

Modeling Macroeconomies as Locally Constructive Sequential Games

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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. Agent-based Computational Economics (ACE)

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

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

- **Goal:** A flexible and logically-rigorous modeling method that permits
 - Careful tailoring of model simplifications *to purposes at hand*

 - Dynamic events to be modeled as open-ended cause-effect processes
Example: “Equilibrium” (or “convergence to equilibrium”) as a testable hypothesis rather than as an imposed model requirement.

 - Careful matching of modeled agents *to empirical referents*
Example: “Human” agents should be permitted “to breathe”.

ACE Modeling Principles (MP1) – (MP7)

(MP1) Agent Definition: An *agent* is a software entity within a computationally constructed world that can affect world outcomes through expressed actions.

(MP2) Agent Scope: Agents can represent a broad range of entities, e.g., individual life-forms, social groupings, institutions, and/or physical phenomena.

(MP3) Agent Local Constructivity: An intended action of an agent at a given instant is determined by the agent's *state* (*data, attributes, and/or methods*) at this instant.

ACE Modeling Principles ... Continued

(MP4) Agent Autonomy: All *agent interactions* (*expressed agent actions*) at a given instant are determined by the ensemble of agent states at this instant.

(MP5) System Constructivity: The state of the world at a given instant is determined by the ensemble of agent states at this instant.

(MP6) System Historicity: Given an initial ensemble of agent states, any subsequent *world event* (*change in agent states*) is induced by prior and/or concurrent agent interactions.

(MP7) Modeler as Culture-Dish Experimenter: The role of the modeler is limited to the configuration and setting of *initial* agent states, and to the *non-perturbational* observation, analysis, and reporting of world outcomes.

ACE Modeling Principles ... Continued

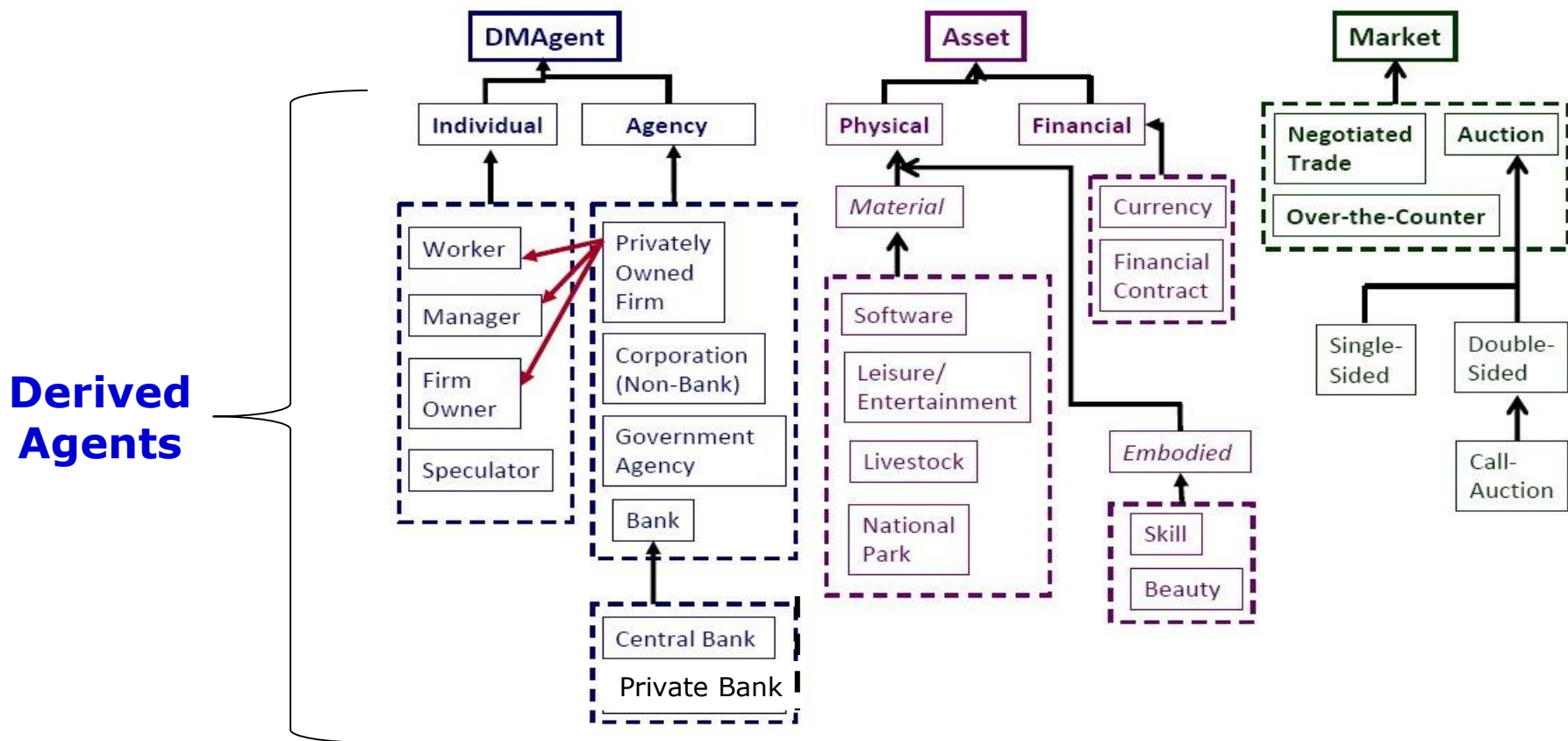
- Together, (MP1) through (MP7) embody the idea that an ACE model is a **computational laboratory**.
- An ACE model **permits a user to explore** how changes in initial conditions affect outcomes in modeled systems over time.
- This exploration process is **analogous to biological experimentation with 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” \uparrow and “has a” \downarrow agent relations

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

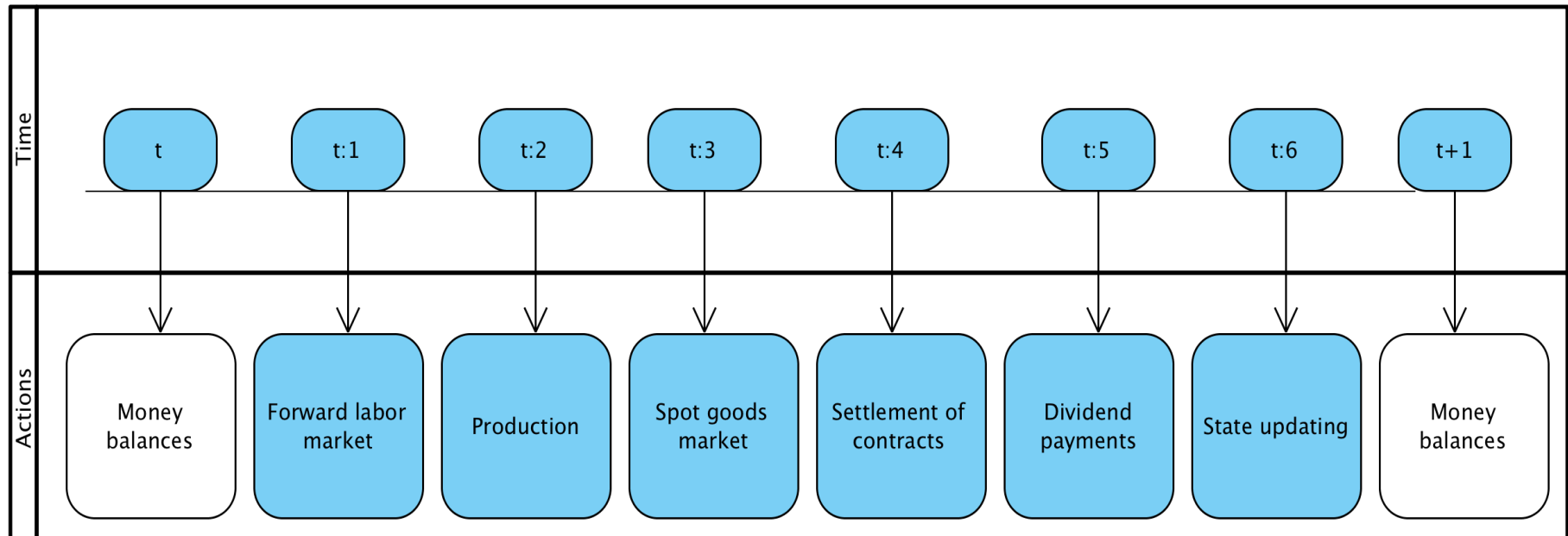


ACE Macroeconomic Application

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:** *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 verisimilitude.
- 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 small-scale model

Basic research
carried out at
universities...

PRL-4: Moderate-fidelity moderate-scale model

PRL-5: High-fidelity moderate-scale model

PRL-6: Pilot study (reflects **expected** field conditions **apart from scale**)

**Valley of
Death**

PRL-7: Prototype large-scale model (reflects **expected** field conditions)

PRL-8: Field study

PRL-9: Real-world implementation

Business,
government,
regulatory
agencies...

PRLs 4-6: Valley of Death

- Infrequency of studies in the “Valley of Death” (PRLs 4-6) hinders policy development from
Concept → *Implementation*
- ACE is well suited for bridging this valley.
 - ACE computational platforms permit policy performance testing at PRLs 4-6.
- Moreover, ACE permits the implementation of *Iterative Participatory Modeling (IPM)*, i.e., researchers and stakeholders repeatedly cycling through PRLs 1-9 in an ongoing open-ended learning process.

6. ACE Standardized Presentation Protocols

- How can **Policy Readiness Levels (PRLs)** facilitate the clear presentation of ACE policy models & findings to stakeholders, regulators, and other interested parties?

Proposal: *Develop a standardized sequence of PRL-conditioned presentation protocols*

Example: Extend the “one size fits all” **ODD Presentation Protocol** to a sequence ODD-1, ODD-2,... in parallel with PRL-1, PRL-2,...

ODD = **O**verview, **D**esign concepts, and **D**etails

(Volker Grimm et al., 2006, *Ecological Modelling*, V. 198, 115-126)

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:**
 - Verification and empirical validation methods;
 - Policy readiness level (PRL) 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>

➤ Background Papers:

L. Tesfatsion (2017), “Modeling Economic Systems as Locally-Constructive Sequential Games,” *J. of Economic Methodology*, Vol. 24, No. 4, 384-409

https://lib.dr.iastate.edu/econ_workingpapers/23/

L. Tesfatsion (2022), “Agent-Based Computational Economics: Overview and Brief History,” to appear in R. Venkatachalam (Ed.), *Artificial Intelligence, Learning, and Computation in Economics and Finance*, Springer.

https://lib.dr.iastate.edu/econ_workingpapers/126/