Agent-Based Market Design

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**(borrowing from Marks 2006,
and Kunchamwar, Marks, & Midgley 2005)**

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Outline of Talk

1. Introduction
2. Analysis and Simulation
3. Learning
4. Analysis $\longrightarrow$ Design
5. Market Mechanisms
6. Designing Electricity Markets
7. Designing Auctions
8. Conclusions

1. Introduction

What is "market design"?

Designing the structure and rules of engagement of markets — the engineering of markets (often repeated auctions).

When?

With the designing and implementing of new, "designer" markets.

Using ACE: Agent-based Computational Economic models.
(See the 2006 *Handbook*, ed. by Tesfatsion & Judd.)

New Designer Markets:

1. **For new financial instruments — options, derivatives.**
2. **Emissions trading: for** SO_2**,** CO_2**,** NO_x**.**
3. **(Electro-magnetic) Spectrum auctions.**
4. **Electricity markets.**
5. **On-line markets, e-commerce.**
6. **Contract design.**

2. Analysis and Simulation

1. **To change, we must understand: analysis**
2. **Complexity calls for simulation**
3. **Understanding leads to improvement: design.**

Closed-Form Analysis:

1. **Observation.**
2. **Need for explanation and understanding is identified;**
3. **A model is built, incorporating simplifying assumptions;**
4. **Model is manipulated to obtain necessary and sufficient results, existence, uniqueness, and stability of an equilibrium,**
5. **Possible improvement in the operation of the system is identified, if possible.**

Analysis, and then synthesis, or *design.*

Simulation and Analysis: Why Simulation?

1. ***Tractability:*** **e.g. continuous double auctions**
2. **To characterise *out-of-equilibrium behavior,* and especially the *dynamic behavior* of an operating market with fluctuating demand, and perhaps varying numbers of sellers, with unpredictable, varying costs.**
3. **Perfect rationality and unlimited computational ability on the part of human traders is *unrealistic.***

   Using computer models agents, can model economic actors in markets as boundedly rational: bounded computational ability, or bounded memory, or bounded perception.
4. **To model *learning.***

3. Learning

- **GA as a model of adaptive population learning agents:**
  - **— individuals**
  - **— routines, ideas, heuristics**
- **Implicit learning from generation to generation.**

Explicit Learning

- **Reinforcement learning — Arthur (1991)**
  $q_{ij}(t-1) = q_{ij}(t) + (x - x_{\min})$
- **Roth & Erev (1995, 1998): include Arthur as a special case**
  $qij(t+1) = (1-\phi)q_{ij}(t) + f(\varepsilon, x - x_{\min}, N)$
  ϕ**: recency,** ε**: experimentation.**
  But inductive learning: not anticipative.
- **Vriend (2000):**
  - **— social learning of the single-population GA**
  - **— individual learning of the non-GA ACE model**
- **Significance of the learning model?**

4. Analysis → Design

Roth (1991): market design is a suitable case for using three complementary approaches:

1. **traditional closed-form game-theoretic analysis;**
2. **experimental results from economics laboratories;**
3. **computational exploration of different designs. "Exploration:" analysis and synthesis.**
4. **(and, finally, direct design — optimisation of an objective function, where possible)**

Bottom-up design:

Historical market institutions were not been imposed from above but have emerged from the bottom up as a consequence of a multitude of actions and interactions.

Evolutionary and agent-based computation raises the possibility of bottom-up design or emergence through simulation.

Sufficiency or Necessity?

- **Closed-form → necessary & sufficient**

  Where the mapping is sufficiently well understood, and where closed-form analytic solution is possible, it should be possible to describe not only sufficiency — if the market has this structure, and the rules of trading are such and such and the traders are given this information, then this performance and behavior will follow, at least in general form — but also necessity — if you want this performance and behavior, then this is the only set of designs (combinations of structure and rules) that will produce it.

- **Simulation $\rightarrow$ sufficient condition**

  With human experiments or with computer simulations, necessity is usually out of reach because of many degrees of freedom, and we make do with sufficiency.

  Only if small numbers of degrees of freedom will simulation $\rightarrow$ necessity.
  e.g. DNA structure and mechanism

Marketplace Design Framework
(MacKie-Mason & Wellman, 2006)

A transaction:

1. **the connection**
2. **the deal**
3. **the exchange**

The Marketplace system:

- **agents**
- **market mechanism**
- **embedded in an amount of social institutions**

∴ Design of:

- **market mechanism**
- **agents**

5. Market Mechanisms

i.e. “the deal”: allowable actions $\rightarrow$ settlement

Specify:

- **which concerns of agents are recognised**
- **permissable rules**
- **rules: actions $\rightarrow$ allocations**

Model the constraints:

eg no external subsidies, maintain horizontal equity, etc

6. Designing Electricity Markets

Design objectives are specified in a performance space (or behavior space) and the building occurs in a design space. The mapping from the designed structure to the desired performance may not be clear.

With evolution, the design would occur in the genome space, while the behavior or performance occurs in the phenome space.

Syntactic Complexity

Edmonds & Bryson (2003) speak of the *syntactic complexity* of design:

no clear mapping: design → behavior:
the only way to know behaviour is to run the system.

Analysis is not able to predict the outcome.

Mapping: initial conditions of structure and rules → behavior and performance is not smooth or continuous:

Design Trade-offs

Possible criteria for a single auction (Phelps et al., 2002, 2005):

1. **maximising seller revenue**
2. **maximising market efficiency**
3. **discouraging collusion**
4. **discouraging predatory behaviour**
5. **discouraging entry-deterring behaviour**
6. **budget balance**
7. **individual rationality**
8. **strategy-proofness**

For an electricity market:

- reliable service (no blackouts or brownouts)
- fair and open access at reasonable prices
- effective price signals: investment in generation and transmission
- effective oversight to mitigate market power.

Market power has been a focus of ACE electricity modellers, given the degrees of freedom closed-form analysis is deprecated.

Design of ACE Markets
(LeBaron, 2006)

1. economic environment & object traded
2. agent’s preferences
3. market clearing & price formation
4. the fitness measure
5. use of information
6. market learning
7. benchmarking

Use of Agents

ACE derives aggregate behaviour from the bottom up, with autonomous agents, unlike, say, System Dynamics, which is top-down, with no agents.

With several design trade-offs, and the possibile emergence of new behaviour.

In finance, ACE design useful for exploring:

- **— stockmarkets**
- **— microfoundations**
- **— tick sizes**
- **— different learning mechanisms**
- **— etc**

Early Electricity Modelling

"Arguably, a well-constructed computer model could improve the accuracy of our competitive analysis in at least two ways: by explicitly representing economic interactions between suppliers and loads at various locations on the transmission network, and by accounting for the actual transmission flows that result from power transactions." and

"Consistency of data sources and consistent application of those data is an attraction, but such techniques require time, education, and consistent refinement. Moreover, adequate data may not be available. I hope the benefits will be worth our trouble and investment. Our economists are trying to get a handle on precisely that equation."

— then FERC Chairman, James Hoecker, 1998.

“Single-Population GAs” v. ”Agent-based Models“

At first, research models mainly used single-population GAs: Curzon Price (1997) discussed this possibility.

ACE models are becoming more popular than single-population GA-based models, as seen in citations in the IEEE Xplore on-line database.

Antecedents:

- **Roth (1991), (2000), (2002)**
- **Marks (1992), (1995), (1997)**
- **Hämäläinen et al. (1994), (1994), (1995), (1996),**
- **Andreoni & Miller (1995)**
- **Wellman et al. (1998),**
- **Curzon Price (1997)**
- **Richter & Sheblé et al. (1998), (1999), (2000),**
- **Bunn et al. (1998), (2000), (2001), (2001), (2001), (2003),**
- **MacGill & Kaye (1999),**
- **Harp (2000),**
- **Nicolaisen et al. (2000, 2001)**

Engineers and economists:

- **The Finns.**
- **Bunn and associates.**
- **Tesfatsion and associates.**
- **Computer scientists.**

Early users of ACE methods

The Finns

1994: object-oriented demand-side modelling, without learning.

1995: agent-based modelling framework

1997: a von Stackelberg market; maximising market efficiency (sum of buyers’ and sellers’ surplus); both sides as agents

Tesfatsion and associates

Two influential papers (2000 & 2001):
Both use discriminatory-price clearinghouse k-DA
Both focus on market power
Both assume sellers seek to max their profits

Compare GA learning and RL

Found that RL produced better results (higher efficiency) than did single-population GAs, due to extra-market social learning (Vriend).

Bunn and associates

2000/2001: Focussed on changes to wholesale electricity markets, and auction form: uniform v. discriminatory.
Used GA learning.

Higher prices with discriminatory.

2003: what market conditions sufficient for exercise of market power?
Used RL.
Agents can price and withold capacity.

Recent Studies

Entriken et al. (2003):

“agent-based simulation is a useful tool for analyzing existing and proposed design features of electricity markets

“does not rely directly on real economic practice, nor does it rely completely on theory — an attempt to write computer programs for deciding how to bid into electricity markets in ways similar to those found by the experimental economists

“important comparisons were made with theoretical results and documented economic experiments with human subjects in order to ensure reasonable behavior of the agent-based simulations.

“Simulating decisions, whether how to bid or how to change market rules, before implementing them can have enormous benefits. As we have learned the hard way, the unintended the consequences of such decisions can be very costly.

“configured the agents in an attempt to eliminate experimental bias. First, the demand players always bid their willingness-to-pay: price takers. The suppliers exercise all of the strategy in our simulation, and each one uses an identical strategy of aggressive profit maximization.

“marginal suppliers utilize a very simple naïve rule as a greedy algorithm for rent capture: test the margin by raising their bid prices.”

7. A Synthetic Auction Design

Byde (2002): A auction where the highest bidder wins and pays an amount given by

$$(1 - w)bid_1 + wbid_2,$$

where bid_1 is the highest (sealed) bid and bid_2 the second-highest.

When w = 0: a first-price auction;
when w =1: a second-price auction.

Used a GA to explore the impacts on seller's revenue.

Found under certain plausible conditions that seller's revenue is maximised when w = 0.3, a synthetic auction superior to both first-price and second-price auctions.

8. Conclusions

Leombruni & Richiardi (2005) question reluctance of main-stream economists to embrace ACE modelling. (From 1970, only 8 ACE articles of 26,698 in top 20 econ journals.)

Possible reasons:

i. **interpretation of the simulation dynamics and generalization of the results,**

ii. **estimation of the simulation model**

iii. **I would add: in general,** *no necessary conditions* **from simulation, just sufficient conditions**

iv. **and validation of the model.**
(but also applies to closed-form models)

Validation

- **In the 2006 *Handbook*, a search reveals that only 4 of 24 chapters meantioned “validation”, a total of 9 times.**
- **But: Solving the equations right, versus Solving the right equations.**
- **Verification: model does what modeller wants. Validation: model is accurate and appropriate.**
- **Model $\leftrightarrow$ Theory $\leftrightarrow$ Phenomenon**

Validation is difficult

- **Especially a model of a complex system (with emergence). (Kelton et al. 2001)**
- **A large parameter space. (Shervais et al. 2003)**
- **Path dependence, positive feedback, extreme sensitivity to initial conditions.**
- **Little knowledge of micro-details.**

LeBaron (2006)’s steps

- **Replicate difficult empirical features: do ACE models fit facts not otherwise explained?**
- **Put parameters under evolutionary control: learning rates, memory depth.**
- **Use results from lab experimental markets: learning dynamics for ACE models.**

ACE modellers try harder:
the challenge of validation to gain acceptance is an opportunity to demonstrate the relative indifference of the closed-form traditionalists to validation.

How to Validate

Need for —

- **benchmarking: against history, against other models;**
- **seeking the extremes or “breaking” the model: what levels of inputs (separately or in combination) result in absurd outputs?**
- **looking at the model as a “black box” and exploring its response to step functions (off & on, min & max, one input variable at a time),**
- **statistically estimating the model as a function from inputs to outputs (inputs as independent vars, outputs as dependent vars).**

First convince oneself

Judgement of modeller $\rightarrow$ acceptance of policy-makers?

Modeller should convince herself, as the most skeptical observer. Lawyers?

Conclusions

Market Design in the face of complexity in the mapping from initial conditions (structure, parameters) in the design space to behavior in the performance space requires iteration to explore the mapping.

So: Why ACE?

- **Explanation, using bottom-up modelling.**
- **Occam's Razor: trade-off between simplicity and encompassing reality.**
  But reality might be simpler than theory suggests.
- **Validation: We try harder!**