Agent-Based Computational Economics
Growing Economies from the Bottom Up

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Lecture Notes
What is Agent-based Computational Economics (ACE) in a nutshell?

Simple labor market illustration, implemented via the Trade Network Game (TNG) Laboratory

Four main strands of ACE research

Potential advantages and disadvantages of ACE for economic modeling
What is ACE?

- *Computational modeling* of economic processes as open-ended dynamic systems of interacting agents

- A *culture-dish approach* to the conceptual and practical study of economic processes
ACE Culture-Dish Analogy

- Modeler constructs a virtual economic world populated by various agent types
- Modeler sets initial world conditions
- Modeler then steps back to observe how the world develops over time without intervention (no imposed equilibrium, rational expectations, etc.)
- World events are driven by agent interactions
ACE Agent Types

Agents = Encapsulated software programs representing individual, social, biological and/or physical entities

* Cognitive agents are capable (in various degrees) of
  
  • Behavioral adaptation
  • Social communication
  • Goal-directed learning
  • Endogenous evolution of interaction networks
  • “Autonomy” (self-activation and self-determinism based on private internal processes)
Initial World Conditions
(Experimental Treatment Factors)

- Structural conditions
- Institutional arrangements
- Behavioral dispositions of agents
ACE Culture Dish Analogy

Initial World Conditions
(Experimental Treatment Factors)

World Develops Over Time
(Culture Dish of Agents)

Macro Regularities
Illustrative ACE Application Area: Labor Institutions and Market Performance

Some Key Issues:

◆ Labor contracts typically incomplete

◆ Supplemented by government programs with numerous eligibility restrictions

◆ Difficult to test program effects by means of conventional analytical and/or statistical tools
Example: U.S. State Programs Providing Unemployment Benefits (UB)

Typical Features of State Programs (e.g., Iowa):

◆ UB only paid to “no fault of their own” unemployed
◆ UB recipients must continue to seek employment
◆ UB levels based on past earnings
◆ UB of limited duration
◆ UB financed by employer contributions at rates determined in part by each employer’s “benefit ratio” = [UB paid out to former employees divided by the employer’s taxable payroll]
◆ Additional UB often granted when unemployment rate is abnormally high for prolonged periods

➔ Complicated Rules!!
Preferential job search (workers $W \rightarrow$ employers $E$) with choice and refusal of partners

Purple directed arrow =: Refused work offer
Black directed arrow =: Accepted work offer
ACE Labor Market

- 12 workers with same observable structural attributes in initial period T=0
- 12 employers with same observable structural attributes in initial period T=0
- Only observable source of heterogeneity among workers and among employers is their expressed behaviors on the work-site
ACE Labor Market ...

- Each worker can work for at most one employer in each period $T$
- Each employer can provide at most one job opening in each period $T$
- Work-site strategies in the initial period $T=0$ are randomly determined and private information
Each worker and employer has ...

- **Publicly available information** about various market/policy protocols (e.g., unemployment benefit eligibility rules)

- **Private behavioral methods** that can change over time

- **Privately stored data** that can change over time
A Computational Worker

Public Access:

// Public Methods
Protocols governing job search
Protocols governing negotiations with potential employers
Protocols governing unemployment benefits program
Methods for receiving data
Methods for retrieving Worker data

Private Access:

// Private Methods
Method for calculating my expected utility assessments
Method for calculating my actual utility outcomes
Method for updating my worksite strategy (learning)

// Private Data
Data about myself (my history, utility fct., current wealth…)
Data recorded about external world (employer behaviors,…)
Addresses for potential employers (permits communication)
A Computational Employer

**Public Access:**

// **Public Methods**
- Protocols governing search for workers
- Protocols governing negotiations with potential workers
- Protocols governing unemployment benefits program
- Methods for receiving data
- Methods for retrieving Employer data

**Private Access:**

// **Private Methods**
- Method for calculating my expected profit assessments
- Method for calculating my actual profit outcomes
- Method for updating my work-site strategy (learning)

// **Private Data**
- Data about myself (my history, profit fct., current wealth...)
- Data recorded about external world (worker behaviors,...)
- Addresses for potential workers (permits communication)
Flow of Activities in the ACE Labor Market

- Workers make offers to preferred employers at a small cost per offer (quits allowed)
- Employers accept or refuse received work offers (firings allowed)
- Each matched pair engages in one work-site interaction (PD game with 2 possible moves: cooperate or defect)
- Any unemployed (unmatched) worker or vacant (unmatched) employer receives a UB payment
- After 150 work periods, each worker and employer updates its work-site strategy
Flow of Activities in the ACE Labor Market

Initialization

Work Period:
- Search/Match
- Worksite Interactions
- Update Expectations

Evolution Step:
- Evolve Worksite Strategies

Do 1000 Loops

Do 150 Loops
Worksite Interactions as Prisoner’s Dilemma (PD) Games

Employer

C

D

Worker

C

(40, 40)

(10, 60)

D

(60, 10)

(20, 20)

D = Defect (Shirk);  C = Cooperate (Fulfill Obligations)
Key Issues Addressed

How do changes in the level of the unemployment benefits (UB) payment affect...

➢ Worker-Employer Interaction Networks

➢ Worksite Behaviors: Degree to which workers/employers shirk (defect) or fulfill obligations (cooperate) on the worksite

➢ Market Efficiency (total surplus net of UB program costs, unemployment/vacancy rates,...)

➢ Market Power (distribution of total net surplus)
Experimental Design

- **Treatment Factor:** Unemployment Benefits Payment (UB)
- **Three Tested Treatment Levels:**
  - UB=0, UB=15, UB=30
- **Runs per Treatment:**
  - 20 (1 Run = 1000 Generations; 1 Gen.=150 Work Periods)
- **Data Collected Per Run:** Network patterns, behaviors, and market performance (reported in detail for generations 12, 50, 1000)
Three Unemployment Benefit (UB) Treatments in Relation to PD Payoffs

① $\text{UB}=0 < \text{L}=10$

② $\text{L}=10 < \text{UB}=15 < \text{D}=20$

③ $\text{D}=20 < \text{UB}=30 < \text{C}=40$

❖ **NOTE:** Work-site PD payoffs are given by

$L$ (Sucker) = 10 < $D$ (Mutual-D) = 20

< $C$ (Mutual-C) = 40

< $H$ (Temptation) = 60
Market Efficiency Findings

As UB level increases from 0 to 30...

- *higher* average unemployment and vacancy rates are observed; ➡️ **KNOWN EFFECT**
- *more* work-site cooperation observed on average among workers & employers who match. ➡️ **NEW EX POST EFFECT**

**Note:** These two effects have *potentially offsetting effects* on market efficiency.
Market Efficiency (Utility less UB Program Costs) Averaged Across Generations 12, 50, and 1000 for three different UB treatments
Efficiency Findings...

- UB=15 yields *highest* efficiency

- UB = 0 yields *lower* efficiency (too much shirking)

- UB=30 yields *lowest* efficiency (UB program too costly)
Multiple Attractors

Two “attractors” observed for each NEP treatment

UB=0 and UB=15:
- **First Attractor** = Latched network supporting *mutual cooperation*;
- **Second Attractor** = Latched network supporting *intermittent defection*

UB=30:
- **First Attractor** = Latched network supporting *mutual cooperation*
- **Second Attractor** = Completely disconnected network (*total coordination failure*)
Multiple Network Attractors ... Network Details

* Two “attractors” observed for each UB treatment

- No UB (0) or Low UB (15):
  - First Attractor = *Latched W-E network* supporting *mutual cooperation*;
  - Second Attractor = *Latched W-E network* supporting *intermittent defection*

- High UB (30):
  - First Attractor = *Latched W-E network* supporting *mutual cooperation*
  - Second Attractor = Completely disconnected network (*total coordination failure*)
The Following Diagrams Report ...

1. Two-sided (W-E) network distributions
   - **0** = Stochastic fully connected network
   - **12** = Latched in pairs
   - **24** = Completely disconnected

2. Worksite behaviors supported by these networks
Network Distribution for \( UB=0 \)
(Sampled at End of Generation 12)

Network Distribution for ZeroT:12

![Network Distance vs Number of Runs](image)

- [ ] Intermittent Defection
- [ ] Mutual Cooperation
Network Distribution for UB=0
(Sampled at End of Generation 50)
Network Distribution for UB=0
(Sampled at End of Generation 1000)
Network Distribution for **UB=15**
(Sampled at End of Generation 12)
Network Distribution for UB=15
(Sampled at End of Generation 50)

Network Distribution for LowT:50

Network Distance
Number of Runs
Intermittent Defection Mutual Cooperation
Network Distribution for UB=15
(Sampled at End of Generation 1000)

Network Distribution for LowT:1000

Number of Runs

Network Distance

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

Intermittent Defection Mutual Cooperation
Network Distribution for $UB=30$
(Sampled at End of Generation 12)

Network Distribution for HighT:12

Number of Runs

Network Distance

- Intermittent Defection
- Mutual Cooperation
- Coordination Failure
Network Distribution for UB=30
(Sampled at End of Generation 50)
Network Distribution for UB=30
(Sampled at End of Generation 1000)

Network Distribution for HighT:1000

Network Distance
Number of Runs

Mutual Cooperation
Coordination Failure

Network Distance

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

0 2 4 6 8 10 12 14 16 18 20

Number of Runs

Mutual Cooperation
Coordination Failure
Four Main Strands of ACE Research

➢ **Normative Understanding**
  (institutional design, policy selection, ...)

➢ **Empirical Understanding**
  (possible reasons for empirical regularities)

➢ **Qualitative Insight/Theory Generation**
  (self-organization of decentralized markets, ...)

➢ **Method/Tool Advancement**
  (representation, visualization, empirical validation, ...)
ACE and Institutional Design

**Key Issue:** Does an institutional design ensure efficient, fair, and orderly social outcomes over time despite attempts by participants to “game” the design for their own personal advantage?

**ACE Approach:**

- **Construct an agent-based world** capturing salient aspects of the institutional design.

- **Introduce agents with behavioral dispositions, needs, goals, beliefs, etc.** Let the world evolve. Observe and evaluate resulting social outcomes.

*Examples:* Unemployment benefit programs, Internet auctions, stock markets, negotiation protocols, electricity markets...
ACE and Empirical Regularities

Key Issue: Is there a causal explanation for persistently observed empirical regularities?

ACE Approach:

- Construct an agent-based world capturing salient aspects of the empirical situation.
- Investigate whether the empirical regularities can be reliably generated as outcomes in this world.

Example: ACE financial market research seeking the simultaneous explanation of financial market “stylized facts”
https://www2.econ.iastate.edu/tesfatsi/afinance.htm
ACE and Qualitative Analysis

Illustrative Issue: What are the performance capabilities of decentralized markets? (Adam Smith, Ludwig von Mises, Friedrich von Hayek, John Maynard Keynes, Joseph Schumpeter ...)

ACE Approach:

- Construct an agent-based world qualitatively capturing key aspects of decentralized market economies (firms, consumers, circular flow, limited information, ...)

- Introduce traders with behavioral dispositions, needs, goals, beliefs, etc. Let the world evolve. Observe the degree of coordination that results.

Examples: Decentralized exchange economies (no “Walrasian Auctioneer”), double-auction markets (learning traders vs. “zero intelligence” traders),...
Potential Disadvantages of ACE for Economic Modeling

- Intensive experimentation is often needed (fine sweeps of parameter ranges to attain robust findings)
- Multi-peaked rather than central-tendency outcome distributions can arise (strong path dependence possible)
- Can be difficult to ensure platform robustness (i.e., results that are independent of the hardware and/or software implementation of a model)
- Effort required to gain computer modeling skills can be significant (creative computational modeling, not simply the use of pre-existing models/programs, requires good computer programming knowledge)
Potential Advantages of ACE for Economic Modeling

- **Permits systematic experimental study** of empirical regularities, economic institutions, and dynamic behaviors of complex economic processes in general.

- **Facilitates creative experimentation** with realistically rendered economic processes:
  - Using ACE comp labs, researchers/students can evaluate interesting conjectures of their own devising, with immediate feedback and no original programming required.
  - Modular form of ACE software permits relatively easy modification/extension of features.
ACE Resources

 sabot  ACE Website
https://www2.econ.iastate.edu/tesfatsi/ace.htm

https://www2.econ.iastate.edu/tesfatsi/hbace.htm
Current ACE Research Areas

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

- Learning and embodied cognition
- Network formation
- Evolution of norms
- Specific market case studies (labor, electricity, finance...)
- Industrial organisation
- Technological change and growth
- Multiple-market economies
- Market design
- Automated markets and software agents
- Development of computational laboratories
- Parallel experiments (real and computational agents)
- Empirical validation.... *and many more areas as well!*