# *The Effect of Customer Participation in Electricity Markets: An Experimental Analysis of Alternative Market Structures*

*(Reliability and Markets)*

*by*

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**in Consultation with LBNL**

## DOE/CERTS Peer Review

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# *Why Demand Responsiveness? (Program Objectives)*

1. Get Customers into the Game
2. Mitigate Supplier Market Power
3. Efficient Use of Resources
4. It’s Fair
5. System Reliability

# *Questions:*

1. Why Has Utility Promotion been so Tepid?
2. Why Haven't Marketers Jumped In?

-------------------------------------------------------

3. What Type of Demand-Side Market Structure
   a. Is Most Efficient?
   b. Is Understood and Effectively
      Used by Customers?
   c. Might be Selected by Customers,
      Given a Choice?

# *Why Laboratory Experiments?*

1. To Avoid Social Cost of
   Experiments of the Whole (e.g. California)
2. Low Cost Alternative for Winnowing
   Out Alternatives
3. Reveals Human Cognitive Processes (Learning & Lags)
4. Value as Educational Tool

**But To Be Effective,**

**_ _ _ Participants Must be Paid!**

# *Key Stakeholders*

1. Customers (connected through LBNL surveys)
2. Regulators
   a. FERC
   b. State Agencies (NY PSC involved in earlier experiments)
3. NY ISO (intimately involved and participants in experiments)
4. Suppliers (contacts through NY ISO)

# *Demand-Side Experiments: Work to Date*

- Rassanti, Smith & Wilson (July, 2001)

  _ _ _Show How Active Demand Will

  Discipline Suppliers in Two-Sided Market

- Cornell Team, Demand-Side Only, Demonstration (Dec. 2002 and April 2003)

  _ _ _ Construct Active Demand with:

  1. Day/Night Substitution Possibilities.
  2. Testable Response to a Variety of Market Structures and Policy Initiatives.

- Cornell Team, Two-Sided Markets ( Sept. and Nov. 2003)

  1. Efficiency and Price Spikes
  2. User-Preferences

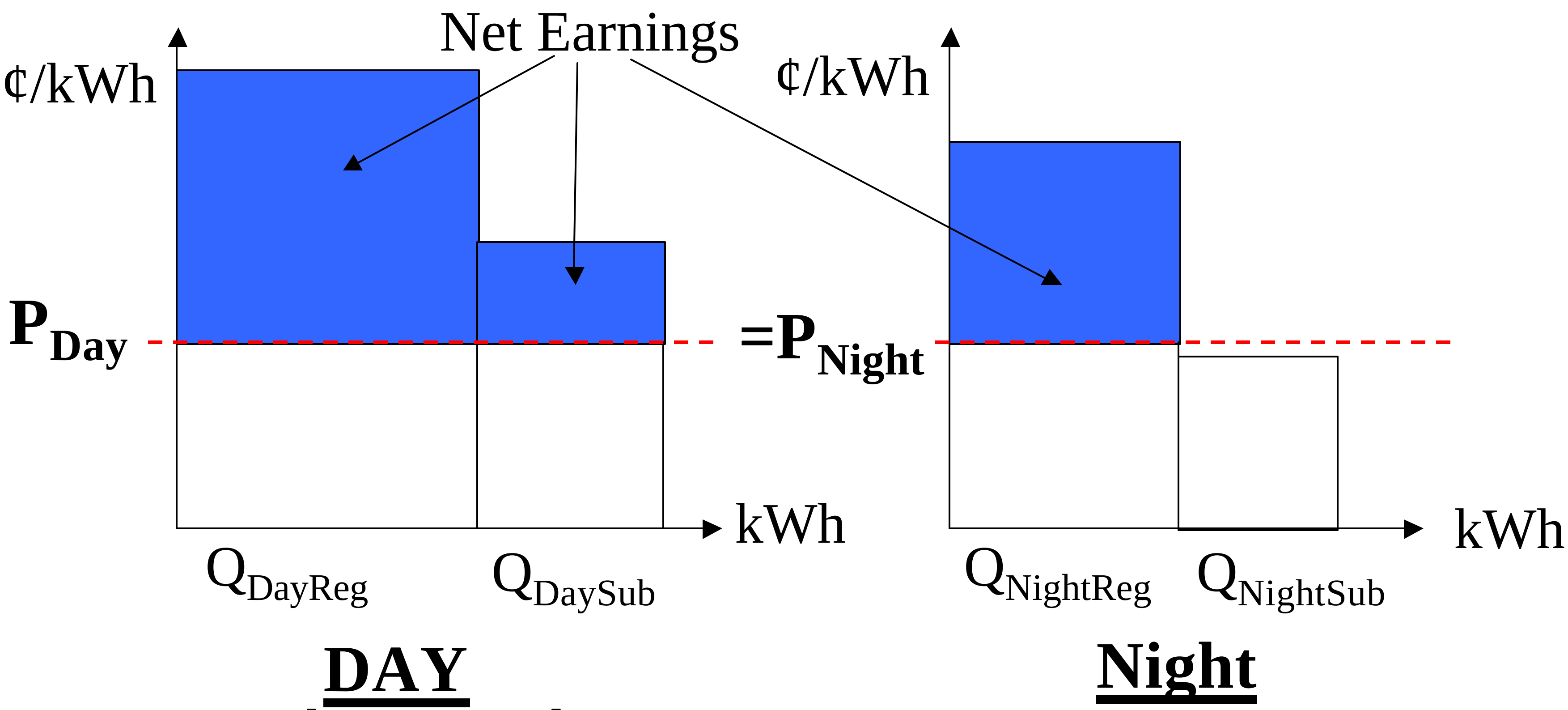
# *Demand-Side Behavioral Representation*

1. **Start with Final Demand:** We Need to Understand Behavior of End-Use Customer Before We Represent Marketing Agents
2. Disaggregate Observed Market Demand Characteristics to Representative Individual Buyers
3. Develop "Induced Valuation" Relationships for Individuals
4. Customer's Problem:

   Select Electricity Consumption in Each Period to Maximize Total Value – Total Expenditures
5. Compensate Players in Proportion to Net Benefits

   (as computed in 4).

# *Illustration of Buyer's Problem*
## *(with Constant Price)*




In this Example: $Q_{Day} = Q_{DayReg} + Q_{DaySub}$

$Q_{Night} = Q_{NightReg} + 0$

$Q_{DaySub} + Q_{NightSub} \leq Q_{SubMAX}$

# Buyer's Computer Screen

POWER WEB

**Name:** [test] Test User Logout
**Session:** [ 2 ] Example Session
**Representing:** [ 34 ] Buyer 1

Period
**FP-1**

| **SYSTEM DATA** | Day | Night |
|---|---|---|
| Market Condition | Normal | Normal |
| Fixed Price (¢/kWh) | 8.5¢ | 8.5¢ |

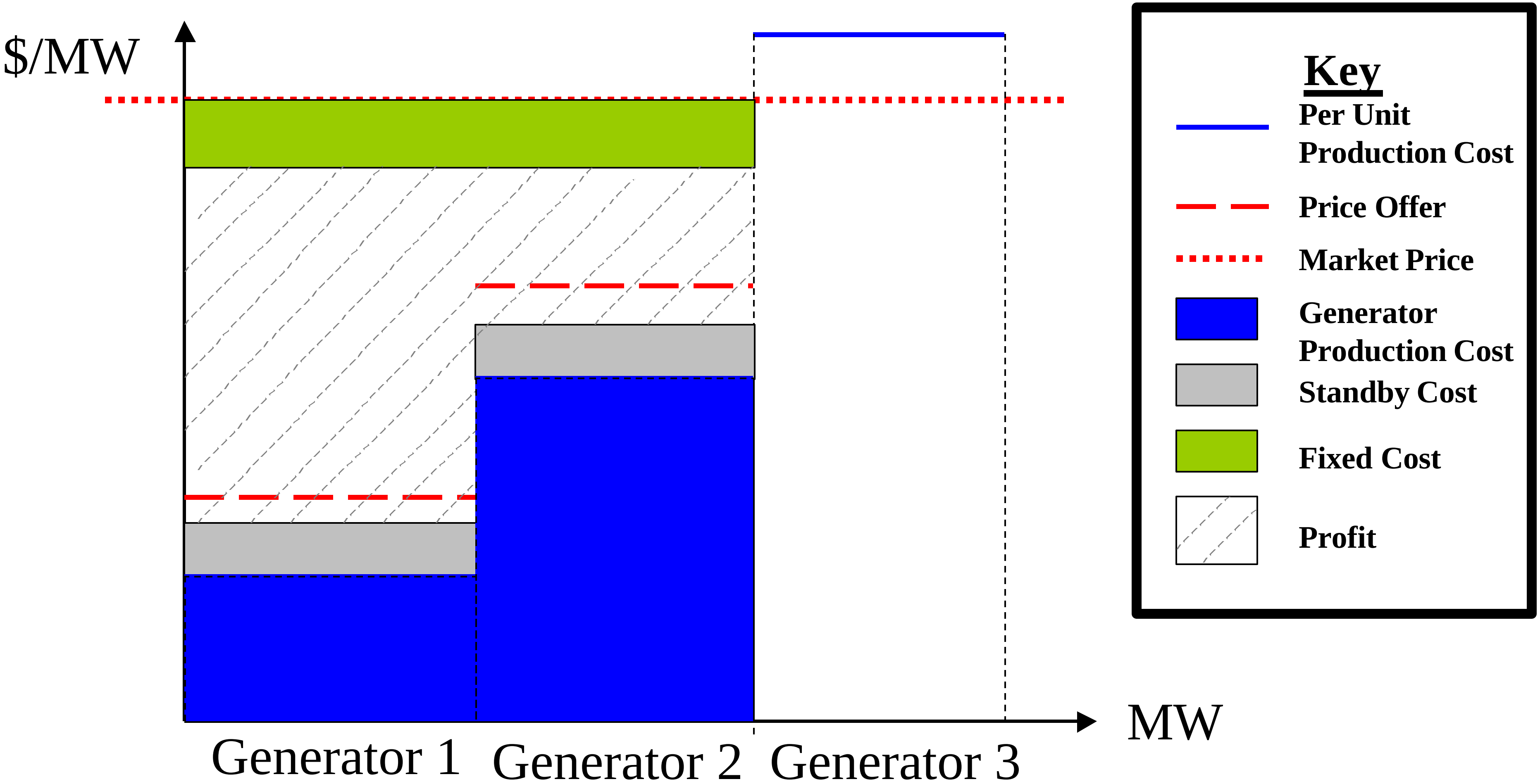
| **BUYER DATA** | Day | Night |
|---|---|---|
| Regular Energy Value (¢/kWh) | 15.0¢ | 13.0¢ |
| Regular Max Energy Quantity (kWh) | 7000 | 5000 |
| Substitutable Energy Value (¢/kWh) | 11.0¢ | 7.0¢ |
| Substitutable Max Quantity (kWh) | 2000 | |

| **MY BIDS** | Day | Night |
|---|---|---|
| Energy Quantity Bid (kWh) | 9000 | 5000 |
| | Submit | |
| Regular (kWh) | 7000 | 5000 |
| Substitutable (kWh) | 2000 | 0 |

| **EARNINGS** | Day | Night |
|---|---|---|
| Benefits from Energy Consumption | $ 1270 | $ 650 |
| Cost of Energy Purchased | $ 765 | $ 425 |
| Energy Earnings | $ 505 | $ 225 |

Gray background indicates computed values.

# *Illustration of Seller's Problem*



# Seller's Computer Screen

POWER WEB

**Name:** [test] Test User Logout
**Session:** [ 2 ] Example Session1
**Representing:** [ 29 ] Seller 3

Period
**FP-1**

| **SYSTEM DATA** | Day | Night |
|---|---|---|
| Market Condition | Normal | Normal |
| Forecast Load (MW) | 196.0 | 118.0 |

| **GENERATOR DATA** | Day | | | Night | | |
|---|---|---|---|---|---|---|
| | Gen 7 | Gen 8 | Gen 9 | Gen 7 | Gen 8 | Gen 9 |
| Max Capacity (MW) | 20.0 | 15.0 | 20.0 | 20.0 | 15.0 | 20.0 |
| Per-Unit Production Cost ($/MW) | $22.00 | $50.00 | $61.00 | $22.00 | $50.00 | $61.00 |
| Standby Cost ($/MW) | $5.00 | $5.00 | $5.00 | $5.00 | $5.00 | $5.00 |
| Fixed Cost ($) | $20.00 | $20.00 | $20.00 | $20.00 | $20.00 | $20.00 |

| **MY OFFERS** | Day | | | Night | | |
|---|---|---|---|---|---|---|
| | Gen 7 | Gen 8 | Gen 9 | Gen 7 | Gen 8 | Gen 9 |
| Capacity Offer (MW) | 20 | 15 | | 20 | 15 | |
| Price Offer ($/MW) | 22 | 100 | | 22 | 100 | |

Note: Initial offers are set at your previous offer levels.

Submit

# *Conceptual Framework for Efficient Market Structures*

1. Reliability provided through networks has public good aspects: Market Cannot Solve Completely!
2. Efficient Customer Response Requires Both:
   - ➢Real Time Pricing of Energy (**RTP**)
   - ➢Demand Reduction Program (**DRP**) to represent offset need for generation reserves
3. Work on Incorporating Voltage Support

# *Initial Demand-Side Scenarios*

**Baseline:** Pre-announced, Identical Price in All Periods (**FP**)– Quantity Bids

**Case A:** Baseline with Demand Response Program (**DRP**) – Quantity Bids with Preset Savings for Quantity Below Benchmark

**Case B:** Real Time Pricing (**RTP**/Quantity Bids) with Forecast Day/Nite Price-Pair;

Quantity Bids: Customers Pay Actual Clearing Price

**Case C:** Real Time Pricing (**RTP**/Quantity Bids, Price Limit)

Quantity Bids with Limit Price: Customers Pay Actual Clearing Price

**Note: No Price Controls or Market Power Mitigation**

**Early Result:** Eliminate Case C since buyers performed better in trials with simpler Case B, RTP.

# *Experimental Design for Three Treatments over 11 Day/Nite Pairs*

Participants: 7 Suppliers (6 Experienced Grad. Students + 1 Agent)
19 Customers (Undergrad. and Grad.Students and Agents)

Treatments: **FP** (Baseline); **DRP** (Specified/kWh credit);
**RTP** (Forecast Prices, Q-Bids, Pay Mkt. Price)

Characteristics of Day/Nite Pairs:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|
| N | S | H | N | N | N | H+S | H+S | N | S | H |

N=Normal; H=Heat Wave; S=Random Supply Shortage

Preference Poll, "What Do You Prefer: DRP or RTP?":

After FP
After DRP
After RTP ➔ Determines Selection of Additional "High Stakes" Runs

# *Details on Market Sequence*

1. Load Forecasts (ISO) for Day/Nite Pair
2. Quantity-Price Offers (Suppliers)
3. Prices (ISO) for Day/Nite Pair
    a. FP: Firm 8.5 ¢/kWh
    b. DRP: Firm 8.5 ¢/kWh + whether a 7.9 ¢/kWh DRP Credit Applies
    c. RTP: Day/Nite Forecast
4. Purchases (Buyers) for Day/Nite Pair
5. Market Clears (ISO) at Last Accepted Offer or External Purchase, if Required.

# *Details on Market Sequence (cont.)*

6. Settlement (ISO)
   a. Buyers Pay:
      **1. FP**: 8.5 ¢/kWh
      **2. DRP**: 8.5 ¢/kWh - DRP credit if applies
      **3. RTP**: Market Clearing Prices for Step 5.
   b. Sellers Receive:
      Market Clearing Prices in All Cases
7. Required Rate Change (ISO) after 11 Day/Nite Pairs *for FP and DRP*

# Two Sets of Experimental Results

1. Which Market Structure is **Most Efficient**?

| | Active Demand/Preset Cost-Based Supply with Random Shift | Full Two-Sided Market |
|---|---|---|
| RTP | 99.6% | 98.8% |
| DRP | 96.9% | 98.0% |
| FP | 98.7% | 98.5% |

2. What **Rate Change** is Required After Runs to Balance the Budget?

| | Active Demand/Preset Cost-Based Supply with Random Shift | Full Two-Sided Market |
|---|---|---|
| RTP | | -- |
| DRP | **N/A** | 2.1 ¢/kWh increase |
| FP | | 1.5 ¢/kWh increase |

# *Experimental Results (cont.)*

3. Which Structure Maximizes **Consumer Value**?

| | **Active Demand/Preset Cost-Based Supply with Random Shift** | **Full Two-Sided Market** Without Rate Increase | With Rate Increase |
|---|---|---|---|
| RTP | 101.8% | 96.9% | 96.9% |
| DRP | 97.2% | 100.9% | 97.2% |
| FP | 95.7% | 99.3% | 96.0% |

4. Which Structure Do Participants **Say They Prefer?**

Before Trying DRP and RTP:

**67% Prefer DRP** **74% Prefer DRP**

After Trying DRP and RTP (Basis for Selecting Treatment in "High Stakes" Round):

**76% Prefer RTP** **74% Prefer RTP**

Note: Participants Told Rate Change would be Implemented in High Stakes Rounds for Two-Sided Market Experiment

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# Statistical Test
# (Based on Individual Consumer Quantities)

❖ Quantity Differences Relative to Socially Optimal Quantities

*Active Demand/Preset Cost-Based Supply with Random Shift*

| | | | |
|---|---|---|---|
| FP: | Significant Difference | @ 95% | 13 out of 22 periods (2+/11-) |
| DRP: | | @ 95% | 15 out of 22 periods (15-) |
| RTP: | | @ 95% | 1 out of 22 periods (1-) |

*Two-Sided Market*

| | | | |
|---|---|---|---|
| FP: | Significant Difference | @ 95% | 0 out of 22 periods |
| DRP: | | @ 95% | 12 out of 22 periods (12-) |
| RTP: | | @ 95% | 1 out of 22 periods (1-) |

Note: + Indicates Quantity > Optimal; - Indicates Quantity < Optimal

# Statistical Test (cont.) (Based on Individual Consumer Surplus)

❖ Surplus Differences Relative to Socially Optimal Surplus Levels

*Active Demand/Preset Cost-Based Supply with Random Shift*

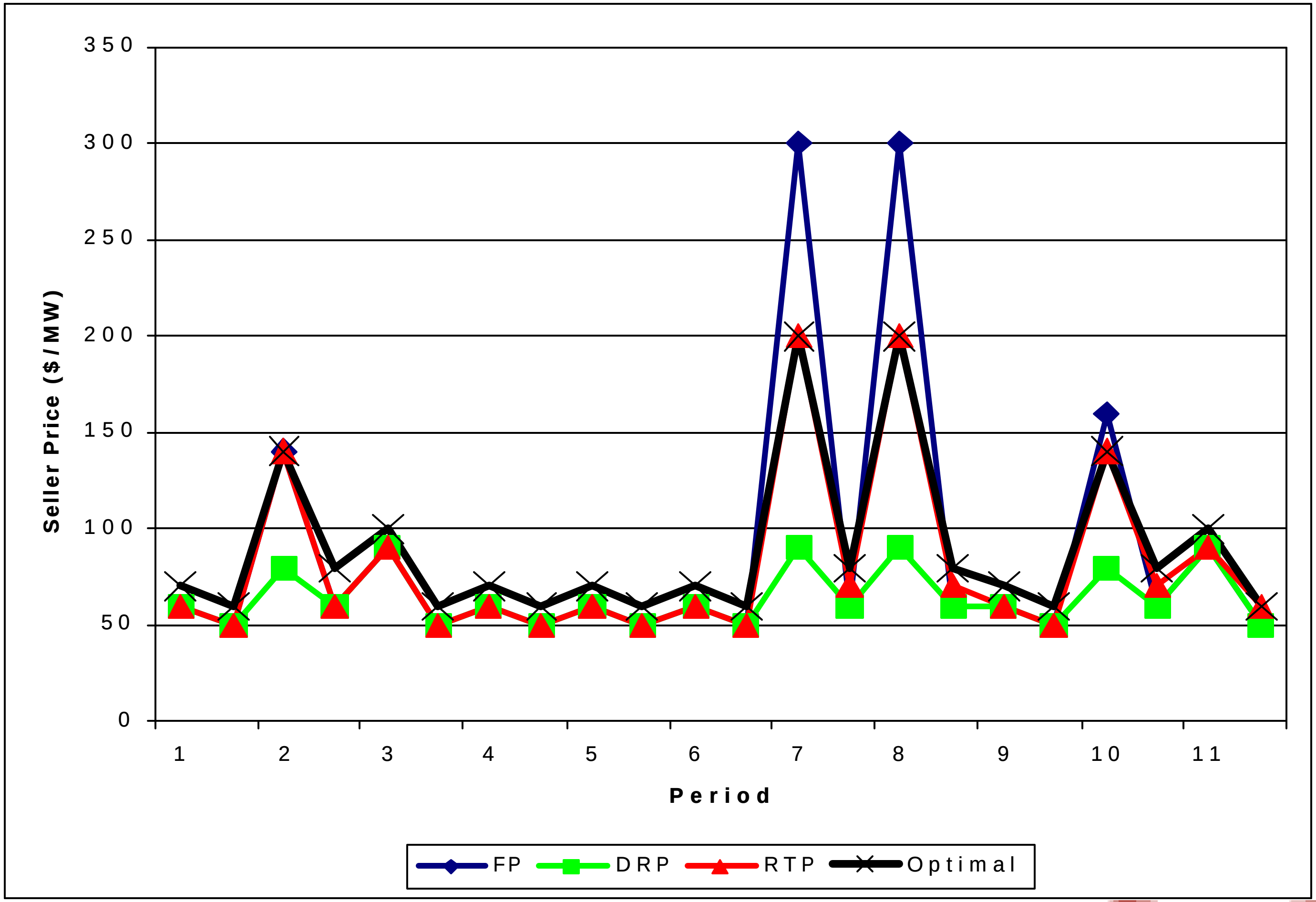
FP: Significant Difference @ 95% 9 out of 11 period pairs (2+/7-)
DRP: @ 95% 11 out of 11 period pairs (4+/7-)
RTP: @ 95% 8 out of 11 period pairs (8+)

*Two-Sided Market (Adjusted for Rate Increase)*

FP: Significant Difference @ 95% 10 out of 11 periods (10-)
DRP: @ 95% 1 out of 11 periods (1-)
RTP: @ 95% 11 out of 1 periods (11-)

Note: + Indicates C.S. > Optimal; - Indicates C.S. < Optimal

# Prices: Active Demand/Preset Cost-Based Supply with Random Shift (Group 1)

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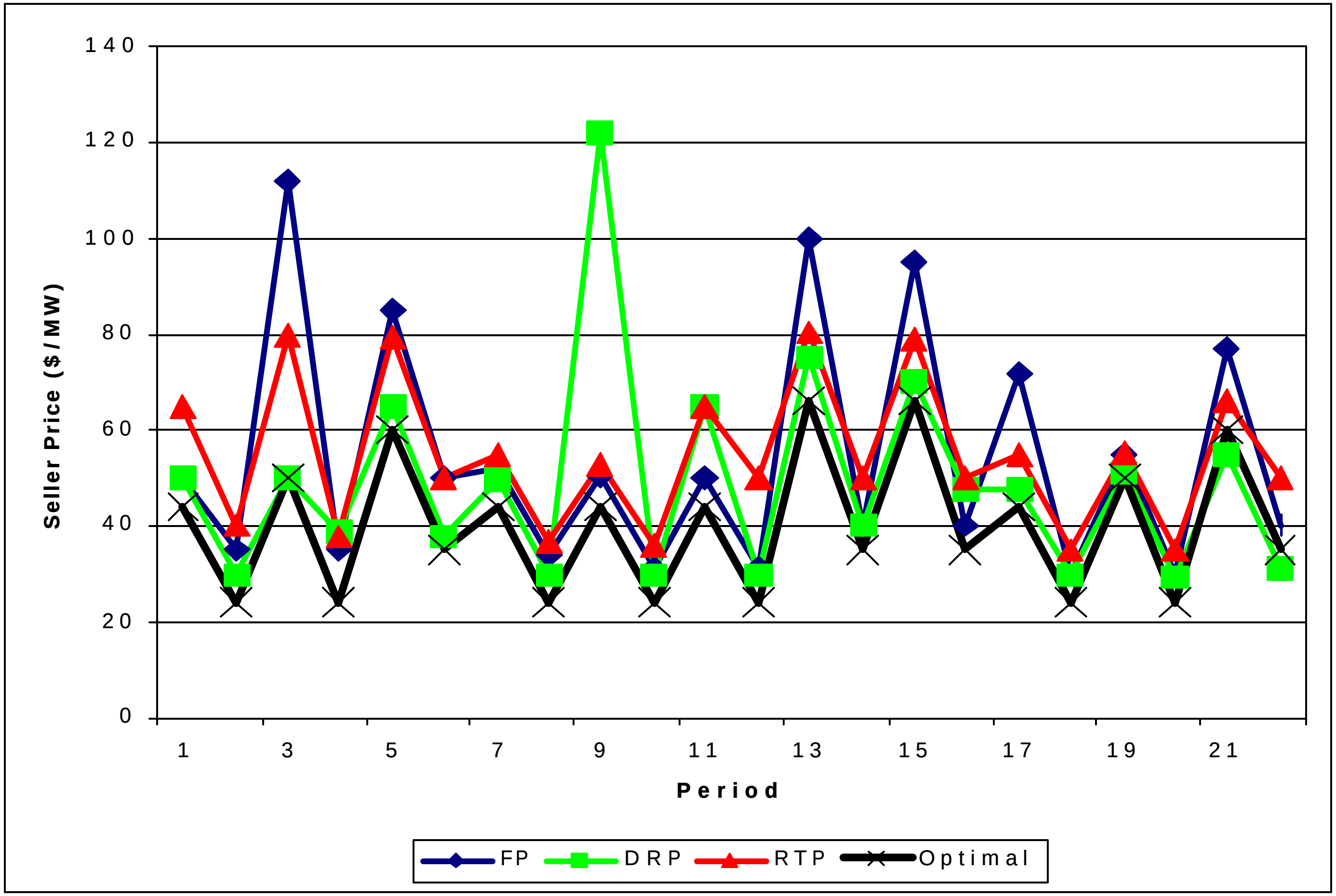
# *Prices: Two-Sided Market*

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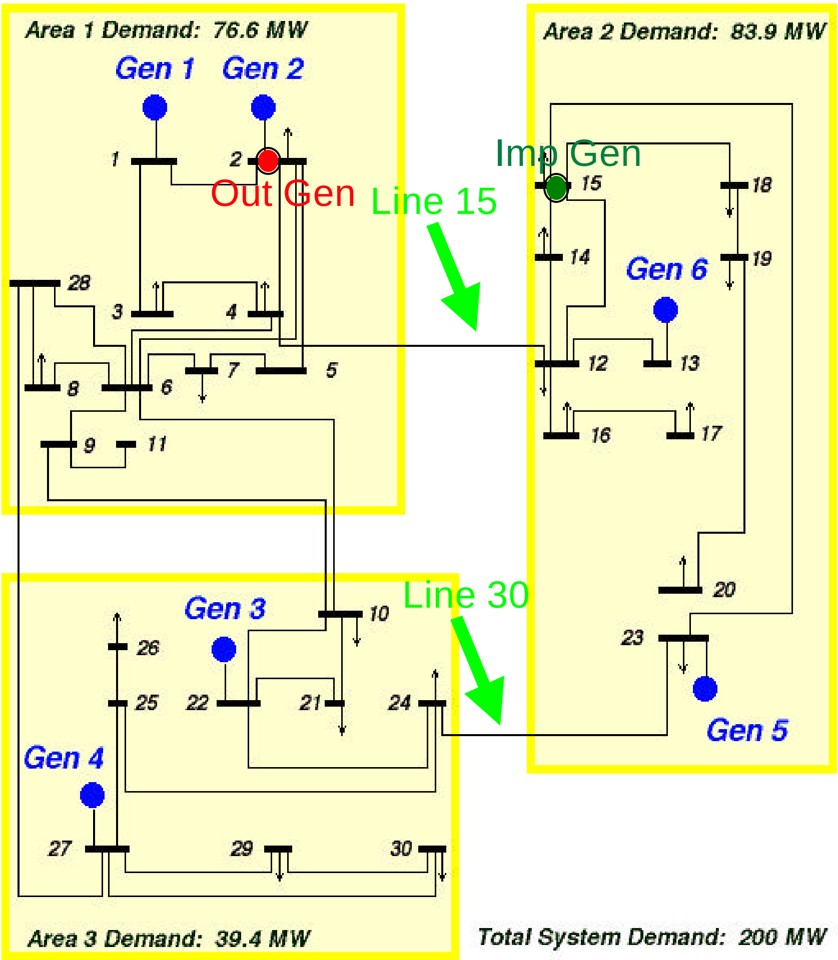
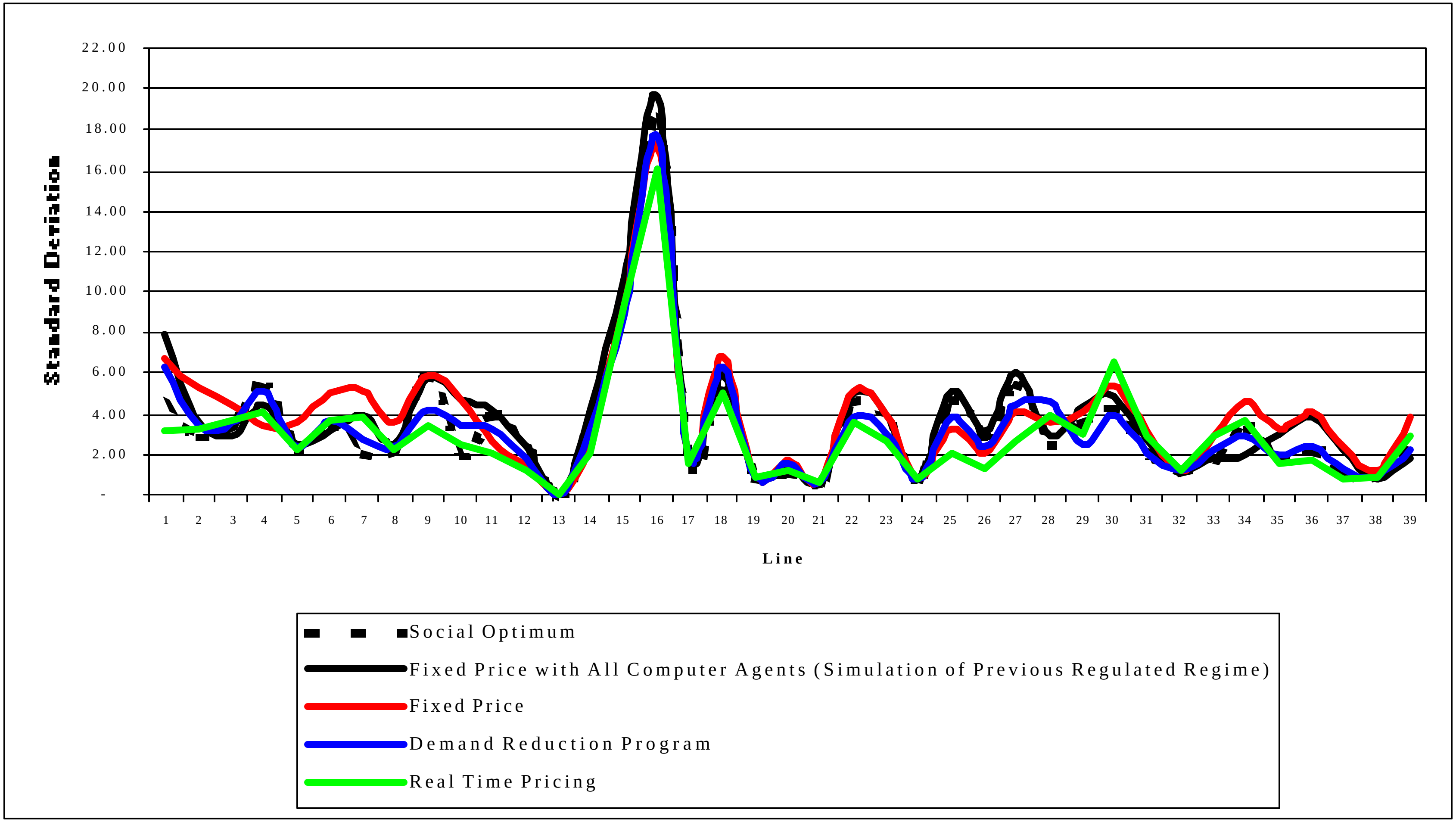
# Schematic of Underlying Electricity Network



# Standard Deviation in Line Flows

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# Relationship Between Line Flows and System Load

| | | | Results with Active Participants | | |
|---|---|---|---|---|---|
| | Social Optimum | (Reg. Regime) Fixed Price with All Computer Agents | Fixed Price | Demand Reduction Program | Real Time Pricing |
| *Regression Results for Tie Line 15* | | | | | |
| Intercept | 40.1779 | 38.1995 | 21.6108 | 33.5226 | 32.0311 |
| Std Err | 4.4018 | 3.1170 | 5.2433 | 4.5931 | 5.9929 |
| Slope Coefficient | (0.1982) | (0.1826) | (0.1167) | (0.1864) | (0.1813) |
| Std Err | 0.0242 | 0.0167 | 0.0284 | 0.0291 | 0.0344 |
| R-Squared | 0.7701 | 0.8562 | 0.4585 | 0.6716 | 0.5814 |
| F-Statistic | 66.9834 | 119.0523 | 16.9338 | 40.8949 | 27.7791 |
| P-value | 0.0000 | 0.0000 | 0.0005 | 0.0000 | 0.0000 |
| *Regression Results for Tie Line 30* | | | | | |
| Intercept | (17.5262) | (17.7288) | (8.7817) | (11.1943) | (19.6806) |
| Std Err | 2.2651 | 2.4109 | 3.4224 | 2.6266 | 3.9270 |
| Slope Coefficient | 0.0751 | 0.0698 | 0.0517 | 0.0674 | 0.1312 |
| Std Err | 0.0125 | 0.0129 | 0.0185 | 0.0167 | 0.0225 |
| R-Squared | 0.6449 | 0.5921 | 0.2808 | 0.4495 | 0.6288 |
| F-Statistic | 36.3151 | 29.0375 | 7.8081 | 16.3300 | 33.8794 |
| P-value | 0.0000 | 0.0000 | 0.0112 | 0.0006 | 0.0000 |

Note: The following linear regression equation was estimated with OLS.
Line Power Flow = Bo + B1 x System Load

# *Results (and Their Significance)*

1. Customers Can Perform Efficiently in Electricity Markets, if Given the Chance.
2. Markets Perform More Efficiently with Customer Participation, without the Need for Market Power Mitigation.
3. Real Time Pricing Performs Better than Pre-announced Demand Response Programs.
4. Customers Prefer DRP before trying RTP, but Switch their Preferences after Experiencing RTP.
5. Line Flows May be More Predictable under RTP.

# *Deliverables*

**Publications:**

- Mount, Schuler & Schulze, "Markets for Reliability and Financial Options in Electricity:  Theory to Support the Practice," Proceedings of HICSS-36, Jan. 2003.
- Adilov, Light, Schuler, Schulze & Toomey, "The Effects of Customer Participation in Electricity Markets:  An Experimental Analysis of Alternative Market Structures," presented at HICSS-37, Jan. 2004.
- Toomey, Schulze, Schuler, Thorp & Thomas, " Public Goods and Electric Power: Are Efficient Markets Feasible," draft Oct. 2003.
- Adilov, Light, Schuler & Schulze, "Self-Regulating Electricity Markets," to be presented at 17th Annual Western Rutgers Conference on Regulation and Competition, San Diego, June 24, 2004.

**Practical Deliverables:**

- Through Prof. Schuler's membership on the Board of the NY ISO.

# *Questions for the Future*

1. Longer Experimental Trials (allow for learning lags).
2. Effect of Partial Customer Participation (DRP vs. RTP) on Market Performance.
3. Coordination with LBNL Survey Results: Consideration of Experiments as Customer Training Tool.
4. Detailed Examination of Effects on Line Flow Variability.