Empirical Validation in Agent-Based Models

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ABMs and Empirical Validation

- ABMs 20 years later…
  - Despite a great success…
  - … any impact on economic science?
  - Did ABMs find a place in the standard economics toolbox?
  - Published ABM papers in top economics journals
    - Figures are maybe too pessimistic but overall impact not that big…
- Many obvious reasons why it was so…
  - New vs. established scientific paradigm (Kuhn, Lyotard)
  - ACE is hardly perceived as a robust, alternative paradigm
  - Why? Keywords: Heterogeneity and poor comparability
    - Assumptions and modeling design
    - Analysis of the properties of an ABM
    - **Empirical validation**

… an important remark …

- Too much heterogeneity could be bad…
  - Difficult to compare alternative models of same phenomenon
  - Difficult to advance a new paradigm and contrast it with already existing ones
  - Having a (few) commonly accepted protocol(s) for empirical validation (and model building) would be in general better for the profession

- … but many people think that
  - Also established paradigms are to some extent heterogeneous
  - Heterogeneity and flexibility of assumptions might be considered as *the* values added of ABMs
  - Heterogeneity is a prerequisite for the emergence of a “paradigm” (social process, scientific debate, etc.)

What do we mean by “Empirical Validation”

- Taking the model to the data
  - Data sources: Empirical, Experimental … Casual and Anecdotic Knowledge
  - What part of the model is to be taken to the data?
    - Inputs: Checking validity of assumptions
    - Outputs: Checking validity of implications

- Here we shall focus on output validation
  - Input validation: Experimental Economics, Behavioral Economics, Neuroeconomics, etc.
  - ABMs philosophy should already embody input-validated modules
  - Meaning of Empirical Validation in what follows: “To what extent our ABM is able to statistically replicate the evidence that it wants to address?

Background Literature

- 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 .

- **Fagiolo, G.**, Moneta, A. and Windrum, P. (2007), "A Critical Guide to Empirical Validation of Agent-Based Models in Economics: Methodologies, Procedures, and Open Problems", Computational Economics, 30:195-226.

- **Fagiolo, G.**, Birchenhall, C. and Windrum, P. (Eds.), Special Issue on "Empirical Validation in Agent-Based Models", Computational Economics, 2007, Volume 30, Issue 3.

Fagiolo, Moneta, Windrum (2007)

- Heterogeneity in ABM Empirical Validation Exercises
  - Is it really so?
  - Taxonomizing empirical validation approaches in ABM
- Is it a problem confined only to ABMs in economics?
  - What about neoclassical economics?
  - What happens in other fields (e.g. simulations in engineering)?
- Which are the features of ABMs that favor heterogeneity in empirical validation approaches?
  - Features specific to the development of ABMs in economics
  - More general methodological problems still under debate

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Ex 1: Qualitative Simulation Modeling

- No empirical validation
  - Model as a laboratory to gain knowledge on the underlying causal relationships **only**, not taken to the data
- Stylized Qualitative Models (Evolutionary-Games)
  - Weak relation between micro-macro variables/parameters in the model and empirically observed counterparts
  - Interest in explaining the emergence of qualitative aggregate pattern (cooperation, coordination, etc.)
- Early Evolutionary- and Industry-Dynamics Models
  - Much more micro-founded and empirically-driven, but…
  - If any, empirical validation is done in very weak ways
- A pessimistic view about empirical validation?
  - Socio-economics: open-endedness, interdependence, structural change
  - Precise quantitative implications are difficult to obtain

Ex 2: Replication of Stylized-Facts

- Indirect Calibration
  - Detailed data able to restrict the set of initial conditions and micro/macro parameters is difficult to gather (Kaldor)
  - Empirical validation is done at the aggregate (macroeconomic) level
  - Parameters and initial conditions are not restricted a priori
  - Validation requires joint reproduction of a set of “stylized facts” (SFs)

- Four-Step Procedure (Dosi et al, 2006)
  - **Step 1**: Identifying set of SFs of interest to be explained/reproduced
  - **Step 2**: Keep microeconomics as close as possible to “real-world”
  - **Step 3**: Find parameters and initial conditions for which the model is statistically able jointly to replicate the set of SFs
  - **Step 4**: Investigation of subspace of parameters and initial conditions which “resist” to Step 3 in order to seek for causal relationships (explanations)

Ex 3: Empirical Calibration of ABMs

- Werker and Brenner (2005)
  - Dealing with space of initial conditions and micro/macro parameters
  - Difficult to employ theoretical arguments to restrict the set
  - Use empirical knowledge first to calibrate initial conditions and micro/macro parameters and then to validate

- Three-Step Procedure
  - **Step 1**: Employ empirical knowledge to calibrate initial conditions and parameters ranges
  - **Step 2**: Further restricting initial conditions and parameters space by empirically validate simulated output with real-world data
  - **Step 3**: Abduction. Seek explanations of the phenomena under study by exploring properties of the "possible worlds" that resist to previous steps

Ex 4: History-Friendly Industry Models

- Malerba, Nelson, Orsenigo, and co-authors
  - Models built upon detailed empirical, anecdotic, historical knowledge of phenomenon under study and employed to replicate its precise (qualitative) history

- Prominent role for empirical data
  - Detailed empirical (historical) data on the phenomenon under study assisting model building and validation
  - Specify agents' representation
  - Identify parameters and initial conditions
  - Empirically validate the model by comparing "simulated trace histories" with "actual history" of an industry

Where do they differ?

- Domain of application
  - Micro (industries, markets)
  - Macro (countries, world economy)
- Which kind of empirical observations does one employ?
  - Empirical data about micro/macro variables
  - Casual, historical and anecdotic knowledge
- How to employ empirical observations?
  - Assisting in model building (agents, behaviors, interactions,…)
  - Calibrating initial conditions and parameters
  - Validating simulated output
- What to do first?
  - First calibrate, then validate
  - First validate, then calibrate
  - Validate only

… A first assessment …

- Empirical validation of ABMs in economics
  - Many alternative methodological approaches
  - They differ as to several crucial dimensions (scope, data)

- Is it a problem confined only to ABMs in economics?
  - A lot of competing approaches characterize also
    - Mainstream economics
    - Other fields employing simulations as tool of analysis
  - Heterogeneity in empirical validation approaches in economics ABM may reflect underlying unsettled debate on philosophy of economics

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Heterogeneity of ABMs' Structure

- Object of Analysis
  - Qualitative - Quantitative, Single - Multiple
  - Transients - Long-run, Micro - Macro
- Goal of Analysis
  - In-Sample, Descriptive (most often)
  - Out-of-Sample (forecasting)
  - Prediction/Control (policy implications)
- Methodology of Analysis: Robustness of results to
  - micro/macro parameters
  - initial conditions (ergodicity)
  - across-run variability

Heterogeneity of ABMs' Structure

- Modelling Assumptions
  - **Size of the space of**
    - Micro/macro parameters
    - Micro/macro variables
    - Decision rules
  - **Treatment of time/updating**
    - Discrete / Continuous, Parallel / Asynchronous
  - **Type of decision rules**
    - Adaptive (myopic) vs. optimizing (best-reply), Deterministic vs. Stochastic
  - **Type of interaction structure**
    - Local vs. Global, Deterministic vs. Stochastic
  - **Dynamics of decision rules and interaction structures**
    - Exogenously given/changing, Endogenously selected

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Hot Issues in Empirical Validation of ABMs

- Treatment of initial conditions and parameters
  - How can we deal with all “possible worlds”? Calibration?
- Comparing ABMs’ outputs and real-world observations
  - Simulated Distributions vs. Unique Real-World Observations
- Unconditional-objects critique (Brock, 1999)
  - If many processes are able to explain the same set of SFs, what does replication of SFs add to our knowledge?
- Is available data sufficient?
  - Need for additional, more detailed microeconomics data
  - Need to validate microeconomic foundations with experimental data
- An empirical agenda
  - Searching for theory-free stylized facts
  - Looking for econometric techniques more appropriate for ABMs

Treatment of initial conditions and parameters

- Need for restricting the set of all “conceivable worlds”
  - ABMs (often) as an over-parameterized description of the “world”
  - Each point as a “conceivable” world
  - To which extent (and how) should one employ empirical data to select among all possible worlds?
- Direct vs. Indirect Calibration
  - Calibration of parameters and initial conditions on available data
  - Focusing on parameters and initial conditions that allow for replication of SFs of interest
- What can we learn from the remaining set?
  - Almost impossible to restrict to a unique world
  - Comparative dynamics exercises: Which interpretation?
  - Danger of counterfactuals in evolutionary worlds
    - “indeterminacy weakens the link between antecedent and consequent in the counterfactual” (Cowan and Foray, 2002, p. 552)

ABMs' outputs vs. real-world observations

- Distributional objects vs. unique observations
  - ABM provides DGP which we think real-world observations came from
  - ABM's output are distributional objects
  - Real-world observations are unique
  - "Independence" assumptions are required to transform unique empirical data in distributional objects (e.g. firm sizes or country growth-rates)

- How can the two be compared?
  - How can one know whether real-world observations are "typical" or "low-probability" events (with respect to the "true" DGP)?
  - ABMs: Suppose observed data are "typical" and compare them with statistics (average) of simulated data
    - Crucial to learn about the shape of the entire simulated distribution before comparing its typical outcomes with data (average may not be relevant)
  - Otherwise: Any single (low probability) simulated trace may be important to discover real-world underlying causal relationships

Unconditional Objects Critique

- ABM as a replicator of SFs
  - Given a set of SFs or statistical regularities there are many underlying alternative processes (DGPs) able to replicate it
  - SFs are “unconditional objects” (properties of stationary distributions) and cannot provide information on the dynamics of the process that generated them (Brock, 1999)
  - Replicating does not mean explaining
- How can we learn on the “true” generating process?
  - Brock (1999): Having a model that is able to reproduce a certain set of SFs is good because it always conveys information on the general forces at work and thus restricts the set of all possible generating mechanisms
  - Validating micro-economics of the model, not only macro-economic outputs (Gilbert, 2004; Duffy). A lot of detailed and reliable (empirical, experimental) data on microeconomic variables is required…
  - Looking for explanations as causal relations in simulated ABMs output: New tools from econometrics (graphical models) may help…

An Empirical Agenda

- Need for fresh stylized facts
  - Many empirical regularities are theory-driven (ex: demand)
  - Theory here means “neoclassical theory”
  - Cross-section statistical properties? Dynamics?
  - Going “back to the data” and find fresh stylized facts
  - A phenomenological approach

- Need for a new econometrics for ABMs
  - ABMs are studied using econometric tools developed in very stationary worlds (e.g. regressions)
  - Normality vs. econometrics of heavy-tail distributions
    - Fagiolo, Napoletano and Roventini (2008)
  - How can we detect emergent properties?
  - How can we explore causal relations in ABMs?

Fagiolo, Moneta, Windrum (2007): Summary

- Critical overview of empirical validation in ABMs
  - When models are taken to the data, many competing approaches
- Investigating possible reasons
  - Methodological debate in social sciences and economics still open
  - Neoclassical models suffer from similar degree of heterogeneity
  - A lot of variety in other fields employing simulations as modeling tool
  - Heterogeneity in economics ABMs' structure
- Crucial problems in empirical validation of ABMs
  - Treatment of parameters and initial conditions
  - Comparing simulated distributions with unique real-world observations
  - Learning about generating mechanisms from replication of SFs
  - Need for additional data
  - An "empirical" agenda