# Electricity Market Design

## An Agent-Based Computational Economics Approach


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# Outline

- What is **ACE** (***A***gent-based ***C***omputational ***E***conomics?)
- ACE and Market Design
- Illustrative Application: An Electricity Double Auction

**Key Reference:**

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 economic processes, including entire economies, modeled as open-ended dynamic systems of interacting agents
- Specialization to economics of the basic complex adaptive systems paradigm

# ACE Methodology

***Primary Concerns:***

Microfoundations of observed macro regularities; development and performance testing of institutional designs; derivation and testing of conceptual conjectures

***Primary Tool:***

Computational laboratories

***Basic Approach:***

Culture-dish experiments

# Culture Dish Analogy

- Virtual world populated by agents representing individuals, social groupings, institutions, and/or physical phenomena
- Modeler sets initial conditions of the world
- The world then evolves over time without further external intervention.
- This evolution is driven solely by agent-agent interactions.

# Current ACE Research Areas

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

- Parallel experiments...
- Embodied cognition
- Network formation
- Evolution of norms
- Specific market case studies
- Industrial organization
- Market Design
- Automated markets and software agents
- Computational laboratories

# Economic Research on Electricity Market Design

https://www2.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 the ACE Approach

- Key market participants -- system operator, suppliers (power generators), load-serving entities (LSEs) who manage customer power demands – can all be 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 model and test detailed empirically-based structural market features for individual and/or joint effects on market performance

# ACE Electricity Research

https://www2.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, L. Tesfatsion, *IEEE Transactions on Evolutionary Computation* 5(5), Oct 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.
- To what extent is market structure predictive for market performance?
- To what extent is learning predictive for market performance?

# ACE Electricity Market: Basic Structure

- N Generators and M **L**oad-**S**erving **E**ntities (**LSE**s)
- Repeated participation in wholesale power market operated by an **I**ndependent **S**ystem **O**perator (**ISO**)
- Market conducted as a daily (repeated) discriminatory double auction
- Fully connected transmission grid
- Transmission line capacity constraints are assumed to be non-binding.

# 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:
  In each round, Trader bid/asks result in price & quantity auction 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 (DCAP) to total seller supply capacity (SCAP)

# 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 & individual levels).

# Trader Learning

- Each trader independently uses an ***individual reinforcement learning algorithm*** to determine its ask or bid price in each market period.

- Entire RCON/RCAP experimental design was implemented three times under ***three different specifications for the parameters of the Traders' reinforcement learning algorithms.***

## Trader Learning … Continued

- **Reinforcement learning results compared against an earlier electricity study** by the same authors using the structure for the double auction electricity market.
- ***Difference Between Studies:*** In the *earlier* study, the suppliers used **social mimicry learning** implemented by means of a population-level genetic algorithm; and similarly for the 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 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 ("price taking") market conditions
- **Traditional Economic Conception of 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 can be secured by a trader *by means of 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*