



# Electricity Market Design

## An Agent-Based Computational Economics Approach

*Presenter (October 2003):*

- Leigh Tesfatsion
- Professor of Economics  
and Mathematics
- Iowa State University
- [www.econ.iastate.edu/tesfatsi/](http://www.econ.iastate.edu/tesfatsi/)
- [tesfatsi@iastate.edu](mailto:tesfatsi@iastate.edu)



# 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](http://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](http://www.econ.iastate.edu/tesfatsi/aelect.htm) )***

- Argonne National Lab  
(Macal, North,...)
- CSIRO-Australia (Batten,...)
- Helsinki Univ. (Hamalainen,...)
- Iowa State University  
(Koesrindartoto, Sheble,  
Tefatsion,...)
- 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