Macroeconomies as Locally Constructive Sequential Games

Leigh Tesfatsion

Research Professor & Professor Emerita of Economics
Iowa State University, Ames, Iowa 50011-1054
http://www2.econ.iastate.edu/tesfatsi/
tesfatsi@iastate.edu

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

Joint EARG-Rebuilding Macroeconomics Conference
University of Reading, United Kingdom
24 November 2020, Zoom Meeting

Outline

1. Overview
2. What is ***A***gent-based ***C***omp ***E***conomics (***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

- ***A***gent-based ***C***omputational ***E***conomics (***ACE***)

— permits the study of macroeconomies as locally-constructive sequential games

2. *A*gent-based *C*omputational *E*conomics (*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.

ACE Modeling Principles … Continued

- 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.

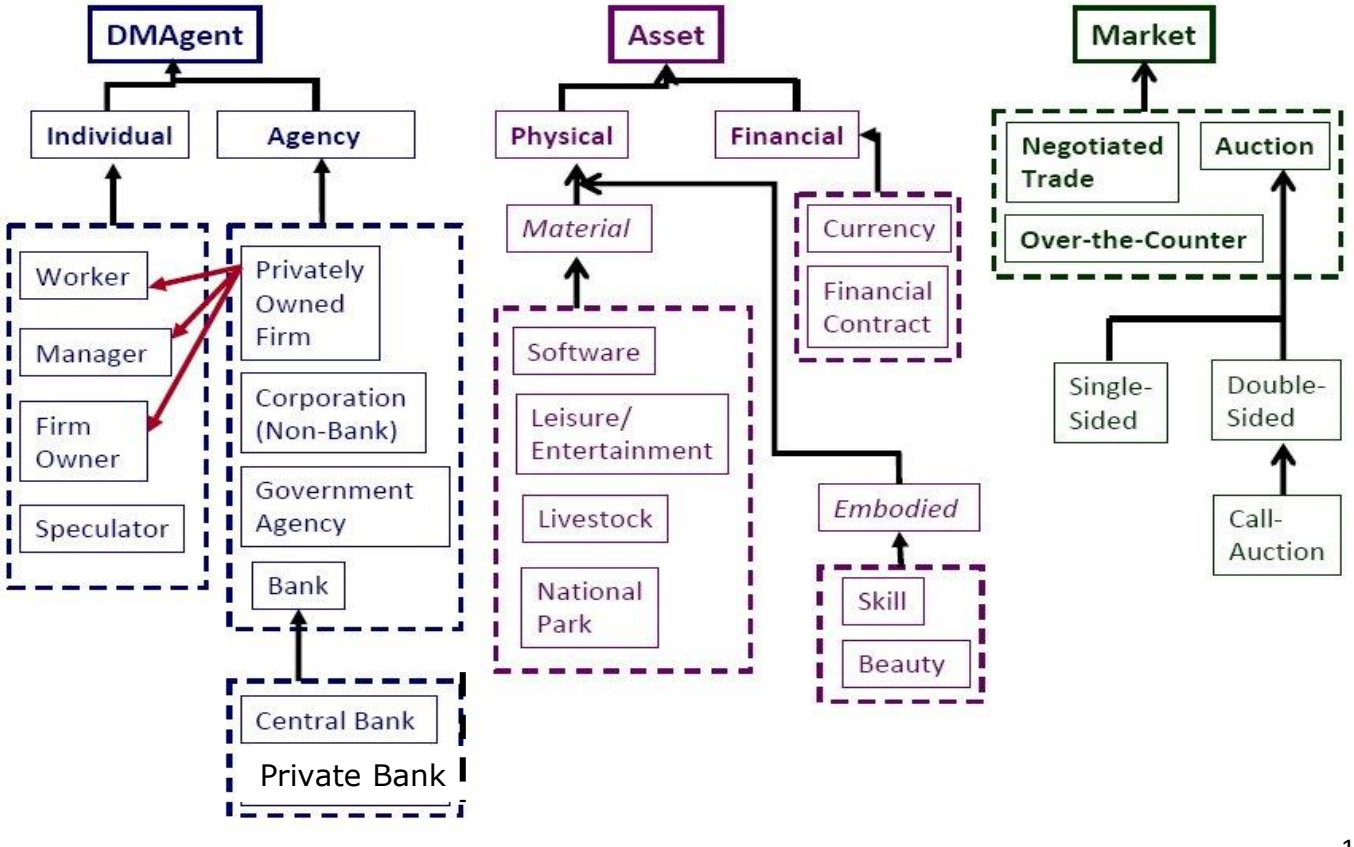
3. ACE Macroeconomic Modeling

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

Illustration: Partial agent hierarchy for a modeled macroeconomy illustrating "is a" ↑ and "has a" ↓ agent relations

Base Agents: **Decision-Makers** **Durable Goods** **Institutions**

Derived Agents

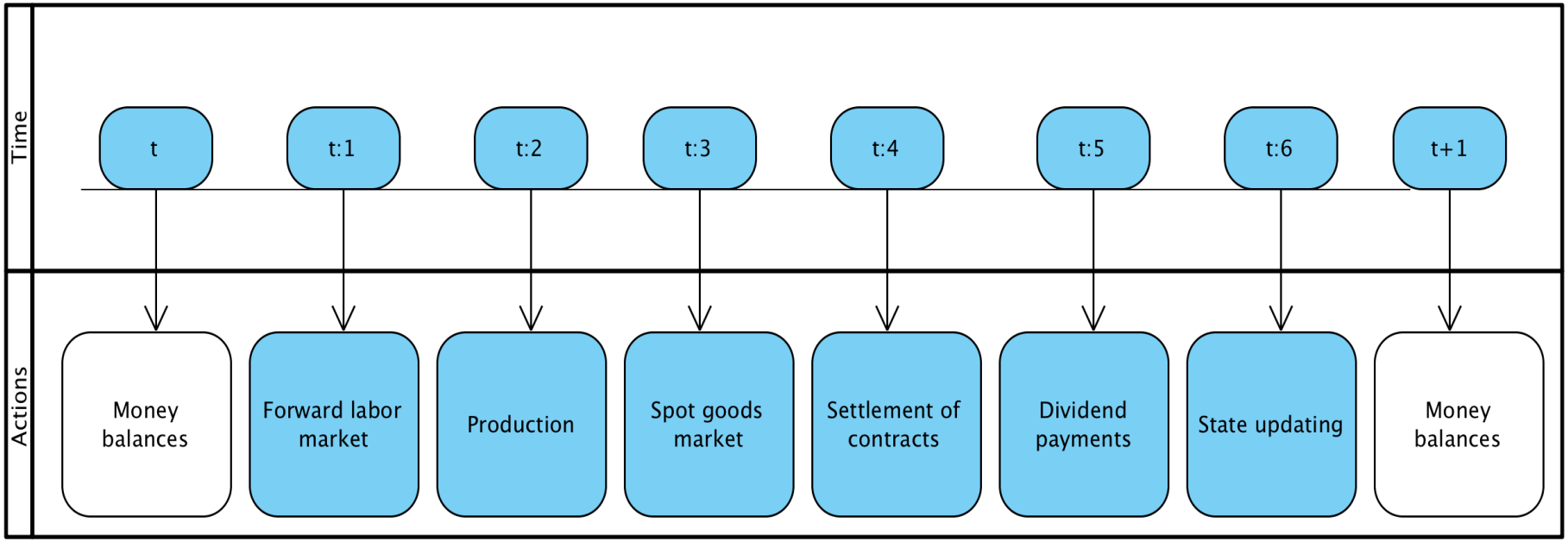


ACE Macroeconomic Application

DSGL = ~~DSGE~~ + Learning Agents

E. Sinitskaya & L. Tesfatsion, Macroeconomies as Constructively Rational Games, *Journal of Economic Dynamics and Control,* 61, 2015, 152-182.

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**: ***R***eactive ***L***earner 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**: ***F***orward-***L***earner that uses Q-learning (Watkins, 1989)
  - **EO-FH**: ***E***xplicit ***O***ptimizer that uses rolling ***F***ixed-***H***orizon learning
  - **EO-ADP**: ***E***xplicit ***O***ptimizer that uses an ***A***daptive ***D***ynamic ***P***rogramming 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

Basic research carried out at universities...

PRL-4: Moderate-fidelity small-scale model

PRL-5: High-fidelity small-scale model

PRL-6: Prototype small-scale model

"Valley of Death"

PRL-7: Prototype large-scale model

PRL-8: Field study

PRL-9: Real-world implementation

Industry, government, regulatory agencies

PRLs 4-6: Valley of Death

- Infrequency of studies in the "Valley of Death" (PRLs 4-6) hinders the development of policy

  Concept ➡ *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
- **ACE Research Area: Macroeconomics**
  http://www2.econ.iastate.edu/tesfatsi/amulmark.htm
- **Empirical Validation of ACE Models**
  http://www2.econ.iastate.edu/tesfatsi/EmpValid.htm
- **Presentation Protocols for ACE Models**
  http://www2.econ.iastate.edu/tesfatsi/amodguide.htm

➢ **Background Paper:** L. Tesfatsion (2017), "Modeling Economic Systems as Locally-Constructive Sequential Games," *J. of Economic Methodology*, Vol. 24, Issue 4, pages 384-409
http://lib.dr.iastate.edu/econ_workingpapers/23