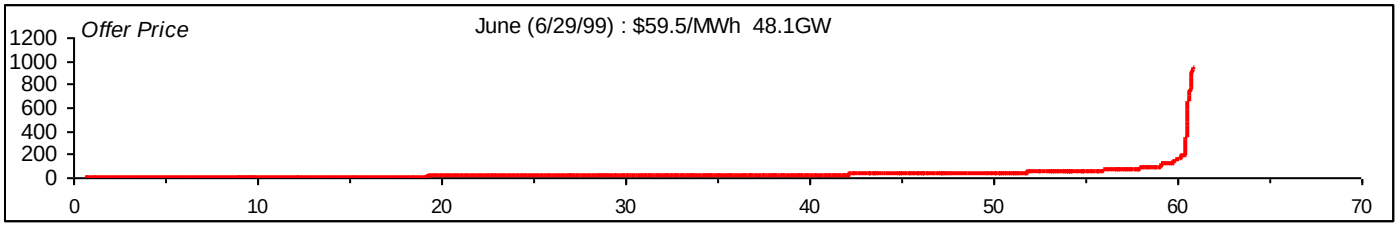


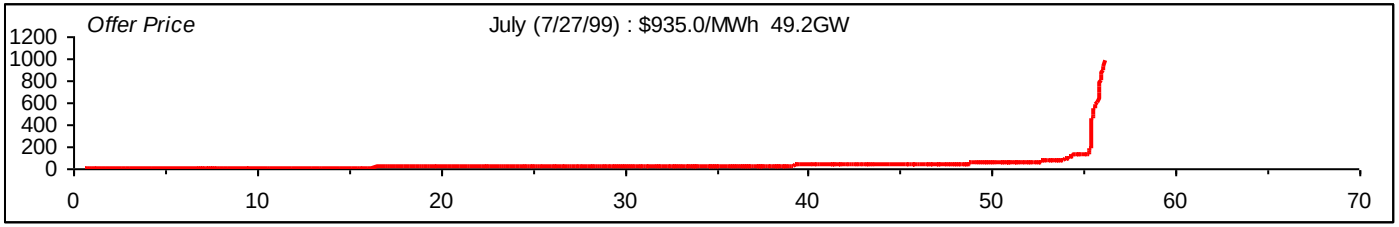


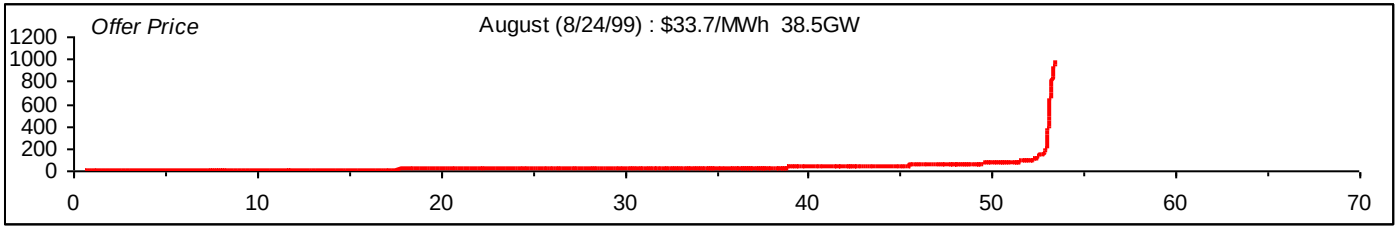
PJM Offer Curves at 5pm from April to August (last Tuesday)











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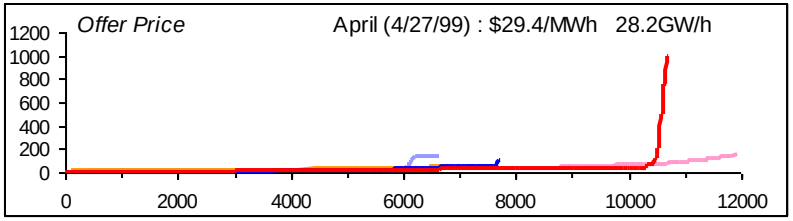
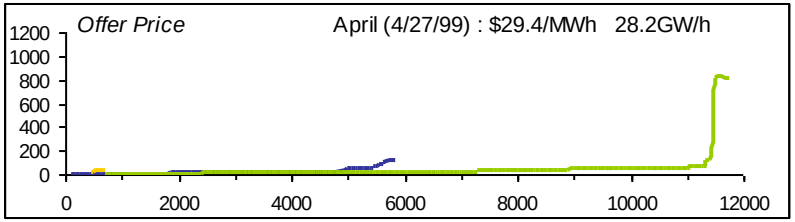
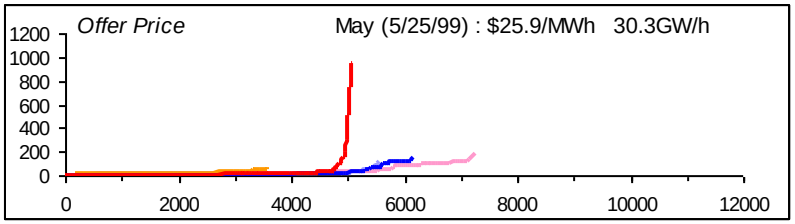
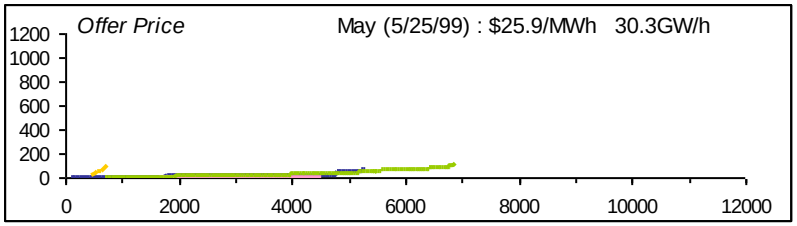
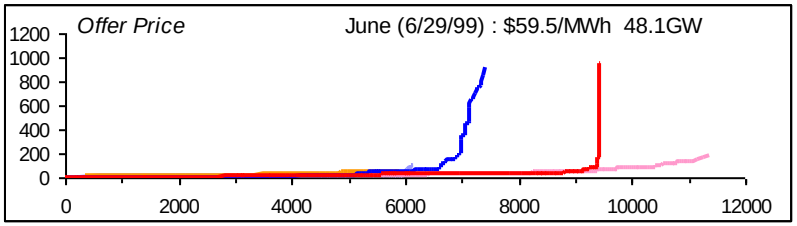
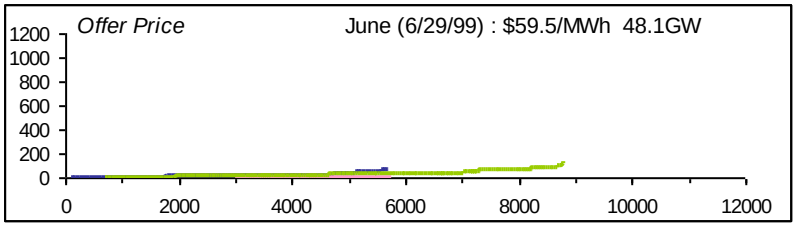


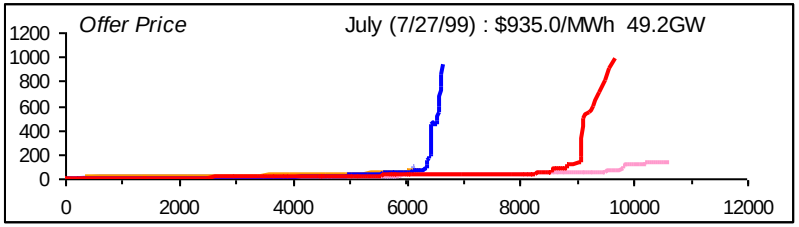


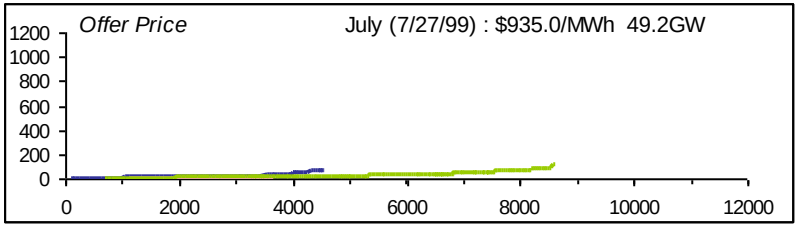


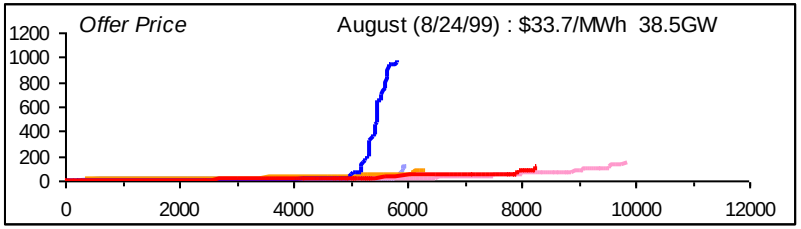


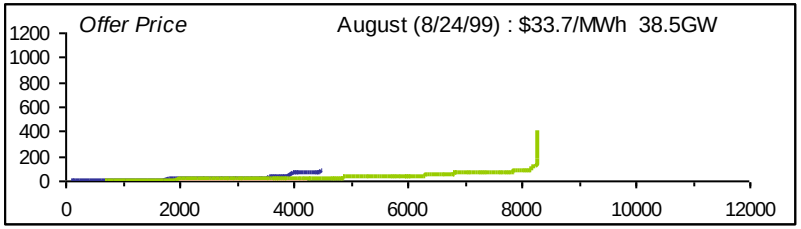




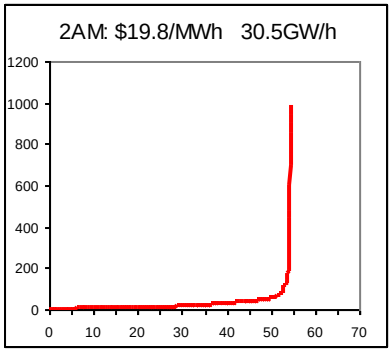


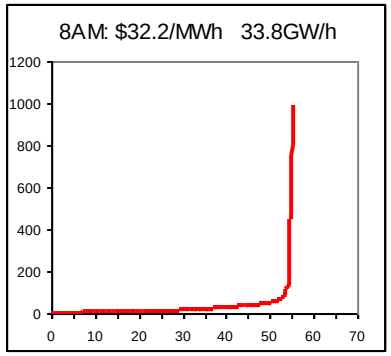


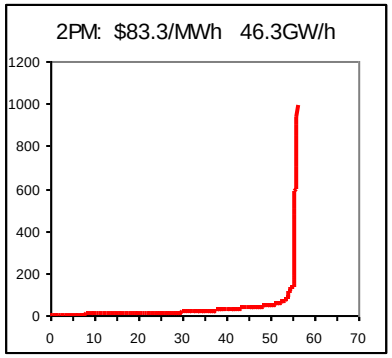


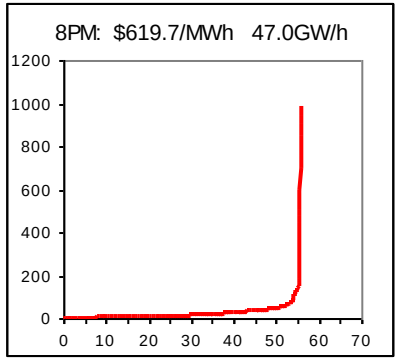


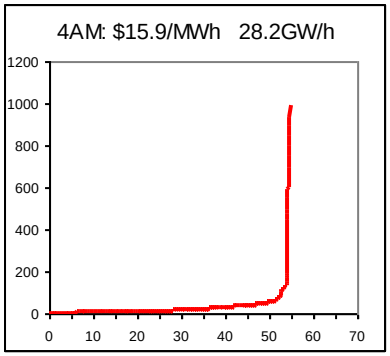
PJM Offer Curves on July 27, 1999 (Tue)

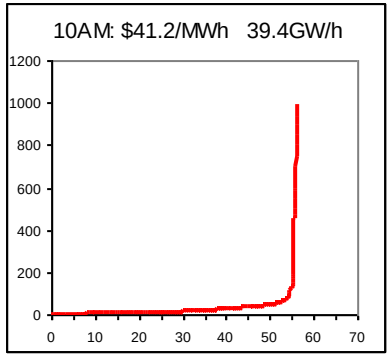


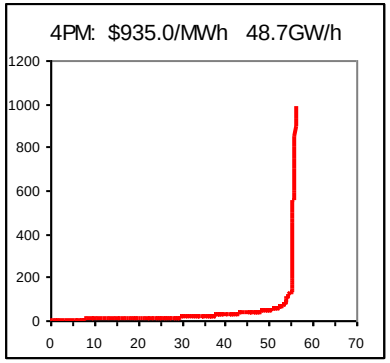


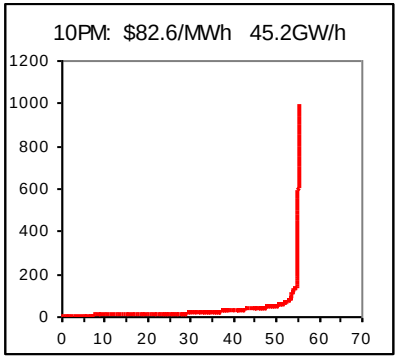


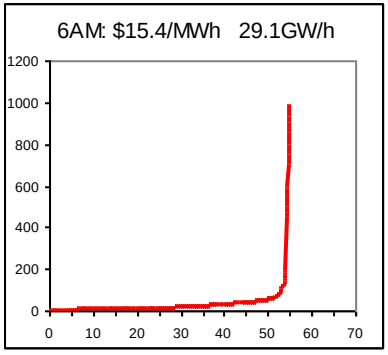


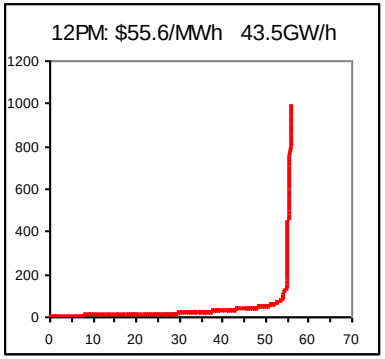


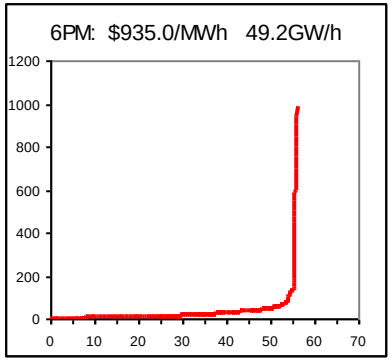


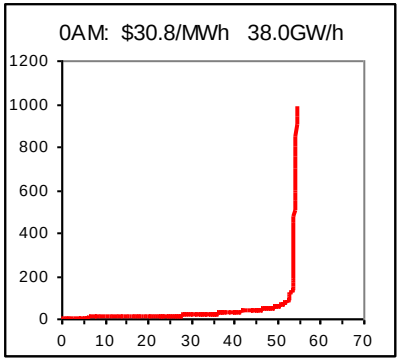




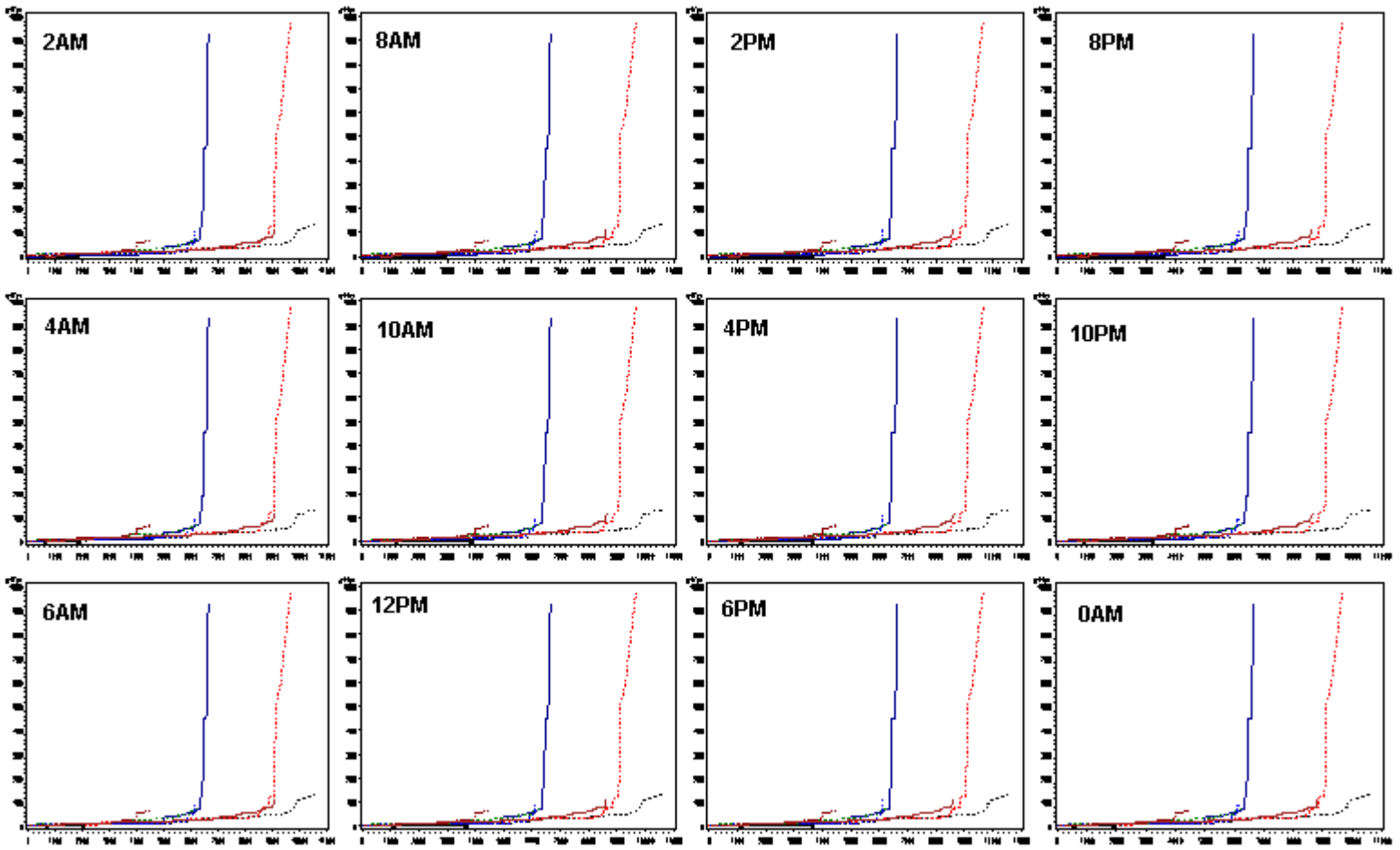








PJM Offer Curves on July 27, 1999 (Tue)

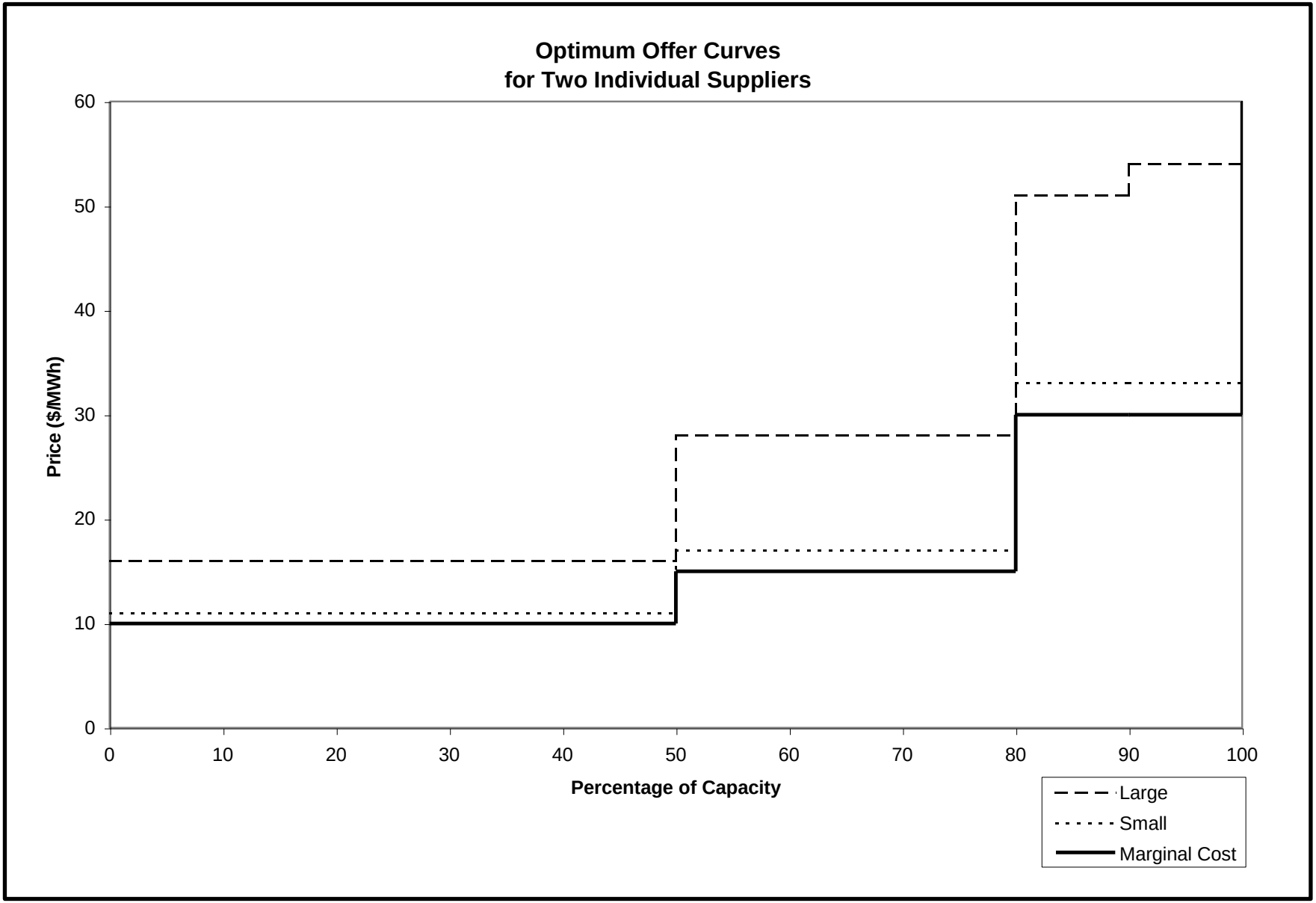


Conclusions about Offers

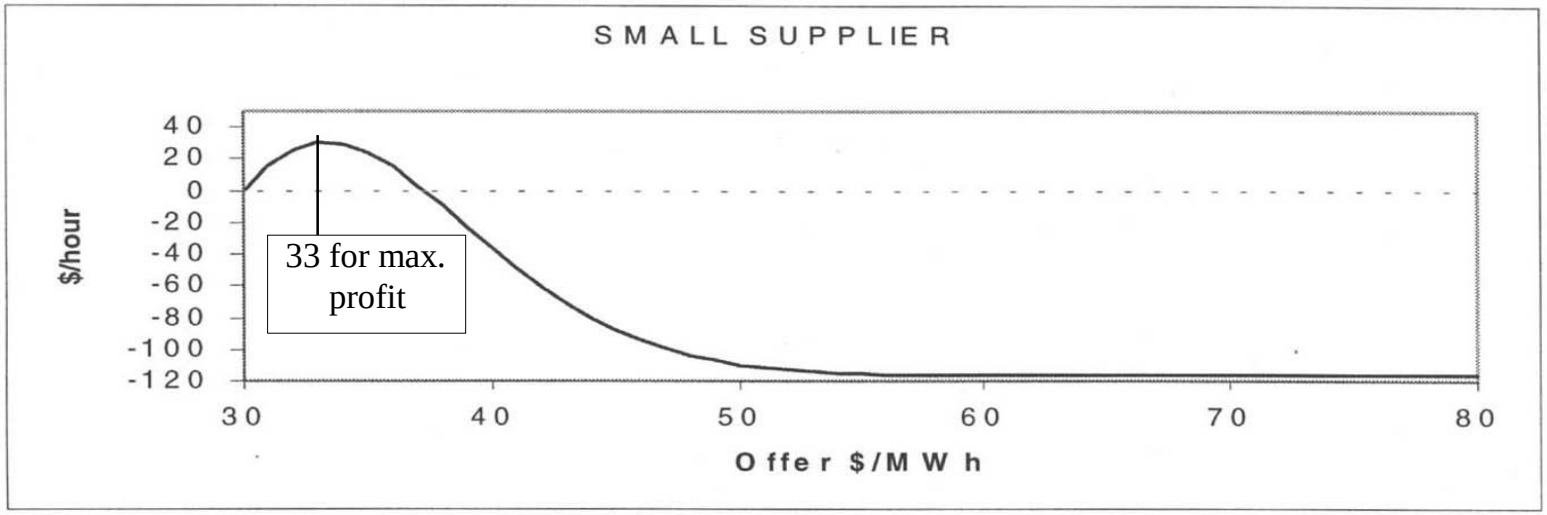
1) The kinked slope of the offer curves is consistent with the stochastic regime-switching model of price behavior.
2) Two or three big companies set prices in the high-price regime, and small companies do not speculate.
3) Withholding capacity is also an important issue.
4) The total offer curve is fairly stable from hour to hour and from day to day.
5) The total offer curve shifts from month to month, but the kinked shape does not change.
6) Price responsive load would be an effective way to limit price spikes.
7) (Total capacity offered/load) is potentially a better variable than load for explaining price behavior.

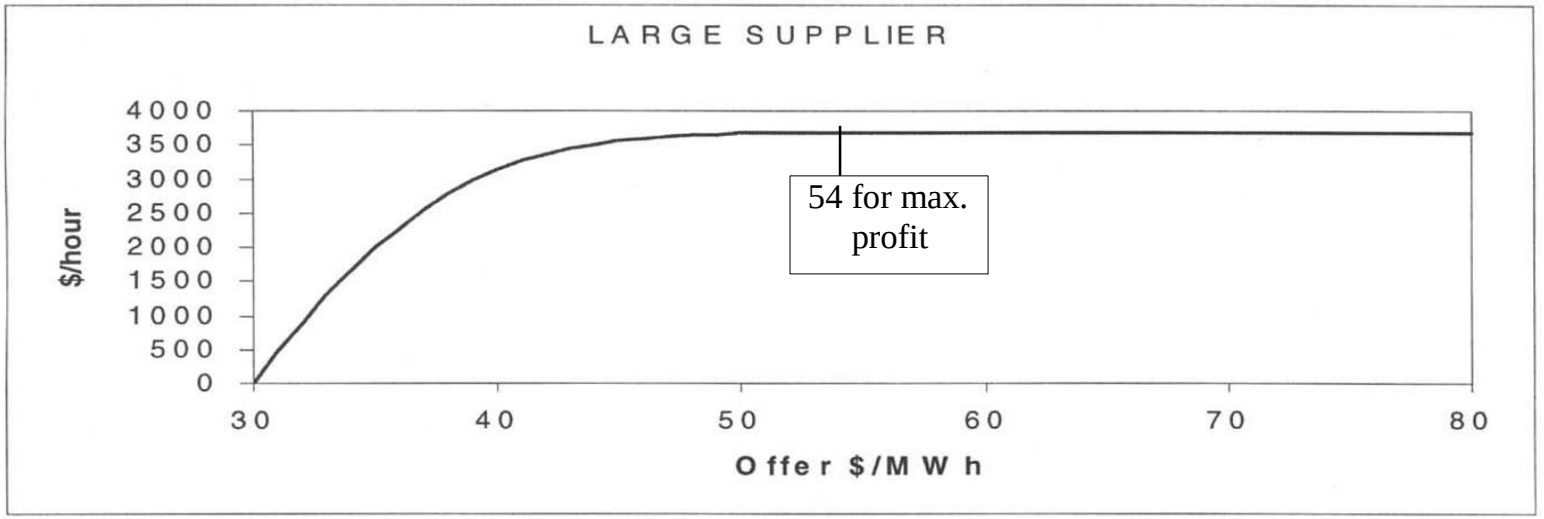
Optimum Offers for a Single Supplier When Other Suppliers are Competitive (submit cost-based offers).

- Load is stochastic
- Capacity from other suppliers is always sufficient to meet load
- Small supplier with 4% of capacity
- Large supplier with 20% capacity

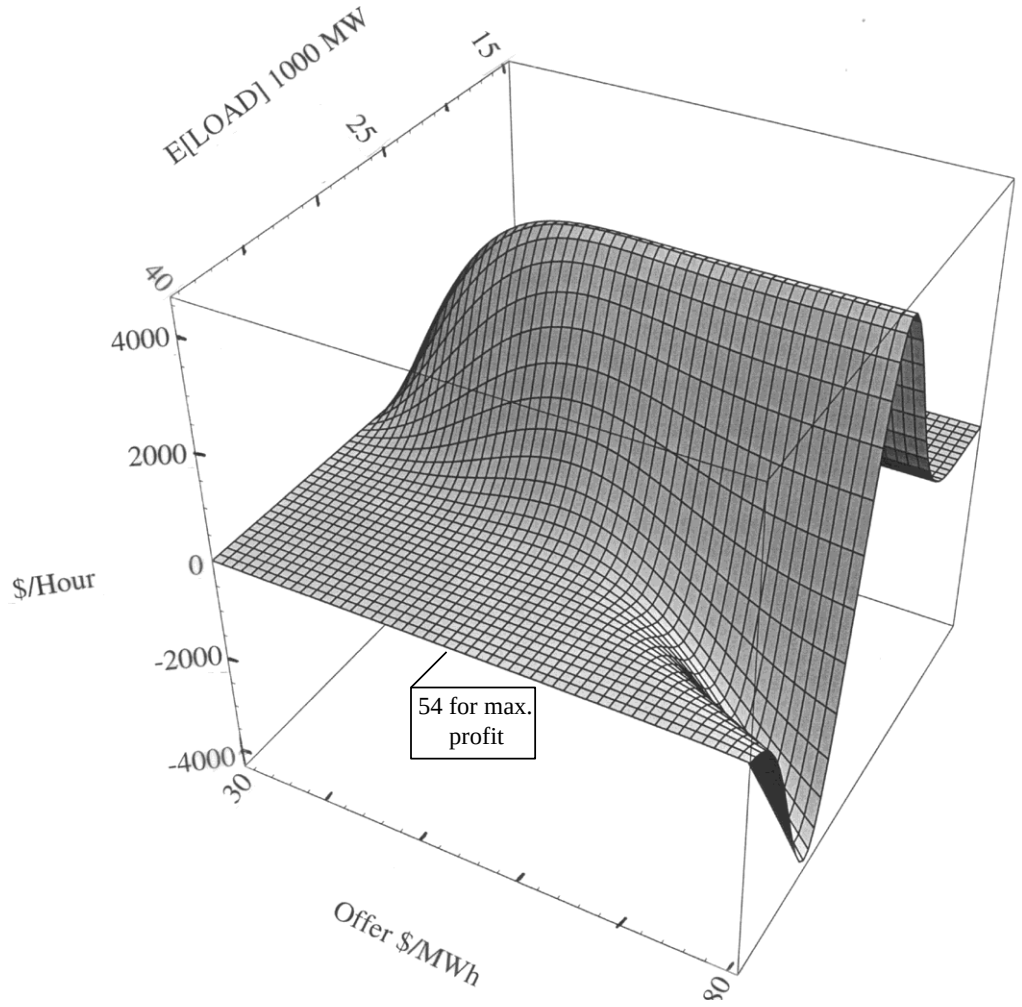

Optimum Offer Curves
for Two Individual Suppliers
Price ($/MWh)
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
Percentage of Capacity
Large
Small
Marginal Cost

Expected Excess Profit





Expected Excess Profit for a Large Supplier



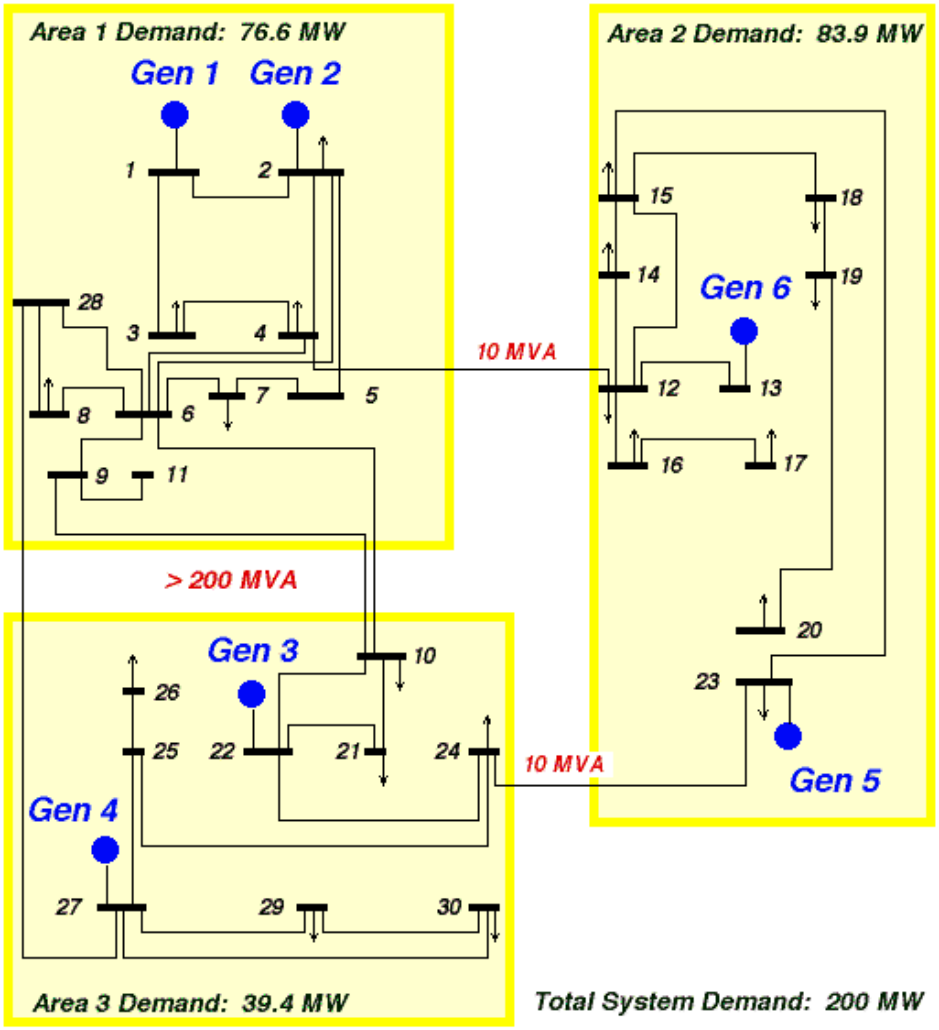
Conclusions about Optimum Offers

1) Not very sensitive to the expected load
2) Small suppliers are punished for being greedy
3) Highest optimum offer is relatively low compared to actual offers
4) Large suppliers are indifferent about having marginal units dispatched
5) Offers submitted by large supplier are sensitive to market rules

Why Use Experiments to Test Markets?

1. Market structures for electricity auctions are too complicated to derive analytical results.
2. Experiments are inexpensive compared to experimenting directly on the public.
3. The effects of specific market characteristics can be tested.
4. PowerWeb supports a full AC network so that the engineering complications of congestion and ancillary services as well as real power can be studied.
5. Paying players in experiments on the basis of performance duplicates market behavior effectively.

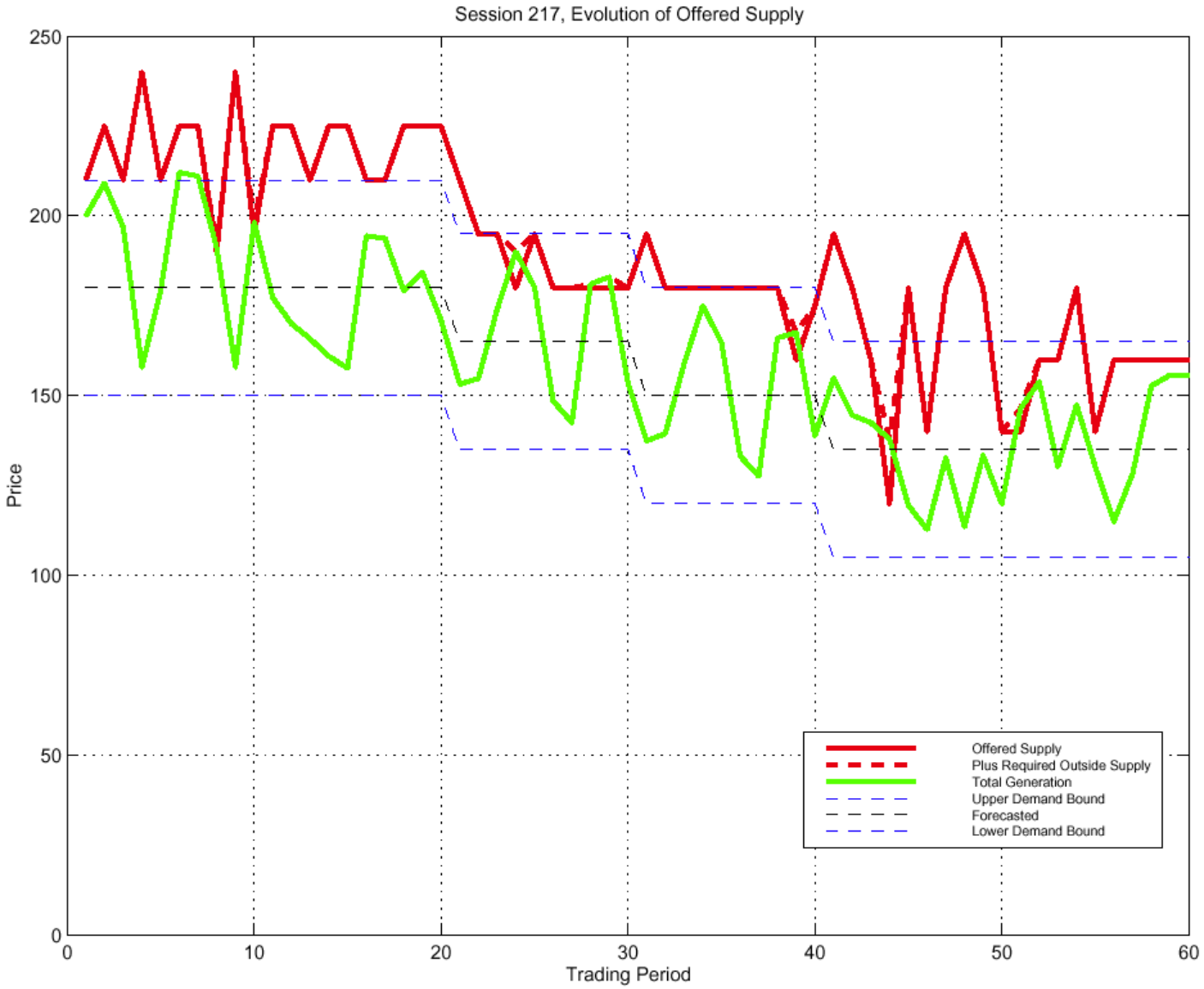
PowerWeb


Area 1 Demand: 76.6 MW
Gen 1
Gen 2
1
2
28
3
4
8
6
7
5
9
11
10 MVA
> 200 MVA
Area 2 Demand: 83.9 MW
15
18
14
Gen 6
19
12
13
16
17
20
23
Gen 5
10 MVA
Gen 3
10
26
25
22
21
24
Gen 4
27
29
30
Area 3 Demand: 39.4 MW
Total System Demand: 200 MW

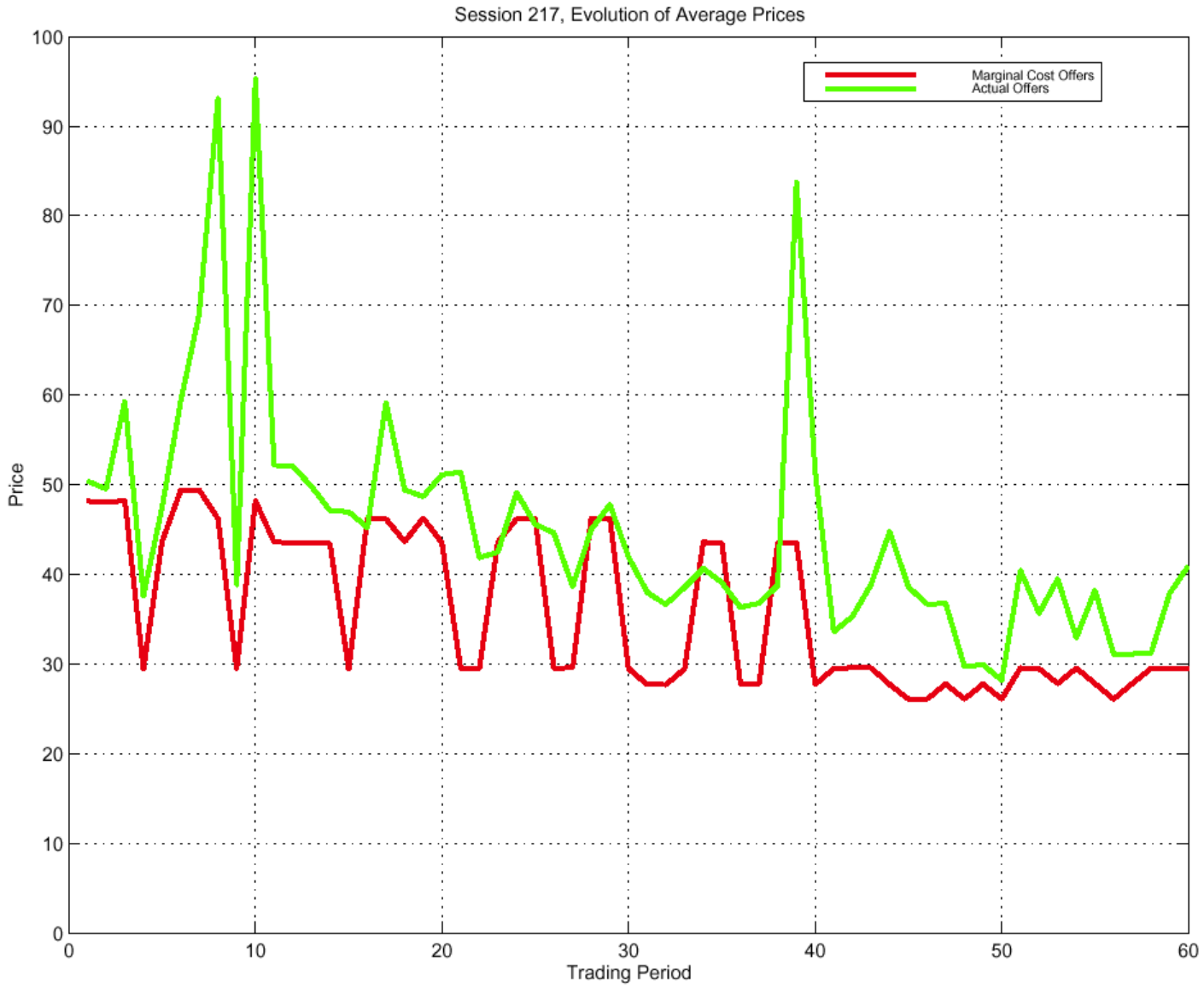
Completed Series of Experiments

1. Does the choice of auction rule affect economic efficiency? Not as much as the number of competitors.
2. Can players exploit market power in load pockets? Yes.
3. Is self-commitment as economically efficient as optimal unit commitment? Yes.
4. Is it easy to generate price spikes in an auction?
   No, unless: a) Load is stochastic
   b) Standby costs are charged

Withholding Capacity



Price Spikes



Current Experiments on Price Spikes

1. Sensitivity to market rules about capacity shortfalls
   a) Price set to maximum allowed price
   b) Price set to highest offer
   c) Price set to highest offer and idle capacity is recalled with a cost penalty

2. Effectiveness of alternative market structures
   a) Price responsive load
   b) Forecasting price before the final settlement
   c) Day-ahead market plus a balancing market
   d) Use a discriminatory auction (pay actual offer) instead of a uniform price auction.

Summary

Predicting Price Spikes

- Stochastic regime switching models describe price behavior well for financial analyses
- Predicting the probability of switching to a high-price regime as a function of load (or a similar variable) gives an effective quantitative measure for anticipating price spikes.

Summary (Continued)

Replicating Price Spikes

- Stochastic load and standby costs are necessary for getting players to produce price spikes in auction experiments.
- Current experiments are focusing on:
  a) market rules for capacity shortfalls
  b) market characteristics
     - price-responsive load
     - forecasting price
     - two-stage market
     - discriminatory auction

Summary (Continued)

Avoiding Price Spikes

- There is no silver bullet
- Price spikes are not always bad
- Need research on Temporally Integrated Markets (TIM) for energy and reserves. Reserves should be used for both economic and engineering contingencies.
- Need a new type of participant in a balanced market. A DERALCo (Distributed Energy Resources and Active Load Company) should determine the net demand/supply of energy and ancillary services for a load center.