Macroeconomies as Locally Constructive Sequential Games

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Macroeconomic and Reality: Where Are We Now?
Session 4: Computational Advances (16:00-16:45)

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Outline

1. Overview

2. What is Agent-based Comp Economics (ACE)?

3. ACE modeling of macroeconomies as locally constructive sequential games

4. Comprehensive empirical validation

5. Bridging the “valley of death” for macro policy development

6. Standardized presentation protocols

7. Conclusion & online resources
1. Overview

- Concerns all macroeconomists share
  - How do real-world macroeconomies work?
  - How could they work better?
Real-world macroeconomies are locally constructive sequential games

- *Heterogeneous* interacting participants

- *Open-ended* dynamic systems

- Human participants are *strategic* decision-makers

- All participants are *locally constructive*, i.e., constrained to act on the basis of their own local states (data, attributes, methods)

- *Reflexive*: Actions taken by participants at any given time affect future local states
Agent-based Computational Economics (ACE)

permits the study of macroeconomies as locally-constructive sequential games
2. **Agent-based Computational Economics (ACE)**

http://www2.econ.iastate.edu/tesfatsi/ace.htm

- Computational modeling of economic processes (including whole economies) as open-ended dynamic systems of interacting agents

**ACE Goals:**

- Enable modeling of real-world economic systems for which coordination is possible but not a modeler-imposed restriction

- Let agents be as free to act within their virtual worlds as their empirical counterparts within the real world

- Let events be fully driven by agent interactions, starting from user-set initial conditions (culture-dish modeling)
ACE Modeling Principles (MP1) – (MP7)

(MP1) **Agent Definition:** An *agent* is a software entity within a computationally constructed world capable of acting based on its own *state*, i.e., its own internal data, attributes, and methods.

(MP2) **Agent Scope:** Agents can represent individuals, social groupings, institutions, biological entities, &/or physical entities.

(MP3) **Agent Local Constructivity:** The action of an agent at any given instant is determined as a function of the agent’s own state at that instant.
ACE Modeling Principles … Continued

(MP4) **Agent Autonomy:** Coordination of agent interactions cannot be externally imposed by means of free-floating restrictions, i.e., restrictions not embodied within agent states.

(MP5) **System Constructivity:** The state of the computationally constructed world at any given instant is determined by the ensemble of agent states at that instant.

(MP6) **System Historicity:** Given initial agent states, all subsequent events in the computationally constructed world are determined solely by agent interactions.

(MP7) **Modeler as Culture-Dish Experimenter:** The role of the modeler of the computationally constructed world is limited to the setting of initial agent states and to the non-perturbational observation, analysis, and reporting of world outcomes.
Together, (MP1) through (MP7) embody the idea that an ACE model is a computational laboratory.

An ACE model permits a user to explore how changes in initial conditions affect outcomes in modeled systems over time.

This exploration process is analogous to biological experimentation with cultures in petri dishes.
Illustration: Partial agent hierarchy for a modeled macroeconomy illustrating “is a” ↑ and “has a” ↓ agent relations.
ACE Macroeconomic Application

DSGL = DSGE + Learning Agents


http://www2.econ.iastate.edu/tesfatsi/MacroConstructiveRationalityWP.SinitskayaTesfatsion.pdf

Sequence of locally-constructive trading activities during a typical time-period t
Four Tested Locally-Constructive Decision Methods for Consumers and Firms

- **Reactive Learner:** If this has happened, what should I do?
  - **RL:** Reactive Learner that uses a modified version of a Roth-Erev reinforcement learning algorithm (Roth/Erev GEB 1995, AER 1998)

- **Anticipatory Learner:** If I do this, what will happen?
  - **FL:** Forward-Learner that uses Q-learning (Watkins, 1989)
  - **EO-FH:** Explicit Optimizer that uses rolling Fixed-Horizon learning
  - **EO-ADP:** Explicit Optimizer that uses an Adaptive Dynamic Programming learning method (DP value function approximation)

Pareto-optimal Nash equilibrium for the consumer & firm decision methods was found to be: (Consumers EO-FH, Firms EO-FH)
ACE permits macroeconomic researchers to test for the existence (or absence) of various multi-level “equilibrium” conceptualizations:

- The economy exhibits an *unchanging structure*: Agent attributes and methods are not changing over time.
- The economy exhibits *unchanging rules of behavior*: Agent methods are not changing over time.
- The economy exhibits an *unchanging trade network*: Who is trading with whom, and with what regularity, is not changing over time.
- The economy exhibits *unchanging outcome distributions*: Realized outcomes are consistent with stationary outcome probability distributions.
- The economy exhibits *continual product market clearing*: Supply is at least as great as demand in each product market over time, with supply = demand for any non-durable product selling at a positive price.
- The economy exhibits *steady-state growth*: In the aggregate, production levels and consumption levels are growing at constant rates over time.
- Other possibilities …
4. ACE Modeling Permits Comprehensive Empirical Validation: EV1 – EV4
http://www2.econ.iastate.edu/tesfatsi/EmpValid.htm

**EV1. Input Validation:** Are the exogenous inputs for the model empirically meaningful and appropriate for the purpose at hand?

— **Examples:** Initial state conditions, functional forms, shock realizations, data-based parameter estimates, &/or parameter values imported from other studies

**EV2. Process Validation:** How well do modeled physical, biological, institutional, and social processes reflect real-world aspects important for the purpose at hand? Are all process specifications consistent with essential scaffolding constraints, such as physical laws, stock-flow relationships, and accounting identities?
EV3. Descriptive Output Validation:

How well are model-generated outputs able to capture the salient features of the sample data used for model identification? (in-sample fitting)

EV4. Predictive Output Validation:

How well are model-generated outputs able to forecast distributions (or distribution moments) for sample data withheld from model identification, or for new data acquired at a later time? (out-of-sample forecasting)
5. ACE Modeling Permits Bridging of the Macro Policy “Valley of Death”

- Ideally, policy implementation should be based on strong empirical evidence.

- Ensuring a policy is ready for implementation will typically require a series of modeling efforts at different scales, and with different degrees of empirical validation.

- Moving too soon to policy implementation entails a major risk of unintended consequences.
Standardized Policy Readiness Levels

PRL-1: Conceptual policy idea
PRL-2: Analytic formulation
PRL-3: Low-fidelity model
PRL-4: Moderate-fidelity small-scale model
PRL-5: High-fidelity small-scale model
PRL-6: Prototype small-scale model
PRL-7: Prototype large-scale model
PRL-8: Field study
PRL-9: Real-world implementation

Basic research carried out at universities...

“Valley of Death”

Industry, government, regulatory agencies
Infrequency of studies in the “Valley of Death” (PRLs 4-6) hinders the development of policy implementation. ACE is well suited for bridging this valley.

ACE computational platforms permit policy performance testing at PRLs 4-6.
Iterative Participatory Modeling

Moreover, ACE permits the implementation of Iterative Participatory Modeling (IPM)

— **IPM for Complex Policy Problems**: Modelers & stakeholders repeatedly cycle through the nine policy readiness levels (PRLs 1-9) in an ongoing open-ended learning process.

— **Goal of IPM for Complex Policy Problems**: Ongoing learning rather than the attempted delivery of a probably-wrong “definitive solution”
6. ACE Standardized Presentation Protocols

- How can ACE policy models & findings be clearly presented to stakeholders, regulators, and other interested parties?

**Proposal:** Develop a nested sequence of standardized presentation protocols tailored to the PRL of a modeling effort.

- **Example:** Extend the current “one size fits all” ODD protocol (Grimm et al.) to a sequence ODD-1, ODD-2,... in parallel with PRL-1, PRL-2,...
7. Conclusion

- ACE modeling is a useful addition to the toolkits of researchers studying real-world macroeconomies.
- ACE modeling principles have been designed to promote both clarity and practical applicability.

- **But much remains to be done:**
  - Empirical validity;
  - Policy readiness level refinements;
  - Standardized presentation protocols;
  - Demonstrated value for real-world macro applications.
On-Line Resources

- **ACE Website: Homepage**
  [http://www2.econ.iastate.edu/tesfatsi/ace.htm](http://www2.econ.iastate.edu/tesfatsi/ace.htm)

- **ACE Research Area: Macroeconomics**
  [http://www2.econ.iastate.edu/tesfatsi/amulmark.htm](http://www2.econ.iastate.edu/tesfatsi/amulmark.htm)

- **Empirical Validation of ACE Models**
  [http://www2.econ.iastate.edu/tesfatsi/EmpValid.htm](http://www2.econ.iastate.edu/tesfatsi/EmpValid.htm)

- **Presentation Protocols for ACE Models**
  [http://www2.econ.iastate.edu/tesfatsi/amodguide.htm](http://www2.econ.iastate.edu/tesfatsi/amodguide.htm)

  [http://lib.dr.iastate.edu/econ_workingpapers/23](http://lib.dr.iastate.edu/econ_workingpapers/23)