Agent-Based Models in Economics: An Overview

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Research Areas

- Agent-Based Computational Economics (ACE)
  - Methodology: Empirical validation in ACE models
  - Applications: ACE models and policy
- Networks
  - Game-theoretic models of strategic network formation
  - Empirical properties of economic networks
- Industrial dynamics: models/empirical evidence
  - Geography of industrial agglomeration
  - Firm size and growth dynamics: the role of financial constraints
- Statistical properties of micro/macro dynamics
  - Statistical properties of household consumption patterns
  - Statistical properties of country-output growth

Homepage

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Outline

- Why Agent-Based Models in Economics?
  - Problems with neoclassical models
  - Empirical and experimental findings
  - Philosophical underpinnings
- Building Blocks of Agent-Based Models
  - Classes of assumptions
  - The structure of an agent-based model
  - Analysis of an agent-based model
- Open Issues in Agent-Based Models
  - Interactions with mainstream community
  - Policy Implications
  - Empirical validation

Background Papers

- Windrum, P., **Fagiolo, G.** and Moneta, A. (2007), "Empirical Validation of Agent-Based Models: Alternatives and Prospects", *Journal of Artificial Societies and Social Simulation*, 10, 2, available at: http://jasss.soc.surrey.ac.uk/10/2/8.html .

- Pyka, A. and **Fagiolo, G.** (2005), "Agent-Based Modelling: A Methodology for Neo-Schumpeterian Economics". In: Hanusch, H. and Pyka, A. (Eds.), *The Elgar Companion to Neo-Schumpeterian Economics*, Edward Elgar, Cheltenham.

Agent-Based vs. Neoclassical Models

- Benchmark: micro-macro (neoclassical) models
  - Endogenous or exogenous micro-founded growth models
- Based on over-simplifying assumptions
  - Heterogeneity irrelevant: the “representative individual” hypothesis and its consequences for aggregation
  - Fully-rational agents without computational bounds
  - Equilibrium analysis: empirical observations as equilibria
  - No interactions among agents (other than price-related ones)
- Why such a set of assumptions?
  - Need for a sharp relation between assumptions and implications
  - Analytical solutions strongly required
  - Instrumentalist approach *à la* Friedman

Empirical and Experimental Findings (1/2)

- Persistence of heterogeneity among agents
  - Examples: Firms and industry characteristics
  - Aggregation in theory: average of behaviors different from behavior of the average (Kirman, Lippi)
  - Aggregation in practice: aggregate properties may have nothing do to with individual characteristics (ex: law of demand, see Gallegati, Kirman, etc.)
- Equilibrium analysis?
  - Economy as a complex evolving system
  - Economic observations as equilibria of some kind?
  - Ex: Turbulence in the patterns of industrial dynamics
  - State of the economy as emergent properties: statistical features that last sufficiently long to be observed

Empirical and Experimental Findings (2/2)

- Real-World Economic Agents are not Rational
  - Majority of rationality axioms persistently violated in reality
  - Departures from axioms are systematic
  - Examples: framing, probabilistic judgment and intuition

- Relevance of Interaction Networks
  - Agents form interaction networks to exchange commodities, information, knowledge
  - Real networks have peculiar and persistent properties (small-worlds, scale-free, etc.)
  - Network structure does influence aggregate results (ex: market design)

Evidence vs. Models (1/2)

- Relevance of standard neoclassical models
  - Dick Day: "*Can one do good science based on models whose assumptions are clearly at odds with empirical evidence?*"
- An old (but still open) philosophical problem
  - Models as abstractions of reality
  - What does "realistic assumptions" really mean?
  - Models as solutions of the trade off between simplicity and usefulness
- Empirical validity of an economic model
  - To what extent is a model able to explain and replicate existing reality (and possibly predict future trends)?
  - Are neoclassical models really good at explaining and replicating stylized facts?

Evidence vs. Models (2/2)

- Empirical validity of neoclassical models?
  - Industrial dynamics and organization
  - Micro-founded models of growth
  - Macroeconomic models of investment and output dynamics
  - Micro-founded models of labor-market dynamics
  - … and so on
- Difficulties
  - Dynamics and distributions (Paul's empirical agenda)
  - Joint replications of SFs
- Exploiting "instrumentalism" at its best
  - If the model is not able to replicate stylized facts, assumptions can be freely replaced
  - Why not using assumptions "more in line" with empirical evidence?

Agent-Based Models

- A tool to model economies where agents
  - are boundedly rational entities
  - directly interact in non trivial networks
  - might be persistently heterogeneous
- … and
  - State of the economy is not necessary an “equilibrium”
- A bottom-up approach
  - Modeling agents behaviors and their interactions first
  - Statistical analysis of models output
  - Matching with empirical data

ACE/Evolutionary Approaches

- Two competing brands?
  - Sharing almost same ingredients and philosophical underpinnings
- Evolutionary Models
  - Stress on selection-based market mechanisms…
  - … less on tools used
- ACE Models
  - Stress on tool used (OOP)…
  - … focus on open-ended systems where behavioral rules endogenously evolve as well

The Structure of Agent-Based Models

- Main ingredients (to cook an ABM)
  - Bottom-up (agent-based) Philosophy (Tesfatsion, 1997)
  - Agents live in complex systems evolving through time (Kirman, 1998)
  - Agents might be heterogeneous in almost all their characteristics
  - “Hyper-rationality” not viable (Dosi et al., 1996)
  - Agents as boundedly rational entities with adaptive expectations
  - “True” dynamics: Systems are typically non-reversible
  - Agents interact directly, networks change over time (Fagiolo, 1997)
  - Endogenous and persistent novelty: open-ended spaces
  - Selection-based market mechanisms (Nelson & Winter, 1982)

The Structure of Agent-Based Models

• Time	$t = 0, 1, 2, \ldots, (T)$	… Discrete
• Sets of Agents	$I_t = \{1, 2, \ldots, N_t\}$	… Often $N_t = N$
• Sets of Micro States	$i \rightarrow \underline{x}_{i,t}$	… Firm's output
• Vectors of Micro-Parameters	$i \rightarrow \underline{\theta}_i$	… Res. Wage
• Vector of Macro-Parameters	$\Theta \in \Re^m$	… Opportunities
• Interaction Structures	$G_t \in \wp(I_t)$	… Networks
• Micro Decision Rules	$R_{i,t}(\bullet \mid \bullet)$	… Innovation rule
• Aggregate variables	$\underline{X}_t = f(\underline{x}_{1,t}, \ldots, \underline{x}_{N_t,t})$	… GNP

Flexibility of ACE/EV Paradigm

- Micro Decision rules
  - deterministic (best-replies, routines) → stochastic → algorithmic
- Dynamics of Micro Decision Rules
  - fixed → exogenously changing → endogenously adapting
- Expectations
  - myopic/adaptive → econometric → AI-based (neural networks)
- Interactions
  - global → local
  - symmetric, bilateral → asymmetric, unilateral
- Dynamics of Interaction Structures
  - static → exogenously evolving → endogenously evolving

A Large Set of Models…

- Evolutionary-Games (P. Young, Kandori et al., Blume, Ellison…)
- (Local) Interaction Models (Kirman, Weisbuch, Lux, Topol, IPD Models…)
- Endogenous Network Formation (Vega-Redondo, Goyal, Jackson-Watts…)
- Polya-Urn Schemes (Arthur, Dosi, Kaniovski, Lane, …)
- ….
- ….
- Industry-Dynamics Models (Nelson + Winter tradition, Paul's Type II Models)
- Evolutionary Growth Models (Silverberg, Verspagen, Dosi et al., …)
- ACE Models of Market Dynamics (Axtell, Epstein, Tesfatsion, Vriend, …)

The Outcomes of ACE/EV Models

Micro-Dynamics
(induced by decision rules, interactions and expectations)

⇨

Macro-Dynamics
(obtained as aggregation of individual behaviors)

- Stochastic components in decision rules, expectations, interactions imply that the dynamics of micro and macro variables can be described by some (Markovian) stochastic process parametrized by $(\underline{\theta}_i)$, Θ :

$$(\underline{x}_{i,t}) \mid (\underline{x}_{i,t-1}), (\underline{x}_{i,t-2}), \ldots ; (\underline{\theta}_i), \Theta$$

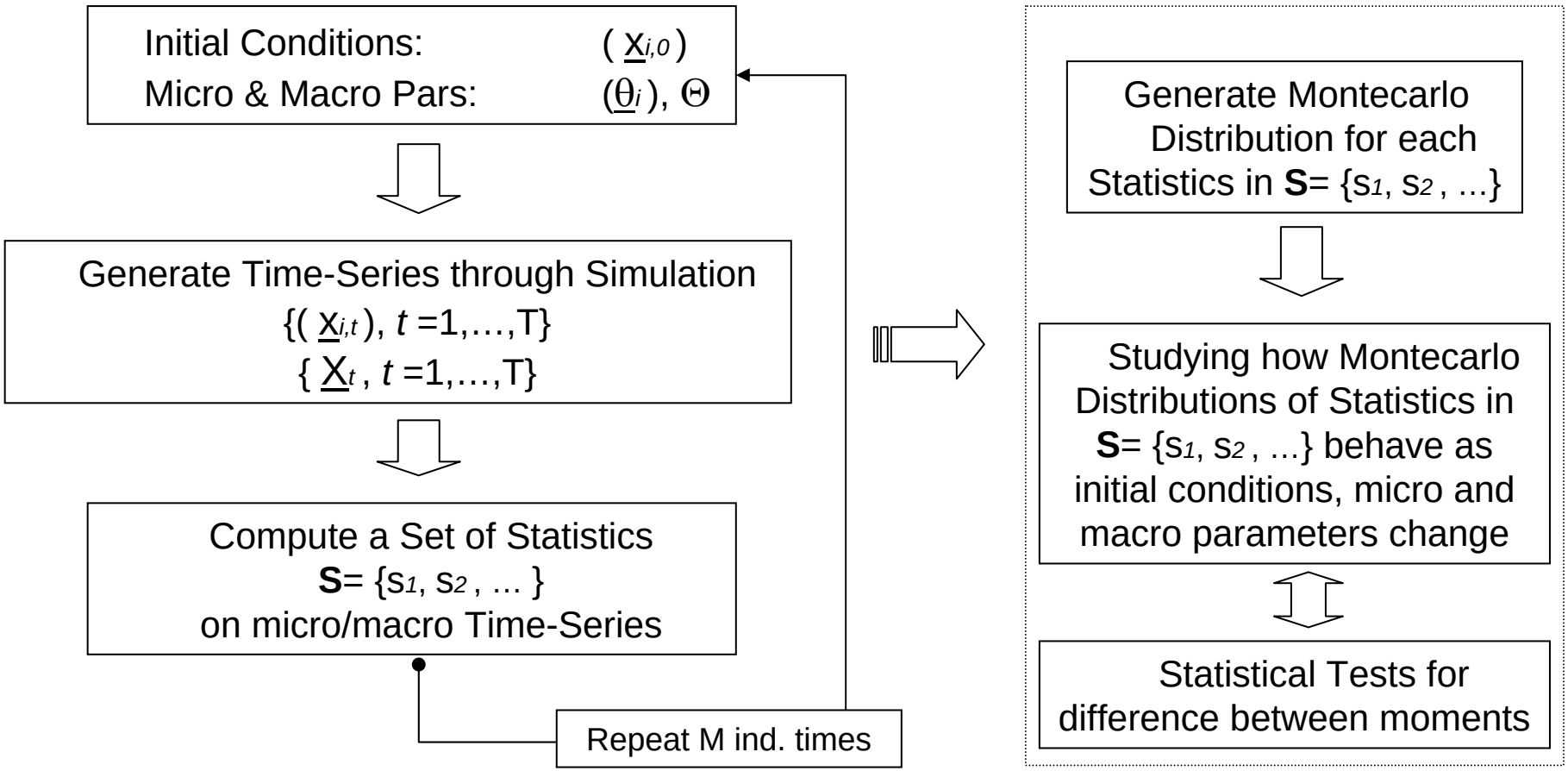
$$\underline{X}_t \mid (\underline{X}_{t-1}, \underline{X}_{t-2}, \ldots ; (\underline{\theta}_i), \Theta)$$

- Non-linearities in decision rules, expectations, interactions **may** imply that it is **hard** to analytically derive laws of motion, kernel distributions, time-*t* probability distributions, etc.

Analysis of Agent-Based Models

- Analytical tractability?
  - Analytical solutions only for particular cases
  - Models must often be built and simulated (via computer)
  - Object-oriented programming languages (C++) as natural tools for agent-based models
- Analyzing the output of agent-based models
  - Initial conditions for all micro and macro variables of interest
  - Parameterization of the model
  - Model as a “data generation process” for the underlying unknown mechanisms
  - Run of the model: set of time-series (and statistics thereof)
  - Stochastic elements and need for Monte-Carlo analysis
  - Sensitivity analysis vs. parameters and initial conditions

Analysis of Agent-Based Models



Agent-Based Models: Applications

- **Agglomeration and geographical concentration**
  - Bottazzi, G., Dosi, G., Fagiolo, G. and Secchi, A. (2007), "Modeling Industrial Evolution in Geographical Space", *Journal of Economic Geography*, forthcoming.
- **Technological adoption**
  - Fagiolo, G. (2005), "Endogenous Neighborhood Formation in a Local Coordination Model with Negative Network Externalities", *Journal of Economic Dynamics and Control*, 29: 297-319.
- **Innovation and endogenous growth**
  - Fagiolo, G. and Dosi, G. (2003), "Exploitation, Exploration and Innovation in a Model of Endogenous Growth with Locally Interacting Agents", *Structural Change and Economic Dynamics*, 14: 237-273.
- **Labor market dynamics**
  - Fagiolo, G., Dosi, G. and Gabriele, R. (2004), "Matching, Bargaining, and Wage Setting in an Evolutionary Model of Labor Market and Output Dynamics", *Advances in Complex Systems*, 14: 237-273.
- **Firms investment and the properties of business cycles**
  - Dosi, G., Fagiolo, G. and Roventini, A. (2006), "An Evolutionary Model of Endogenous Business Cycles", *Computational Economics*, 27, 1: 3-34.

Remarks (1/2)

- A new way of doing economics?
  - Large community: Ph.D. programs, journals, conferences
  - Still a minority vs. neoclassical economics
  - Two ways of seeing agent-based modeling approach
- ABM as a complementary approach
  - Exploring dimensions difficult to address jointly
  - Grounding behavioral assumptions into empirical/experimental evidence
- ABM as an alternative approach
  - Providing robustly an alternative view of how decentralized economies work
  - ABM replicating reality, generating fresh implications, allow for policy implications and predictions

Remarks (2/2)

- Crucial, open issues
  - Pushing policy and design exercises
  - Fostering empirical validation techniques
- Policy implications and market design
  - Agent-based models as very flexible “laboratory” tools
  - Experimenting with alternative policy designs
  - Testing different market designs: the U.S. experience
- Empirical validation of ABMs
  - Allow for a better and deeper replication of stylized-facts
  - Over-parameterization of agent-based models
  - Developing more powerful calibration techniques
  - A new econometrics of ABMs? Causality and graphical models