Modeling Decentralized Market Economies as Distributed Local-Interaction Systems

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Basic References


ACE Resource Site on Multiple-Market Modelling: http://www.econ.iastate.edu/tesfatsi/amulmark.htm
Outline

- Modeling decentralized market economies
- A distributed local-interaction approach
- Illustration: A two-sector market economy
- Computational laboratory implementation (joint work with Chris Cook, ISU CS grad)
- Advantages and disadvantages of this approach for macroeconomic analysis?
The Complexity of Real-World Decentralized Market Economies

- Large numbers of economic agents involved in *distributed market interactions*
- Potential for *strategic behaviour*
- *Pervasive behavioural uncertainty*
- Possible existence of *multiple equilibria*
- *Potentially critical role of institutions*
One Possible Modeling Approach: Walrasian Equilibrium Economy

- **Economy consists of:**
  - price-taking profit-seeking firms
  - price-taking utility-seeking consumers
  - a “Walrasian Auctioneer” pricing mechanism that determines prices to clear all markets

- **Key Issue:**
  Can efficient allocations be price-supported in decentralized market economies?
Example: Two-Sector Walrasian Equilibrium Economy

Fictitious Walrasian Auctioneer

Supply_B(p_B), Div_B(p_B)
Supply_H(p_H), Div_H(p_H)

Bean Firms
Hash Firms

p_B, p_H, Div_B, Div_H
Demand(p_B, p_H, Div_B, Div_H)

Consumer-Shareholders
Alternative Approach: Distributed Local-Interaction Modelling

❖ **Agent-based Computational Economics (ACE):**

Computational study of economic processes modeled as dynamic systems of interacting agents.

❖ **Culture-Dish Approach**

- Computational economy grow itself over time, starting from initial conditions.
- Similar to a culture developing over time in a petri dish.
ACE Modeling: Culture Dish Analogy

- Experimental Treatment Factors (Initial Conditions)
- Economy Develops Over Time (Culture Dish of Agents)
- Macro Regularities
Four Main Strands of ACE Research

- **Empirical Understanding**
  (possible explanations for empirical regularities)

- **Normative Understanding**
  (e.g., development and study of market designs)

- **Qualitative Insight/Theory Generation**
  (e.g., how do decentralized markets work?)

- **Methodological Advancement**
  (agent representation, dynamic visualization, empirical model validation,...)
ACE Study of Decentralized Market Economies

A Key Issue: What are the self-organizing capabilities of decentralized market economies? (Adam Smith, Hayek, Keynes, Schumpeter, ...)

ACE Approach:

- **Construct an agent-based world** qualitatively capturing key aspects of a decentralized market economy (circular flow, limited information, ...)

- **Introduce self-interested traders with learning capabilities.** Let the world evolve. Observe the degree of coordination that results.
Example: From Walrasian Equilibrium to an ACE Trading World

Starting Point:
Two-Sector Walrasian Equilibrium Economy

Exercise:
- **Remove** all imposed *equilibrium* conditions (e.g., market clearing, correct expectations,...)
- **Introduce** minimal *agent-driven* production, pricing, and trade processes needed to re-establish complete circular flow among firms and consumers
- **Experiment** to see if/when resulting economy is able to attain an “equilibrium” state over time
Starting Point: Walrasian Hash & Beans Economy

Fictitious Walrasian Auctioneer

Supply\(_B(p_B), \text{Div}_B(p_B)\)

Supply\(_H(p_H), \text{Div}_H(p_H)\)

p\(_B\), \text{Div}_B\)

p\(_H\), \text{Div}_H\)

Demand\((p_B, p_H, \text{Div}_B, \text{Div}_H)\)

Consumer-Shareholders
Plucking Out the Fictitious
Walrasian Auctioneer

Firm-Consumer Connections??

Consumer-Shareholders

Bean Firms

Hash Firms
Plucking Out the Walrasian Auctioneer

Focus must now be procument processes

❖ **Terms of Trade:** Set production and price levels
❖ **Seller-Buyer Matching:**
  - Identify potential suppliers/customers
  - Compare/evaluate opportunities
  - Submit demand bids/supply offers
  - Select suppliers/customers
  - Negotiate supplier/customer contracts
❖ **Trade:** Transactions carried out
❖ **Settlement:** Payment processing and shake-out
❖ **Manage:** Long-term supplier/customer relations
Illustration: An ACE Hash & Beans Economy

Many-Seller Posted Bean Auction

Many-Seller Posted Hash Auction

Consumer-Shareholders $k=1,\ldots,K(0)$

Supply Offers $SO=(q,p)$

$SO_B1$, $SO_B2$, $SO_B3$, $SO_{H1}$, $SO_{H2}$, $SO_{H3}$, $SO_{H4}$

Div$_B$, Div$_H$
ACE Hash & Beans Economy: Dynamic Flow of Activities

1. Hash & Beans World Constructed
2. Solvent firms post supply offers
3. Surviving consumers search for lowest prices
4. Matched firms-consumers trade
5. Firms/consumers update their situations
ACE Hash & Bean Firms

- Each firm $f$ starts out ($T=0$) with money $M_f(0)$ and a production capacity $\text{Cap}_f(0)$.
- Firm $f$’s fixed cost $\text{FC}_f(T)$ in each $T \geq 0$ is proportional to its current capacity $\text{Cap}_f(T)$.
- At beginning of each $T \geq 0$, firm $f$ posts a supply offer = (production level, unit price).
- At end of $T \geq 0$, firm $f$ is insolvent if it has $\text{NetWorth}(T) = \left[ \text{Profit}(T) + M_f(T) + \text{ValCap}_f(T) \right] \leq 0$.
- If solvent, firm $f$ allocates its profits (+ or -) between $M_f$, $\text{CAP}_f$, and dividend payments.
ACE Consumer-Shareholders

- Each consumer $k$ starts out ($T=0$) with a \textit{lifetime money endowment profile} \( (M_{kyouth}, M_{kmiddle}, M_{kold}) \)

- In each $T \geq 0$, consumer $k$’s \textit{utility} is measured by \( U_k(T) = (\text{hash}(T) - h_k^*)^{\alpha_k} \cdot (\text{beans}(T) - b_k^*)^{1-\alpha_k} \)

- In each $T \geq 0$, consumer $k$ seeks to secure maximum utility by \textit{searching} for beans and hash to buy at \textit{lowest possible prices}.

- At end of each $T \geq 0$, consumer $k$ \textit{dies} if he fails to consume at least \((b_k^*, h_k^*)\).

- Computational laboratory under construction for the ACE Hash-and-Beans Economy
- Programming language C#/.Net (all WinDesktops)
- For use in Econ 308 (ACE course)

www.econ.iastate.edu/classes/econ308/tesfatsion/
What is a Computational Laboratory?

◆ **Computational framework**
  for the study of complex system behaviors by means of controlled and replicable experiments

◆ **Graphical user interface (GUI)**
  permits experimentation by users with no background in programming

◆ **Modular/extensible software support**
  permits computational laboratory capabilities to be changed or extended by users who have programming skills
ACE Hash & Beans Economy: World Event Schedule

World Constructed. World configures Markets, Firms, Consumers and starts the clock.

Firms receive time signal and post quantities/prices in H & B markets

Consumers receive time signal and begin price discovery process

Firms-consumers match, trade, calculate profits/utilities & update wealth levels

Firms update their exp’s & prod/price strategies
A Computational World

**Public Access:**

// Public Methods
- World Event Schedule (system clock);
- Protocols governing the ownership of stock shares;
- Protocols governing firm collusion and insolvency;
- Methods for receiving data;
- Methods for retrieving stored World data.

**Private Access:**

// Private Methods
- Methods for gathering, storing and sending data.

// Private Data
- World attributes (e.g. spatial configuration);
- World inhabitants (Markets, Consumers, Firms,...);
- Data about World inhabitants;
- Methods of World inhabitants;
- A record of past and current World events.
A Computational Market

Public Access:

// Public Methods
getWorldEventSchedule(clock time);
Protocols governing the price discovery process;
Protocols governing the trading process;
Methods for receiving data;
Methods for retrieving stored Market data.

Private Access:

// Private Methods
Methods for gathering, storing, and sending data.

// Private Data
Data recorded about Firms (posted supply offers,…);
Data recorded about Consumers (demand bids,…);
Firm and Consumer addresses (for offer/bid transmittal).
## A Computational Consumer

### Public Access:

#### Public Methods
- `getWorldEventSchedule(clock time);`
- `getWorldProtocols (stock share ownership);`
- `getMarketProtocols (price discovery process, trade process);`
Methods for receiving data;
Methods for retrieving stored Consumer data.

### Private Access:

#### Private Methods
- Methods for gathering, storing, and sending data;
- Method for determining my budget constraint;
- Method for updating my demand bids (LEARNING).
#### Private Data
- Data about me (history, utility function, current wealth,...);
- Data about external world (posted supply offers, ...);
- Address book (communication links).
A Computational Firm

Public Access:

// Public Methods
getWorldEventSchedule(clock time);
getWorldProtocols (collusion, insolvency);
getMarketProtocols (posting, matching, trade, settlement);
Methods for receiving data;
Methods for retrieving Firm data.

Private Access:

// Private Methods
Methods for gathering, storing, and sending data;
Methods for calculating expected & actual profit outcomes;
Method for allocating my profits to my shareholders;
Method for updating my supply offers (LEARNING).

// Private Data
Data about me (history, profit function, current wealth,...);
Data about external world (rivals’ supply offers, ...);
Address book (communication links).
Learning via Roth-Erev
Stochastic Reinforcement Learning

Agents maintain action choice propensities that are translated into action choice probabilities and updated on the basis of profit/utility outcomes.
1. **Initialize** action propensities to an initial propensity value.
2. **Generate** choice probabilities for all actions using current propensities.
3. **Choose** an action according to the current choice probability distribution.
4. **Update** propensities for all actions using the outcomes from the last chosen action.
5. **Repeat** from step 2.
ACE Hash & Beans Comp Lab: Experimental Design Treatment Factors

- Initial size of consumer sector \([ K(0) ]\)
- Initial firm concentration \([ N(0), J(0), \text{Cap}(0)] \)
- Firm learning (supply offers, profit allocations)
- Firm cost functions
- Firm initial money holdings \([ M_f(0) ]\)
- Firm rationing methods (for excess demand)
- Consumer price discovery methods
- Consumer money endowment profiles (rich, poor, ↗, ↖, life cycle u-shape)
- Consumer preferences \((\alpha_k \text{ utility parameters})\)
- Consumer subsistence needs \((b_k^*, h_k^* \text{ values})\)
Interesting Issues for Exploration

- Initial conditions → **carrying capacity?** (Survival of firms/consumers in long run)
- Initial conditions → **market clearing?** (Walrasian equilibrium benchmark)
- Initial conditions → **market efficiency?** (Walrasian equilibrium benchmark)
- Standard concentration measures at T=0 → **good predictors of long-run market power?**
- Importance of **learning vs. market structure** for market performance? (*Gode/Sunder, JPE, 1993*)
Firm Money & Capacity Attributes: Setting Screen
Firm Total Cost Functions: Setting Screen

Total Cost = Fixed Cost + \( 1.0 \times \text{Units Produced} + 0.25 \times \text{Units Produced}^2 \)

Fixed Cost = \( 10 + 0.1 \times \text{Units of Capacity} \)
Firm Profit Allocation Methods: Setting Screen
Firm Learning Methods: Setting Screen

Learning Method: Default
Learning Probability: 25%

Count: 6
Type: Hash, Beans, both

Add Firms
Consumer Money Endowments: Setting Screen

[Image of a computer screen showing a user interface for setting consumer money endowments in a Multi Market Economy Demo. The interface includes options for selecting money endowment profiles such as Poor, Middle Class, Rich, and lifecycle, with a count of 30 consumers.]
Consumer Utility Functions: Setting Screen
Possible Model Extensions

- Situate the economy in a spatial setting
- Permit other coordination mechanisms:
  Examples: Retail stores, insurance companies,...; Evolution of trust, implicit contracts, loyalty....
- Let behaviours and institutions co-develop:
  Example: “Best” trader learning methods depend on auction protocols, and “best” auction protocols depend on trader learning methods.
- Demographics/biological reproduction:
  Consumer agents can have “genotypes” as well as “phenotypes,” permitting haploidy or diploidy reproduction (parent(s) → children)
Advantages and Disadvantages of ACE Modeling for Macroeconomics?

**On the minus side...**

- Requires *detailed initial specifications* of structural attributes, behavioral methods, and institutions.
- Requires construction of *dynamically complete process model* driven solely by agent interactions.
- Dynamic outcomes can exhibit high sensitivity to initial specifications (*strong path dependence*).
- Can ACE models be sufficiently scaled up for the useful study of macroeconomic systems? (*new taxonomy needed for “representative” agents?*)
But on the plus side...

**Freedom from analytical tractability constraints!!**

- Facilitates systematic experimental study of microfoundations → *interactions* → macro events

- Facilitates systematic experimental study of *coordination* and *self-organizing capabilities*

- Facilitates *estimation & calibration of structural attributes, behavioral methods, and institutions based on real-world data* (econometrics, case studies, human subject lab experiments, iterative participatory modeling...)

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