Wholesale Power Market Design

An Agent-Based Computational Economics Approach

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Outline

• What is Agent-Based Computational Economics (ACE)?
• ACE and Electricity Market Design
• Illustrative Application (Electricity Double Auction)
• A More Substantial Application (Testing the reliability of FERC’s 2003 Wholesale Power Market Platform design)
What is ACE?

- Computational study of economies modeled as evolving systems of autonomous interacting agents with learning capabilities
- Specialization to economics of the basic complex adaptive systems paradigm
Culture Dish Analogy

- Virtual economic world with both passive and active agents
- Modeler sets initial conditions of the world
- The world then evolves over time without further outside intervention
- Driven solely by agent-agent interactions
Current ACE Research Areas

(http://www.econ.iastate.edu/tesfatsi/aapplic.htm)

- Embodied cognition
- Network formation
- Evolution of norms
- Specific market case studies
- Industrial organization
- Market Design
- Automated markets and software agents
- Development of computational laboratories
- Parallel experiments with real and computational agents
- Others...
Economic Research on Electricity Market Design
(www.econ.iastate.edu/tesfatsi/epres.htm)

• **Analytical/Empirical:**
  - Berkeley (Borenstein, Bushnell, Oren,...); Cambridge (Green, Newbery,...); EPRI (Chao, Peck,...); Harvard (Hogan,...); MIT (Joskow, Tirole,...); U of Oslo (Halseth, von der Fehr,...); Stanford (Wilson, Wolak,...); ...

• **Human-Subject Experiments:**
  - Cornell (Mount,...); George Mason U (Rassenti, Smith, Wilson,...); ...
Potential Contributions of ACE Approach

- Key market participants (system operator, generators, buyers...) modeled as autonomous interacting agents

- **Agent learning** can be calibrated to data (empirical, human-subject experimental)

- Behaviors and interaction networks evolve over time

- Easier to include and test **detailed structural market features** for individual and/or joint effects
ACE Electricity Research:
(www.econ.iastate.edu/tesfatsi/aelect.htm)

- Argonne National Lab (Macal, North,...)
- CSIRO-Australia (Batten,...)
- Helsinki Univ. (Hamalainen,...)
- Iowa State University (Koesrindartoto, Sheble, Tesfatsion,...)
- London Business School (Bunn, Day,...)
- Los Alamos National Lab (Barrett, Marathe,...)
- Pacific Northwest National Lab (Roop,...)
- Others (see website above)
Key Issues for Wholesale Power Markets

- **Short-Run**: Efficient production of electricity from *existing* generation capacity
- **Short-Run**: Efficient transmission of electricity to *existing* load-serving entities over *existing* transmission lines
- **Longer-Run**: Efficient planning and investment for *new* generation and *new* transmission capacity
Illustrative ACE Study of a Wholesale Power Market

“Market Power and Efficiency in a Computational Electricity Market with Discriminatory Double-Auction Pricing”

ACE Wholesale Power Market: Basic Structure

- N Generators and M Load-Serving Entities (LSE’s)
- Repeated participation in a wholesale power market operated by an Independent System Operator (ISO)
- Market run as a discriminatory double auction
- Fully connected transmission grid (ATC constraints non-binding in this study)
Wholesale Power Market: Logical Flow

- Construct and initialize the Independent System Operator (ISO), the Traders (Generators and LSEs), and the Market
- Compute competitive equilibrium benchmark
- Enter the auction loop
- ISO runs auction for RMax rounds (trader bids/asks \(\rightarrow\) price and quantity outcomes)
- Compare results against competitive equilibrium benchmark
Flow Diagram

Auction Process

Init.

Traders
Buyers
Sellers

Submit bids/asks based on real MC/MR

Traders

Matches bids/asks
Competitive equilibrium outcomes

Auctioneer

Submit strategic bids/asks

Traders

Matches bids/asks
Clearing prices, quantities

Auctioneer

Accept results from auction
Updating & learning

Traders

Report
End

End

Report

Updating & learning

Accept results from auction

Traders

Clearing prices, quantities

Matches bids/asks

Auctioneer

Submit strategic bids/asks

Traders

Competitive equilibrium calculation
Key Issues Addressed

- Sensitivity of market performance to changes in market structure when wholesale traders evolve their bid/ask pricing strategies over time.

- Is market structure strongly predictive of market performance despite learning effects?
**Two Structural Treatment Factors**

Let “Sellers” = Generators and “Buyers” = Load-Serving Entities

- **RCON = Relative Concentration**
  - Ratio NS/NB of Number of Sellers to Number of Buyers

- **RCAP = Relative Capacity**
  - Ratio DCAP/SCAP of total buyer demand capacity to total seller supply capacity
Experimental Design

- **Two Structural Treatment Factors:**
  - RCAP, RCON

- **Three Tested Treatment Levels:**
  - 1/2, 1, 2

- **Runs per Treatment:**
  - From 1000 to 10,000

- **Data Collected Per Run:**
  - Market efficiency; Seller market advantage; Buyer market advantage (aggregate and individual levels)
## Structural Treatment Factor Values

<table>
<thead>
<tr>
<th>RCAP</th>
<th>1/2</th>
<th>1</th>
<th>2</th>
</tr>
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<tr>
<td>2</td>
<td>Ns = 6 Nb = 3 Cs = 10Cb = 10</td>
<td>Ns = 6 Nb = 3 Cs = 10Cb = 10</td>
<td>Ns = 6 Nb = 3 Cs = 10Cb = 20</td>
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<tr>
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<td>Ns = 3 Nb = 3 Cs = 20Cb = 10</td>
<td>Ns = 3 Nb = 3 Cs = 20Cb = 10</td>
<td>Ns = 3 Nb = 3 Cs = 20Cb = 20</td>
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<tr>
<td>1/2</td>
<td>Ns = 3 Nb = 6 Cs = 40Cb = 10</td>
<td>Ns = 6 Nb = 3 Cs = 20Cb = 10</td>
<td>Ns = 3 Nb = 6 Cs = 20Cb = 10</td>
</tr>
</tbody>
</table>
Aggregate Demand and Supply

Cell (3,1)

Cell (3,2)
Trader Learning

- Each trader uses *individual reinforcement learning* to determine their ask or bid price in each market period.

- The entire RCON/RCAP experimental design was implemented three times under *three different specifications* for the reinforcement learning algorithm parameters.
Trader Learning… Continued

- Results compared against an earlier electricity study by the same authors using the same double-auction electricity market structure

- **Difference**: Sellers in *earlier* study used social mimicry learning (population-level genetic algorithm), and similarly for buyers, despite structural heterogeneity -- not a smart thing to do!
Market Efficiency

- **ActualProfits** = *Actual* total profits earned by sellers and buyers

- **MaxProfits** = *Maximum possible* total profits that sellers and buyers *could* earn (i.e., total trader profits in competitive equilibrium)

- **Market Efficiency** = *ActualProfits* as a percentage of *MaxProfits*
Efficiency Findings

- **HIGH** market efficiency obtained when the traders use individual reinforcement learning
- **LOW** market efficiency obtained when the traders use not-so-smart social mimicry learning

**CONCLUSION:**

Efficiency of double-auction electricity market *not* robust against active exercise of bad judgement (e.g., inappropriate social mimicry)
Additional Findings
(Deddy Koesrindartoto, 2001)

- Even with reinforcement learning (RL), market efficiency can be low for certain parameter values

  **Example: Roth-Erev RL Algorithm (1998)**

  - Experimentation parameter $e$ (controls how reward from a chosen strategy affects probability of choosing other strategies).
  - For some settings of $e$, market efficiency can be as low as 20 percent
Efficiency vs Experimentation Parameter $e$

![Graph showing Efficiency vs Experimentation Parameter $e$]

- Cell (3,1)
- Cell (3,2)
- Cell (3,3)
Market Advantage

- **Market Advantage:** the ability of traders to secure higher net profits for themselves than they would obtain under competitive market conditions

- **Market Power:** “the ability to profitably alter prices away from competitive levels” (Stoft, *Power System Economics*, 2002, p. 318)

- Market advantage is a **necessary** condition for the exercise of market power.
Structural vs. Strategic Market Advantage

- **Structural Market Advantage:** The market advantage conferred on a trader by market protocols alone, assuming all traders bid/ask their true reservation prices (no strategic bid/ask pricing behavior)

- **Strategic Market Advantage:** Any additional market advantage that can be secured by a trader through strategic bid/ask pricing behavior
Market Advantage: Aggregate Findings

- **For given RCON**, changes in the aggregate measure RCAP do not exhibit any meaningful correlation with aggregate seller and buyer market advantage outcomes.

- **For given RCAP**, changes in the aggregate measure RCON have only small unsystematic effects on aggregate seller and buyer market advantage outcomes.
Market Advantage: Micro Findings

- **Relative** market advantage of sellers and buyers can be reliably predicted from the *market microstructure*.

- Sellers and buyers are **not** able to secure increases in **relative** market advantage *through strategic pricing*.

- Actual Market Advantage = Structural Market Advantage

- **Conjecture**: Lack of *strategic* market advantage for traders is due to symmetry of double auction electricity market
Summary of Findings for NPT (IEEE-TEC 2001)

- **High** market efficiency is obtained when traders use individual reinforcement learning but **not** when they use social mimicry learning.

- The **microstructure** of the double auction electricity market is strongly predictive for the **relative** market advantage of traders.

- Traders are **not** able to increase their **relative** market advantage through strategic pricing *(importance of demand-side bidding as countervailing power to supply-side offers)*

Joint research by
Deddy Koesrindartoto
and
Leigh Tesfatsion
in association with
Los Alamos National Lab

Work in Progress
Wholesale Power Market Platform - WPMP (FERC, White Paper, 4/03)

WPMP Objectives

- Customer-based competitive wholesale power markets providing reliable service
- Fair and open access to the transmission grid at reasonable prices
- Good price signals to encourage appropriate investment in new generation and new transmission
- Market power mitigation
Key WPMP Features

- Independent operation of the transmission system by RTO/ISO
- Day-ahead electricity market (financial)
- Real-time electricity market to supplement longer-term contracts
- Ancillary services to ensure resource adequacy (e.g., operating reserves,...)
- Congestion management, preferably through Locational Marginal Pricing (LMP) and financial transmission rights
- Market monitoring and market power mitigation
FERC’s Basic WPM Proposal Adopted?

- **Mid-Atlantic states** (PJM) implement similar plan (1998)
- **New York** (NY-ISO) implements similar plan (1999)
- **New England** (NE-ISO) implements similar plan (2003)
- **California** (CAISO) files to adopt similar plan (2003)
- **Midwest** (MISO) files to adopt similar plan (7/2003) and withdraws filing (10/2003)
- **Opposition** from states in Southeast and Northwest
Our ACE WPM Model

- Based on **Standard Market Design (SMD)** implemented by New England (ISO-NE) on March 1, 2003

- **SMD meets basic WPMP structural requirements:**
  - Independent System Operator (ISO)
  - Day-ahead and real-time electricity markets
  - Congestion managed via Locational Marginal Pricing
  - Financial transmission rights
  - Reserve and capacity markets as well as enhanced demand response (in planning stage)
Our ACE WPM Model...

• **Initial Core Model**
  - Independent System Operator (ISO)
  - Day-ahead electricity market
  - Real-time electricity market
  - Congestion managed via LMP
  - AC transmission grid
  - OPF/reliability/settlement handled by ISO
  - 5-bus demo model

• **Planned Model Extensions**
  - Auction market for financial transmission rights (FTRs)
  - Bilateral market
5-Bus Demo Model
ACE WPM Model: Class Hierarchy

- World
  - ISO
    - Reliability
    - OPF
    - Settlement
  - Markets
    - Day-Ahead
    - Supply Re-offers
    - Real-Time
  - Transmission Grid
    - Bilateral
    - FTR
  - Traders
    - Buyers
    - Sellers
  - Load Serving Entities
  - Generators
## ISO Market Operation (Day D)

<table>
<thead>
<tr>
<th>Time</th>
<th>Market Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:00</td>
<td><strong>Day-Ahead Market for D+1</strong></td>
</tr>
<tr>
<td>10:00</td>
<td><strong>ISO evaluates demand bids and supply offers</strong></td>
</tr>
<tr>
<td>12:00</td>
<td><strong>Supply Re-Offers for D+1</strong></td>
</tr>
<tr>
<td>16:00</td>
<td><strong>ISO produces D+1 dispatch schedule for generators and LSEs</strong></td>
</tr>
</tbody>
</table>

**Real-Time (Spot) Market for D**
ACE WPM Model: Activity Flow

Start

Initialization

Monthly Loop

FTR Market

Daily Loop

Hourly Loop

Real Time Market

D+1 Day Ahead Market

D+1 Supply Re-Offer

End
Initial Experimental Design: Treatment Factor Ranges

- Simple reinforcement learning ➔ Learning to learn
- Passive demand ➔ Active demand bidding
- No transmission rights ➔ Point-to-point financial transmission rights
**Longer-Run Research Plans**

- Collaboration with Los Alamos National Lab energy researchers

**Objectives:**

- To scale up ACE wholesale power market model to more realistic dimensions
- To incorporate ACE wholesale power market model into the LANL Marketecture Model for U.S. Energy Infrastructure