AMES Wholesale Power Market Test Bed

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Presentation Outline

- Wholesale power market design proposed in 2003 by the U.S. Federal Energy Regulatory Commission (FERC), the basis of the AMES test bed architecture

- Basic features and capabilities of AMES test bed

  \textit{AMES = Agent-based Modeling of Electricity Systems}

- Illustrative Dynamic 5-Bus Test Case Results

- On-Line Resources
In April 2003 the U.S. Federal Energy Regulatory Commission (FERC) proposed a wholesale electric power market design for common adoption throughout U.S.

Over 60% of North American generation now operates under some version of FERC design.

Adopters to Date: New York (NYISO), Mid-Atlantic States (PJM), Texas (ERCOT), New England (ISO-NE), California (CAISO), Midwest/Manitoba (MISO), & Southwest (SPP)
FERC Wholesale Power Market Design Adopters to Date
Core Features of FERC’s Market Design

- Market to be managed by an *Independent System Operator (ISO)* or *Regional Transmission Organization (RTO)* having no ownership stake

- **Two-settlement system:** Concurrent operation of day-ahead (forward) & real-time (spot) markets

- Transmission grid congestion managed via *Locational Marginal Prices (LMPs)*, where LMP at bus k = least system cost of servicing 1 more MW of fixed demand (load) at bus k

- Oversight & market power mitigation by outside agency
Complexity of FERC Market Design

Example: MISO Business Practices Manual 001

DART = Day-Ahead and Real-Time Markets

Exhibit 2-3: DART Components Overview

Core of FERC design
AMES focus to date

Two-Settlement System
### Typical ISO/RTO Two-Settlement System Activities on a Single Day D-1

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:00</td>
<td><strong>Day-Ahead Market (DAM) for day D</strong>&lt;br&gt;ISO/RTO collects bids/offers from Load-Serving Entities and Generation Companies</td>
</tr>
<tr>
<td>11:00</td>
<td><strong>ISO/RTO solves SCUC/SCED &amp; posts dispatch set-points and LMP schedule for D</strong></td>
</tr>
<tr>
<td>16:00</td>
<td><strong>ISO/RTO opens “re-offer period” for generation, reassesses resource needs for day D, &amp; changes day D schedule as needed</strong></td>
</tr>
<tr>
<td>23:00</td>
<td><strong>Day-ahead settlement</strong></td>
</tr>
</tbody>
</table>

**Real-Time Market (RTM) open all 24 hours of day D-1**

**Real-time settlement**
Typical ISO/RTO Two-Settlement System Activities on Successive Days D-1 and D

Who
- Market Participants
- ISO/RTO

What
- Demand bids & supply offers submitted to the day-ahead market for day D
- ISO/RTO从根本源发布的日间调度和LMP时刻表
- ISO/RTO调整日间调度和日间调度表
- ISO/RTO发布调度信号和计算实时LMPs

When
- 5 A.M.
- 11 A.M.

How
- SCUC/SCED

Day Ahead
- Reliable Assessment

Real Time
- Afternoon of Day D-1 Thru Operating Hour on Day D
Potential Volatility of RTM LMPs under FERC’S Market Design
Real-Time LMPs ($/MWh) in Midwest ISO (MISO)
April 25, 2006, at 19:55

Note this price, $156.35
Five Minutes Later...

73% drop in price in 5 minutes!
Real-Time LMPs ($/MWh) in Midwest ISO (MISO)
September 5, 2006, 14:30

Note this price, $226.25
Five Minutes Later...

79% drop in price in 5 minutes!
Problem: FERC’s market design is a complicated mix of features

Difficult to model and study using standard analytical and statistical tools

AMES Approach: Develop an agent-based test bed permitting careful experimental testing of

- the FERC market design
- new/modified market design features
 Ames Wholesale Power Market Test Bed

https://www2.econ.iastate.edu/tesfatsi/AMESMarketHome.htm

- **Research/teaching/training grade test-bed**
- **Operational validity** ("simple but not too simple")
- Permits **dynamic** testing with **learning traders**
- Permits **intensive experimentation** with alternative scenarios
- **Free open-source Java implementation** (full access to code)
- **Flexible & modular** (easy to modify test bed features)
- **V1.31 released** (IEEE PES General Meeting, June 2007)
- **V2.05 released** (IEEE PES General Meeting, July 2009)
- **All version releases to date** are posted at the AMES homepage
AMES (V2.05) Architecture
(based on business practice manuals for ISO-NE)

➢ **Traders**
   - GenCos (sellers)
   - LSEs (buyers)
   - **Learning** capabilities

➢ **Independent System Operator (ISO)**
   - System reliability assessments
   - Day-ahead scheduling via **bid/offer based optimal power flow (OPF)**
   - Real-time dispatch

➢ **Two-settlement system**
   - Day-ahead market (double auction, financial contracts)
   - Real-time market (settlement of differences)

➢ **AC transmission grid**
   - **Generation Companies (GenCos) & Load-Serving Entities (LSEs)** located at user-specified transmission buses
   - Grid congestion managed via **Locational Marginal Prices (LMPs)**
AMES Modular & Extensible Architecture (Java)

◆ Market protocols & AC transmission grid structure
  — Graphical User Interface (GUI) & modularized class structure permit easy experimentation with alternative parameter settings and alternative institutional/grid constraints

◆ Any AMES decision-maker can be a learning agent
  — Java Reinforcement Learning Module (JReLM)
  — “Tool box” permitting experimentation with a wide variety of learning methods (Roth-Erev, Temp Diff/Q-learning,...)

◆ SCED implemented via an extensible DC-OPF module
  — Bid/offer-based DC Optimal Power Flow Module (DCOPFJ)
  — Permits experimentation with various DC OPF formulations

◆ Output displays and test case templates
  — Customizable chart/table displays & 5-bus/30-bus test cases
AMES Graphical User Interface (GUI)
Tool Bar/Menus for DAM Data Input and Output Displays
Illustration of AMES Dynamics with No Shocks
(day-ahead contracts fulfilled as planned)
### Activities of AMES ISO During a Typical Day D-1

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:00</td>
<td><strong>Day-Ahead Market (DAM)</strong> for day D</td>
</tr>
<tr>
<td></td>
<td>ISO collects energy bids &amp; offers from LSEs &amp; GenCos.</td>
</tr>
<tr>
<td>11:00</td>
<td>ISO solves SCED (bid/offer-based DC OPF) to determine dispatch set-points &amp; LMP schedule for each hour of day D.</td>
</tr>
<tr>
<td>16:00</td>
<td>ISO posts dispatch set-points and LMP schedule for each hour of day D.</td>
</tr>
<tr>
<td>23:00</td>
<td><strong>Day-ahead settlement</strong></td>
</tr>
</tbody>
</table>

**Real-Time Market (RTM)** open for all 24 hours of day D-1

**Real-time settlement**
AMES ISO (Market Operator)

Public Access:

// Public Methods
getWorldEventSchedule( clock time,... );
getMarketProtocols( bid/offer reporting, settlement,... );
Methods for receiving data;
Methods for retrieving stored ISO data;

Private Access:

// Private Methods
Methods for gathering, storing, posting, & sending data;
Method for solving hourly DC optimal power flow;
Methods for posting schedules and carrying out settlements;
Methods for implementing market power mitigation;

// Private Data
Historical data (e.g., cleared bids/offers, market prices,...);
Address book (communication links);
AMES LSE Hourly Demand-Bid Formulation

- Hourly demand bid for each LSE $j$

**Fixed + Price-Sensitive Demand Bid**

- **Fixed** demand bid $= p_{Lj}^F$ (MWs)

- **Price-sensitive** demand bid

  = Inverse demand function for real power $p_{Lj}^S$ (MWs) over a purchase capacity interval:

  \[ F_j(p_{Lj}^S) = c_j - 2d_j p_{Lj}^S \]

  \[ 0 \leq p_{Lj}^S \leq SLMax_j \]
AMES Load-Serving Entity
(Wholesale Energy Buyer)

<table>
<thead>
<tr>
<th>Public Access:</th>
</tr>
</thead>
<tbody>
<tr>
<td>// <strong>Public Methods</strong></td>
</tr>
<tr>
<td>getMarketProtocols(posting, trade, settlement);</td>
</tr>
<tr>
<td>getMarketProtocols(ISO market power mitigation);</td>
</tr>
<tr>
<td>Methods for receiving data;</td>
</tr>
<tr>
<td>Methods for retrieving LSE data;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Private Access:</th>
</tr>
</thead>
<tbody>
<tr>
<td>// <strong>Private Methods</strong></td>
</tr>
<tr>
<td>Methods for gathering, storing, and sending data;</td>
</tr>
<tr>
<td>Methods for forecasting customer energy demands;</td>
</tr>
<tr>
<td>Methods for calculating own expected &amp; actual net earnings;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>// <strong>Private Data</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Own downstream demand, grid location, current wealth...;</td>
</tr>
<tr>
<td>Data recorded about external world (prices, dispatch,...);</td>
</tr>
<tr>
<td>Address book (communication links);</td>
</tr>
</tbody>
</table>
AMES GenCos are learners who report strategic supply offers to the ISO for the DAM

Hourly supply offer for each GenCo $i = \text{Reported}$ linear marginal cost function over a $\text{reported}$ operating capacity interval for real power $p_{Gi}$ (in MWs):

$$MC^R_i(p_{Gi}) = a^R_i + 2b^R_i p_{Gi}$$

$$\text{Cap}_{iL} \leq p_{Gi} \leq \text{Cap}_{iRU}$$

GenCos can learn to report $\text{higher-than-true}$ marginal costs and/or to report $\text{lower-than-true}$ maximum capacity.
AMES Generation Company
(Energy Producer and Seller)

**Public Access:**

```plaintext
// Public Methods
getWorldEventSchedule( clock time,... );
getMarketProtocols( ISO market power mitigation,... );
Methods for receiving data;
Methods for retrieving GenCo data;
```

**Private Access:**

```plaintext
// Private Methods
Methods for gathering, storing, and sending data;
Methods for calculating own expected & actual net earnings;
Method for updating own supply offers (LEARNING);
```

```plaintext
// Private Data
Own capacity, grid location, cost function, current wealth...
Data recorded about external world (prices, dispatch,...);
Address book (communication links);
```
Agent learning in AMES implemented via JReLM module
(Java Reinforcement Learning Module developed by Charles J. Gieseler, Comp Sci M.S. Thesis, 2005)
ISO goal is \( \text{max}[\text{Total Net Surplus}] \) subject to trans & gen constraints: 2-bus example

Cleared load = \( p^F_L \). LSE at bus 2 pays \( \text{LMP}_2 > \text{LMP}_1 \) for each unit of \( p^F_L \). \( M \) units of \( p^F_L \) are supplied by cheaper G1 at bus 1 who receives only \( \text{LMP}_1 \) per unit.

\( r = \) Rate charged by the LSE to its retail customers on flat-rate contracts.

ISO net revenue stream:

**ISO Net Surplus**

\[
\text{ISO Net Surplus} = [ \text{LSE Payments} - \text{GenCo Revenues} ] = M \times [\text{LMP}_2 - \text{LMP}_1]
\]
Total Net Surplus (TNS)
2-Bus Example... Continued

**ISO Net Surplus:**
\[ \text{INS} = M \times [\text{LMP}_2 - \text{LMP}_1] \]

**GenCo Net Surplus:**
Area S1 + Area S2

**LSE Net Surplus:**
Area B

**Total Net Surplus:**
\[ \text{TNS} = [\text{INS} + \text{S1} + \text{S2} + \text{B}] \]

**ISO Objective (DC-OPF):**
maximize \( \text{TNS} \) subject to trans/gen constraints.
AMES Illustration: **Total Net Surplus (TNS)** in Hour 17 for a 5-Bus test case with no transmission congestion

$r = \text{Rate (fixed price) paid to LSEs by their retail customers with flat-rate contracts} = \text{LSEs’ max willingness to pay for each MW of their fixed demand } p_F \text{ in wholesale power market}$
AMES Calculation of TNS: General Form
(Note LMPs cancel out of TNS expression!)

Total Net Surplus for Hour H of Day D+1, based on Day D Supply Offers and Demand Bids:

\[ TNS(H, D) \]

\[ = \text{LSENNetSur}(H, D) + \text{GenNetSur}(H, D) + \text{ISONetSur}(H, D) \]

\[ = \sum_{j=1}^{J} GS_j(H, D) - \sum_{i=1}^{I} [C_i^g(H, D)] \]

where

\[ GS_j(H, D) = [r \cdot p_{Lj}^F(H, D) + \int_0^{p_{Lj}^S(H, D)} F_{jHD}(p)dp] \]

\[ C_i^g(H, D) = \int_0^{P_{Gi}(H, D)} MC_i(p)dp \]

LSE j’s gross surplus from its retail fixed demand sales

LSE j’s gross surplus from its retail price-sensitive demand sales

GenCo i’s total avoidable costs of production
SI unit representation for AMES ISO’s DC-OPF problem for hour H of the day-ahead market on day D+1, solved on day D.

DC-OPF formulation is derived from AC-OPF under three assumptions:

(a) Resistance on each branch \( km = 0 \)

(b) Voltage magnitude at each bus \( k = \text{base voltage} \ V_o \)

(c) Voltage angle difference \( d_{km} = [\delta_k - \delta_m] \) across each branch \( km \) is small so that \( \cos(d_{km}) \approx 1 \) and \( \sin(d_{km}) \approx d_{km} \)

\[ \text{TNS}^R = \text{Total Net Surplus} \]

based on \textit{reported} GenCo marginal cost functions rather than \textit{true} GenCo marginal cost functions.

\[ \text{AMES Day-Ahead Market SCED (DC-OPF) Formulation:} \]

\[ \max \ TNS^R \quad (15) \]

with respect to LSE real-power price-sensitive demands, GenCo real-power generation levels, and voltage angles

\[ p_{L_j}, \ j = 1,\ldots,J; \ p_{G_i}, \ i = 1,\ldots,I; \ \delta_k, \ k = 1,\ldots,K \quad (16) \]

subject to

(i) a real-power balance constraint for each bus \( k=1,\ldots,K \):

\[ \sum_{i \in I_k} p_{G_i} - \sum_{j \in J_k} p_{L_j}^S - \sum_{km} P_{km} = \sum_{j \in J_k} p_{L_j}^P \quad (17) \]

where, letting \( x_{km} \) (ohms) denote reactance for branch \( km \), and \( V_o \) denote the base voltage (in line-to-line KV),

\[ P_{km} = [V_o]^2 \cdot [1/x_{km}] \cdot [\delta_k - \delta_m] \]

(ii) a limit on real-power flow for each branch \( km \):

\[ |P_{km}| \leq P_{km}^{DJ} \quad (18) \]

(iii) a real-power operating capacity interval for each GenCo \( i = 1,\ldots,I \):

\[ \text{Cap}_{i}^{L_i} \leq p_{G_i} \leq \text{Cap}_{i}^{RU} \quad (19) \]

(iv) a real-power purchase capacity interval for price-sensitive demand for each LSE \( j = 1,\ldots,J \):

\[ 0 \leq p_{L_j}^S \leq SLMax_j \quad (20) \]

(v and a voltage angle setting at angle reference bus 1):

\[ \delta_1 = 0 \quad (21) \]
AMES ISO Solves DC-OPF via DCOPFJ Module

DC-OPF raw data (SI) → DCOPFJ Shell → Per Unit conversion → Form SCQP matrices → QuadProgJ: An SCQP solver → Per Unit SCQP output → Solution output (SI)
Extension of AMES to Integrated Retail/Wholesale (IRW) Power System Test Bed
https://www2.econ.iastate.edu/tesfatsi/IRWProjectHome.htm

Wholesale
AMES test bed, developed by ISU Team
communication seam

Retail
GridLAB-D distribution feeders, developed by DOE/PNNL and the ISU IRW Project Group
Illustrative AMES Experimental Findings for a 5-Bus Test Case

**Definition:** *Incentive misalignment* → Institutional design fails to align incentives of power system participants with efficiency objectives (non-wastage of resources) and/or welfare objectives (socially desirable distribution of total net surplus to individual power system participants).

**Experiments Reported Below:** Incentive misalignment problems under FERC wholesale power market design for a range of experimental treatments:

- **Generator learning** [intensive parameter sweep]
- **Sensitivity of wholesale demand to price** [0 to 100%]
5-Bus Transmission Grid
(used in many ISO business practice/training manuals)

Five GenCo sellers G1,...,G5 and three LSE buyers LSE 1, LSE 2, LSE 3

250 MW Capacity

Bus 1  Bus 2  Bus 3
G1  G2  G3
LSE 1  LSE 2

Bus 4  Bus 5
G4  LSE 3

$  $  $$  $$$$
Partial depiction of input data for the 5-bus test case:

<table>
<thead>
<tr>
<th>Base Values$^a$</th>
<th>( S_0 )</th>
<th>( V_o )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100</td>
<td>10</td>
</tr>
</tbody>
</table>

| \( K^b \) | \( \pi^c \) | 5 | 0.05 |

<table>
<thead>
<tr>
<th>Branch</th>
<th>From</th>
<th>To</th>
<th>lineCap$^d$</th>
<th>( X^e )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>250.0</td>
<td>0.0281</td>
</tr>
<tr>
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<td>3</td>
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<tr>
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<td>240.0</td>
<td>0.0297</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>5</td>
<td>240.0</td>
<td>0.0297</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gen ID</th>
<th>atNode</th>
<th>FCost</th>
<th>( a )</th>
<th>( b )</th>
<th>( \text{Cap}^L )</th>
<th>( \text{Cap}^U )</th>
<th>Init$^f$</th>
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<td>1</td>
<td>1600.0</td>
<td>14.0</td>
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<td>0.0</td>
<td>110.0</td>
<td>$1 \text{ M}$</td>
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<td>600.0</td>
<td>$1 \text{ M}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LSE ID</th>
<th>atNode</th>
<th>L-001</th>
<th>L-01</th>
<th>L-02</th>
<th>L-03</th>
<th>L-04</th>
<th>L-05</th>
<th>L-06</th>
<th>L-07</th>
</tr>
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<tbody>
<tr>
<td>1</td>
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<td>350.0</td>
<td>322.93</td>
<td>305.04</td>
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<td>L-08</td>
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<td>L-12</td>
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<tr>
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<td>403.82</td>
<td>408.25</td>
<td>403.82</td>
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<td>349.93</td>
<td>346.13</td>
<td>338.40</td>
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</tr>
<tr>
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<td>4</td>
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<td>282.00</td>
<td>278.83</td>
<td>278.83</td>
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<td></td>
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<td>L-16</td>
<td>L-17</td>
<td>L-18</td>
<td>L-19</td>
<td>L-20</td>
<td>L-21</td>
<td>L-22</td>
</tr>
<tr>
<td>1</td>
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<td>408.25</td>
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<td>430.73</td>
<td>426.14</td>
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<td>412.69</td>
<td>390.37</td>
<td>363.46</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>349.93</td>
<td>384.53</td>
<td>369.20</td>
<td>365.26</td>
<td>361.47</td>
<td>353.73</td>
<td>334.60</td>
<td>311.53</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>291.61</td>
<td>320.44</td>
<td>307.67</td>
<td>304.39</td>
<td>301.22</td>
<td>294.78</td>
<td>278.83</td>
<td>259.61</td>
</tr>
</tbody>
</table>

$^a$For simplicity, the base apparent power \( S_0 \) (MVA) and base voltage \( V_o \) (kV) are chosen so base impedance \( Z_o \) satisfies \( Z_o = V_o^2 / S_0 = 1 \).

$^b$Total number of nodes

$^c$Soft penalty weight \( \pi \) for voltage angle differences

$^d$Upper limit \( P_{km}^U \) (in MWs) on the magnitude of real power flow in branch \( km \)

$^e$Reactance \( X_{km} \) (in ohms) for branch \( km \)

$^f$L-H: Load (in MWs) for hour H, where H=00,01,...,23
GenCo True Cost & Capacity Attributes
In 5-bus study, AMES GenCos use VRE learning
(version of Roth-Erev stochastic reinforcement learning)

- Each GenCo maintains action choice propensities $q$, normalized to choice probabilities $\text{Prob}$, to choose actions (supply offers). A good (bad) reward $r_k$ resulting from an action $a_k$ results in an increase (decrease) in both $q_k$ and $\text{Prob}_k$. 

```plaintext
<table>
<thead>
<tr>
<th>Action Choice $a_1$</th>
<th>Choice Propensity $q_1$</th>
<th>Choice Probability $\text{Prob}_1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Action Choice $a_2$</td>
<td>Choice Propensity $q_2$</td>
<td>Choice Probability $\text{Prob}_2$</td>
</tr>
<tr>
<td>Action Choice $a_3$</td>
<td>Choice Propensity $q_3$</td>
<td>Choice Probability $\text{Prob}_3$</td>
</tr>
</tbody>
</table>
```
R Measure for Demand-Bid Price Sensitivity

Note: In actual U.S. ISO energy regions, $R \approx 0.01$

For LSE j in Hour H:

$\ p^{F}_{Lj} = $ Fixed demand for real power (MWs)

$\ SLMax_{j} = $ Maximum potential price-sensitive demand (MWs)

$$R = \frac{SLMax_{j}}{\left( \ p^{F}_{Lj} + SLMax_{j} \right)}$$

$R=0.0$  
(100% Fixed Demand)

$R=0.5$  
(100% Price-Sensitive Demand)
LSE Hourly Fixed Demands for R=0.0

17 = Peak demand hour
First Experiments: Avg GenCo net earnings (Day 1000) for R=0 under varied learning parameter settings

Li/Tesfatsion, *J. Econ. Behavior and Organization*, 2011

<table>
<thead>
<tr>
<th>Small beta (\cong) “zero-intelligence” budget-constrained trading.</th>
</tr>
</thead>
</table>

Learning matters!

= Sweet-spot region

★ = Selected settings for next experiments
Second Experiments: Avg LMP with/without GenCo learning as demand varies from R=0 (100% fixed) to R=1 (100% price sensitive)

Avg LMP (Locational Marginal Price)  Avg LI (Lerner Market Power Index)

With GenCo Learning (Day 1000)
True Vs. Reported MC (Averaged)* for R=0.0 on Day 422 (Each Generator has converged with Prob ≥ 0.999)

*NOTE: 20-run averages. Typical convergence time = 62 days, max time = 422. Omitted Gen 1 MC curve is similar to Gen 2’s.
Single-Run Illustration of Findings for $R=0.0$ (100% Fixed Demand)

W/O Gen Learning (Day 1000)

**LMPs**

**GenCo Dispatches**

**Branch Power Flows**

---

With Gen Learning (Day 1000)

**LMPs**

**GenCo Dispatches**

**Branch Power Flows**
Implications of Second Experiments
(Li/Sun/Tesfatsion, *Comp Methods in Economic Dynamics*, 2011)

- **Bottom Line:**
  
  For all R, prices (LMPs) much higher under GenCo learning due to strategic GenCo supply offers.

- **Conjectured Need:**
  
  *Active price-sensitive LSE demand bidding* to offset power of strategic GenCos (well-working double auction).

- **Possible Means:**
  
  *Integrated wholesale/retail restructuring* providing array of price-sensitive retail contracts and permitting retail consumers to select their LSE suppliers.
After 2000 Cal/Enron scandal, retail restructuring slowed or stopped altogether.
Third Experiments: Extraction of net surplus by ISOs in day-ahead energy markets under Locational Marginal Pricing (LMP)


Day-ahead market activities on a typical day D
5-Bus Test Case Results **Without** GenCo Learning:

ISO net surplus on Day 1000 as LSE demand varies from R=0.0 (100% fixed) to R=1.0 (100% price sensitive)
5-Bus Test Case Results **With** GenCo VRE Learning:
Mean ISO net surplus on Day 1000 as LSE demand varies from $R=0.0$ (100% fixed) to $R=1.0$ (100% price sensitive)
Empirical Comparisons

- From PJM 2008 report:
  ISO net surplus from day-ahead market: $2.66 billion

- From MISO 2008 report:
  ISO net surplus from day-ahead market: $500 million

- From CAISO 2008 report:
  ISO net surplus from day-ahead inter-zonal congestion charges: $176 million.

- From ISO-NE 2008 report:
  Combined ISO net surplus for real-time and day-ahead markets: $121 million.
Implications of ISO Net Surplus Findings

- ISO net surplus extractions *not well aligned with market efficiency*

- Treatments resulting in *greater* GenCo economic capacity withholding (hence higher & more volatile LMPs) also result in *greater* ISO & GenCo net surplus

- ISO net surplus collections should be allocated for *ex ante* remedy of structural/behavioral problems that encourage GenCo economic capacity withholding.

- Should not be used *ex post* for LMP payment offsets and LMP risk hedge support (current norm)
On-Line Resources

- **Presentation Slides**
  https://www2.econ.iastate.edu/tesfatsi/AMESMarketProject.pdf

- **AMES Test Bed Homepage (Code/Manual/Publications)**
  https://www2.econ.iastate.edu/tesfatsi/AMESMarketHome.htm

- **Agent-Based Electricity Market Research**
  https://www2.econ.iastate.edu/tesfatsi/aelect.htm

- **Agent-Based Computational Economics Homepage**
  https://www2.econ.iastate.edu/tesfatsi/ace.htm

- **Integrated Retail/Wholesale Power Systems Project**
  https://www2.econ.iastate.edu/tesfatsi/IRWProjectHome.htm