Electricity Market Design

An Agent-Based Computational Economics Approach

Presenter (October 2003):

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Outline

- What is ACE (agent-based computational economics?)
- ACE and Market Design
- Illustrative Application: An Electricity Double Auction

J. Nicolaisen, V. Petrov, L. Tesfatsion, "Market Power and Efficiency in a Computational Electricity Market with Discriminatory Double-Auction Pricing," *IEEE Transactions on Evolutionary Computation* 5(5), October 2001, 504-523

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/aapplic.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"

J. Nicolaisen, V. Petrov, and L. Tesfatsion, *IEEE Transactions on Evolutionary Computation* 5(5), October 2001, 504-523

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 RMax rounds (trader bid/asks ➡ 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