Market Design Using ACE Simulations

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VIII. The Design Economist.

>

Simon on Market Design

“The basic idea is that the several components in any complex system will perform particular subfunctions that contribute to the overall function. ... To design such a complex structure, one powerful technique is to discover viable ways of decomposing it into semi-independent components corresponding to its many functional parts. The design of each component can then be carried out with some degree of independence of the design of others... There is no reason to expect that the decomposition of the complete design into functional components will be unique.... Much of classical organization theory in fact was concerned precisely with this issue of alternative decompositions of a collection of interrelated tasks.” (Simon, 1996)

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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, but ...**

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Analysis is not able to predict the outcome.

Mapping: initial conditions of structure and rules $\rightarrow$ behavior and performance is not smooth or continuous:

II. Markets Have *Emerged*

Historical market institutions have in general not been imposed from above (*top-down design*) but have emerged from the bottom up as a consequence of a multitude of actions and interactions of the myriad traders (McMillan 2002).

The omnipotent programmer can experiment with different market forms and different kinds of boundedly rational agents to discover sufficient combinations of each for specific behavior of the market,

But evolutionary computation raises the possibility of *bottom-up design*,

or emergence of market design through simulation.

Purpose of Agent-Based Simulated Market Design

Which?

- **as a model of human behavior (where analysis is followed by design, given the behavior of the agents and the emergent aggregate outcomes) — in which case it is an empirical question as to how boundedly rational the agents should be to best model human agents (Duffy, 2006) *or***
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- **as an end in themselves, because on-line it is possible to use agents (“buy-bots, sell-bots”) to buy and sell, without the errors that human agents are heir to.**

Two Deeper Issues

1. to what extent are the learning processes of human participants in real-world markets mal-adapted to market institutions?

   Could the use of agent-based optimization tools improve human market behavior?

   e.g. in eBay auctions, when bidders use software to enhance their chances of being the high bidder at the deadline.

2. to what extent have existing market protocols (or market designs) evolved or been designed to avoid the need for any great rationality on the part of market participants?

Gode & Sunder (1993) and others seek to answer this question for financial markets; their results may be valid for other markets.

Markets and the Participants

Market performance may depend on the degree of “intelligence” or “rationality” of the agents buying and selling.

What if a market design with agents of low degree of “intelligence” is found to be sufficient for a specific level of market performance?

Then less bounded participants would, through buying and selling, create an efficient market (Walia et al. 2003).

Unless a market loophole, or rent-seeking by more intelligent agents, lowers market efficiency (Arifovic 2001).

See Tesfatsion (2002), LeBaron (2006), Duffy (2006).

III. Market Design Difficulties

Design: a process of building directed by: the pre-specified design objectives, or an explicit how-to plan.

But specifying objectives does not $\rightarrow$ exactly how the model building should occur. Why?

Objectives specified in a performance space (or behavior space), but the building occurs in a design space.

Mapping: designed structure $\rightarrow$ the desired performance not clear.

In evolution: design in the genome space, while behavior or performance in the phenome space.

Designing Markets

In designer markets: policy-makers use theory, human experiments and computer simulations to help the mapping: design (structure and rules) $\rightarrow$ behavior of the economic actors (the performance of the system).

Where the mapping is sufficiently well understood, and where closed-form analytic solution is tractable, 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**

but also *necessity:*

> **If you want this performance and behavior, then this is the only set (or sets) of designs (combinations of structure and rules) that will produce it.**

Sufficiency yes, but Necessity?

With no closed-form analytical solution, but with human experiments or with computer simulations: necessity is in general impossible, only sufficiency.

But with few degrees of freedom, necessity is close:

Watson & Crick (1953): simulated the structure of DNA, given its chemical properties (acid), known atomic composition (and electrical properties), and some X-ray diffractions

The title of their 1953 paper:
"*A* structure of DNA", not *the* structure.

VI. Four Reasons for Simulation of market design

1. **tractability:**
   still very difficult to obtain solutions to the design of some markets, such as continuous double auctions (CDAs).
2. **like to characterize 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. **the assumption of perfect rationality and unlimited computational ability on the part of human traders is unrealistic, and not borne out by laboratory experiments with human subjects.**

   Instead, using computer models of trading agents, should like to model economic actors in markets as “boundedly rational” — bounded computational ability, or bounded memory, or bounded perception (Marks 1998).

4. **to model learning:**
Two reasons to include learning in any models used to design markets:

   a. **Individuals and organizations learn: a model without learning is not as realistic as one incorporating learning.**

   b. **Moreover, learning can help to eliminate many otherwise legitimate Nash equilibria.**

V. ... Enter the Agents

Can design without the use of agents:
given a market with demand and supply schedules, economic efficiency is maximized at the output level where marginal value equals the marginal unit cost, no matter how the social surplus is divided between buyers and sellers.

But such direct design (optimization) requires a well defined problem.

With several design trade-offs and the possible emergence of unforeseen performance in the system:
enter agent-based analysis and design:
models the market system as “evolving systems of autonomous, interacting agents with learning capabilities“ (Koesrindartoto & Tesfatsion, 2004)

AGENT-BASED MODELS

In ABM/ACE models, a population of software objects is:

- **— instantiated, and each agent is given**
- **— certain internal states (e.g., preferences, endowments) and**
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The agents are then permitted to interact directly with one another and a macrostructure emerges from these interactions.

Patterns Emerge

Patterns in this macrostructure may then be (Axtell, 2005).

— compared with empirical data,

— agent internal states and rules revised, and

— the process repeated until an empirically plausible model obtains.

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Another example of an agent that won $2,000,000 in a challenge by the U.S. Department of Defense this October ...


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Agents and agency

Wooldridge & Jennings (1995) would give computer agents these properties:

- **autonomy: no others control their actions and internal state,**
- **social ability: can interact and communicate with other agents**
- **reactive: they perceive their environment and respond**
- **procative: they initiate goal-directed actions**
- **(intentionality: metaphors of beliefs, decisions, motives, and even emotions)**

Eight Desired Attributes of Modelled Agents (G&T)

1. **Knowledge & beliefs.**
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3. **Social models.**
   Agents, knowing about interrelationships between other agents, can develop a “social model”, or a topology of their environment: who’s who. etc.

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4. **Knowledge representation.**
Agents need a representation of beliefs: e.g. predicate logic, semantic (hierarchical) networks, Bayesian (probabilistic) networks.

> [Sebastian] Thrun [leader of the winning team in the 2005 DARPA Grand Challenge] had a Zen-like revelation: "A key prerequisite of true intelligence is knowledge of one's own ignorance," he thought. Given the inherent unpredictability of the world, robots, like humans, will always make mistakes. So Thrun pioneered what's known as probabilistic robotics. He programs his machines to adjust their responses to incoming data based on the probability that the data are correct. — Pacella (2005).

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8. **Emotions.**
   Emergent features? Significant in modelling agents? Or epiphenomenal?

How to Model Agent Architecture?

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Since then, five approaches:

1. **Production Systems**
2. **Object Orientation**
3. **Language Parsing & Generation**
4. **Machine-Learning Techniques, and (most recently)**
5. **Probabilistic Robotics (Thrun et al. 2005).**

VI. A Marketplace Design Framework

— MacKie-Mason & Wellman (2006)

Three fundamental steps that constitute a transaction:

1. **the connection (searching for and discovering the opportunity to engage in a market interaction),**
2. **the deal (negotiating and agreeing to terms),**
3. **the exchange (executing a transaction).**

Define a “marketplace system” as consisting of:

agents and the market mechanism through which they interact, all embedded in an environment of social institutions (language, laws, etc.).

M & W’s Market Mechanism

The set of “rules, practices, and social structures of a social choice process, specifying —

1. permissible actions” (including messages), and
2. market-based exchange transactions as outcomes of a function of agent messages.

If there is some entity, apart from the participating agents, that manages any inter-agent communication and implements the mechanism rules, then the market mechanism is *mediated.*

Thus Several Design Decisions

M&W: this characterization of a marketplace → several design decisions:

1. **the design of the market mechanism, which might be decomposed into the design of mechanisms for, successively, the connection, the deal, and the exchange phases of a transaction.**
2. **design of agents to interact with the market mechanism, whether existing or newly designed.**

M&W define an agent

An agent: an “autonomous decision-making locus in a system of multiple decision-making entities”.

An agent has “type” attributes, such as:

- preferences,
- beliefs,
- intentions, and
- capabilities.

Want consistency between the agents’ behavior, beliefs, and preferences, consistent with some principle of rationality.

Here: focus on design of MacKie-Wellman’s market mechanism, specifically, the deal negotiation task, that govern the settlement from allowable actions.

Market Mechanisms

Mechanisms specify:

1. **the agents' concerns that are recognized, and,**
2. **rules mapping actions into allocation outcomes.**

A rule might:

- **specify which actions are permissible, or**
- **the procedure for choosing a settlement of agents' concerns based on observable actions.**

E.g., auctions have rules governing allowable actions, and rules governing settlement.

Designs are constrained

Design of the market mechanism must be measured,

usually consists of a constrained optimization, even if not explicitly or directly.

E.g. “No external subsidies” or
“maintain horizontal equity”

— are two possible constraints.

The General Market Design Issue:

has become designing a market mechanism that:

- **includes defining a set of concerns over which agents can interact,**
- **specifying rules of permissible actions, and**
- **specifying rules for mapping from actions to settlement and outcomes.**

VII. Design Trade-offs

Where there are several design criteria, the possibility arises of trade-offs between the criteria.

E.g., if a firm has market power, it can maximize its seller revenue, but at the cost of market efficiency, as measured by the sum of seller (or producer) surplus and buyer (or consumer) surplus.

Or it might be possible to improve the fairness of a market outcome, but at the cost of market efficiency.

Such trade-offs must be explicit.

How good is a designed auction market?

(Phelps et al., 2002, 2004) suggest eight possible criteria:

1. **maximizing seller revenue:**
   one of the main criteria in the design of the spectrum auctions, such as the 3G auctions (Milgrom, 2004);
2. **maximizing market allocative efficiency:**
   a desirable policy attribute of a marketplace system;
3. **discouraging collusion**
   to attaining the first and second criteria;
4. **discouraging predatory behavior**
   to help to maximize efficiency;

5. **discouraging entry-deterring behavior to maximize seller revenue;**
6. **budget balance:**
   no third-party payments for a deal to be reached;
7. **individual rationality:**
   the expected net benefit to each participant from the market mechanism should be no less than the best alternative; and
8. **strategy-proofness:**
   participants should not be able to gain from non-truth-telling behavior.

A Design Impossibility Theorem

Myerson & Satterthwaite (1983) derived an impossibility result:

> **No double-sided auction mechanism with discriminatory pricing can be simultaneously efficient, budget-balanced, and individually rational.**

In discriminatory-price auctions (or “pay-as-bid” auctions), distinct trades in the same auction round occur at distinct prices;

In uniform-price auctions, all trades in any given auction round occur at the same price.

Blake’s 7

Blake LeBaron (2004), in examining the use of agent-based models of financial markets, discusses seven basic design questions for his models, which translate across to more general models.

1. **the economic environment itself needs to be resolved: what will be traded? what is the scope of the market?**
2. **how are agents’ preferences to be modelled: with particular functional forms such as mean–variance, Constant Absolute Risk Aversion, myopic or inter-temporal, or perhaps just using evaluation of specific behavioral rules.**

3. **modelling of market clearing and price formation.**
4. **evaluating the fitness of the model: wealth or utility? And whether the evolving rules are forecast-based (what will the price be at time t?) or demand- and action-based.**
5. **how information is precessed and revealed.**
6. **how learning occurs: is it social and direct or at arm's length; is it individual?**
7. **how is benchmarking to be undertaken?**

While these questions relate to the models used to design markets, they may also reflect on the design criteria for the final designer markets.

VIII. The Design Economist

Roth (2000, 2002) points the way forward for market design, with the economist as engineer.

Roth: as engineers have learnt to borrow from the insights of physics, the design economist can use insights from equilibrium mathematical economics, and from computer science.

When these insights are curtailed, perhaps by the tractability of closed-form analytical methods, both economists and software engineers have been using simulation in analysis, to obtain sufficient, but rarely necessary, conditions.

Simulation has occurred using GAs, numerical solutions, and explicit agent-based models, with iteration.

Some Criticisms of the ACE approach to modelling markets

- **Too many parameters,**
- **Questions about the stability of trading to the introduction of new trading strategies, sensitivity to the number of agents trading,**
- **Over-reliance on inductive models of agents, which respond to past rules and forecasts and**
- **Not enough on deductive models which might learn commonly held beliefs about how markets work.**

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