Electricity Market Design

An Agent-Based Computational Economics Approach

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Outline

★ What is ACE (agent-based computational economics?)

★ ACE and Market Design

★ Illustrative Application: An Electricity Double Auction

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
ACE Methodology

- **Primary Concern:**
  Micro-foundations of observed macro regularities

- **Primary Tool:**
  Computational laboratories

- **Basic Approach:**
  Culture-dish experiments
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/aapplc.htm)

- Embodied cognition
- Network formation
- Evolution of norms
- Specific market case studies
- Industrial organization
- Market Design
- Automated markets and software agents
- Computational laboratories
- Parallel experiments…
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,…); 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 (ISO, generators, LSE’s…) 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 on market performance
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)
Illustrative ACE Study of Electricity Market Design

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

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?
ACE Electricity 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 repeated discriminatory double auction
- Fully connected transmission grid (ATC constraints non-binding in this study)
Electricity Market 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 $R_{\text{Max}}$ rounds (trader bid/asks $\rightarrow$ price and quantity outcomes)
- Compare results against competitive equilibrium benchmark
Two Structural Treatment Factors

Let “Sellers” = Generators and let “Buyers” = LSE’s

- **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)
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.
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 traders use individual reinforcement learning

- **LOW** market efficiency obtained when the traders use social mimicry learning

**CONCLUSION:**

Efficiency of double-auction electricity market *not* robust against active exercise of bad judgement (e.g., inappropriate social mimicry)
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 their true reservation prices (no opportunistic bidding behavior)

- **Strategic Market Advantage:** Any *additional* market advantage that could be secured by a trader *by opportunistic bidding 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 traders can be reliably predicted from the market *microstructure*.

- Traders 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

- **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.