Agent-Based Models in Economics: An Introduction

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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
- Some Examples
  - Some recent applications of agent-based modeling
- Open Issues
  - Interactions with mainstream community
  - Empirical validation

Agent-Based vs. Neoclassical Models

- Benchmark: micro-macro (neoclassical) models
  - Endogenous or exogenous micro-founded growth models
- Based on over-simplifying assumptions
  - Fully-rational agents without computational bounds
  - No interactions among agents (other than price-related ones)
  - Heterogeneity irrelevant: the “representative individual” hypothesis and its consequences for aggregation
  - Equilibrium analysis: empirical observations as equilibria
- 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)

- 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 Irrational
  - All rationality axioms are 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 (still open) philosophical problem
  - Models as abstractions of reality
  - Trade off between simplicity and usefulness
- Empirical validity of an economic model
  - To which extent is a model able to explain and replicate existing reality (and possibly predict future trends)?

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

- 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
- Building blocks
  - Economies evolve through time in path-dependent ways
  - 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

The Structure of Agent-Based Models

- Timing of events
  - Discrete time
- Agents
  - Interactions: who is affected by whom across time
  - Behaviors: not necessarily maximizing ones!
  - Role of parameters and stochastic elements
- Aggregation
  - In each time period agents' characteristics are aggregated
  - Inducing macro-dynamics from micro-dynamics
- Institutions
  - Markets can act as selecting devices
  - "Evolutionary Economics" models

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
- 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

Agent-Based Models: Applications

- **Agglomeration and geographical concentration**
  - Bottazzi, G., Dosi, G. and Fagiolo, G. (2006), "On Sectoral Specificities in the Geography of Corporate Location", in Breschi, S. and Malerba, F. (Eds.), *Clusters, networks and innovation*, Oxford, U.K., Oxford University Press.

- **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*, Forthcoming.

Innovation and Endogenous Growth

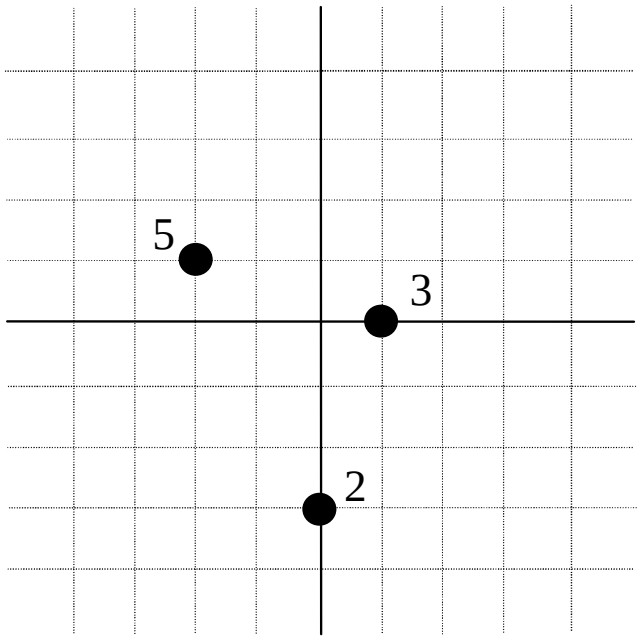
- The “Islands” Model
  - Building a dynamic model of growth that
    - Is able (as a plausibility check) to reproduce the fundamental statistical properties of GDP time series
    - Allows one to disentangle the role of the basic technological sources of growth
- Growth as the result of an exploration-exploitation trade-off driven by
  - Technological opportunities
  - Path dependency in technological accumulation
  - Degree of locality vs. globality of knowledge diffusion
  - Increasing returns to knowledge base exploitation
  - Incentives to explore/exploit of entrepreneurs

The Islands Metaphor

Technological Space	Notionally Unbounded Sea
Technology	Island (‘mine’)
Output	Homogeneous Good
Firms	Stylized Entrepreneurs
Production	Mining/Extracting the Good
Technological Search	Exploration of the Sea
Innovation	Discovering a new island
Technological Diffusion	Spreading knowledge from islands
Imitation	Traveling between already known islands
Technological Difference	Distance between Islands

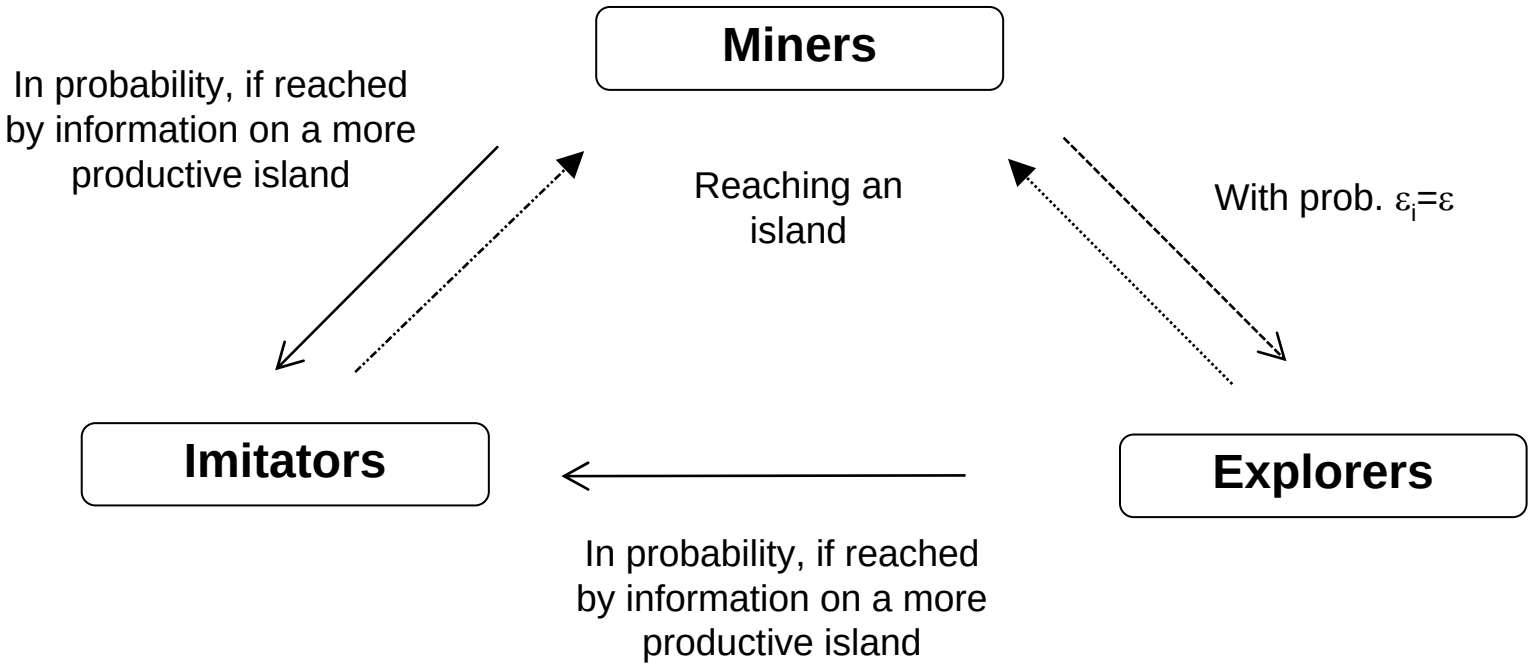
The Model: Key Ingredients

- Technological setup
  - N firms dispersed in a 2-dim boundary-less lattice
  - A node (x,y) is a technology (island) with fixed i.i.d. probability π
  - Islands' productivity proportional to distance from origin
  - At time t=0 firms randomly distributed over existing technologies, all producing GNP under increasing returns to scale



The Model: Dynamics

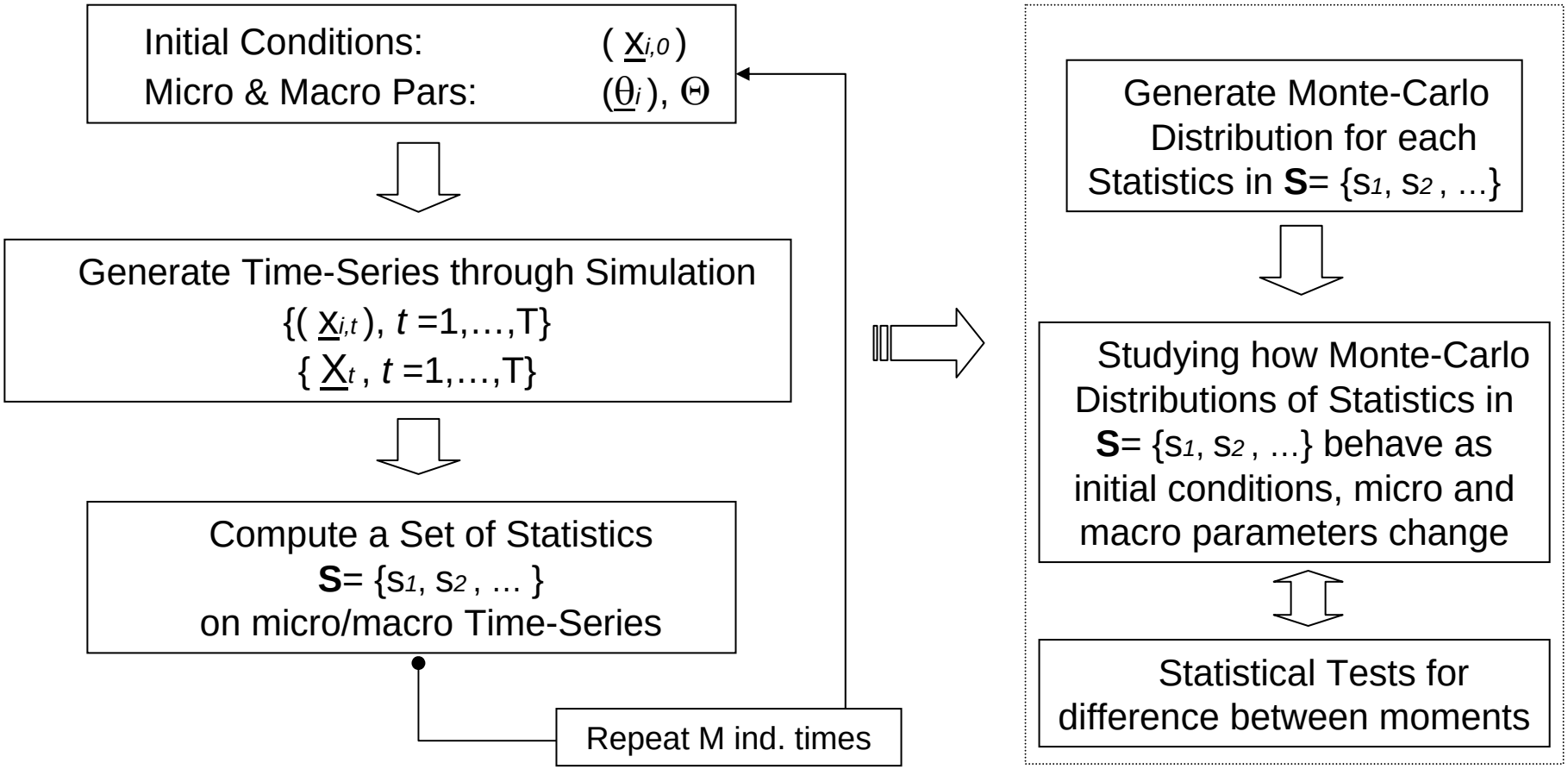
- In each t=1,2,… any firm can be
  - **Miner**: Lives on known islands (production)
  - **Explorer**: Randomly explores the lattice (performing R&D)
  - **Imitator**: Travels towards other known island (imitation)



The Model: Key Parameters

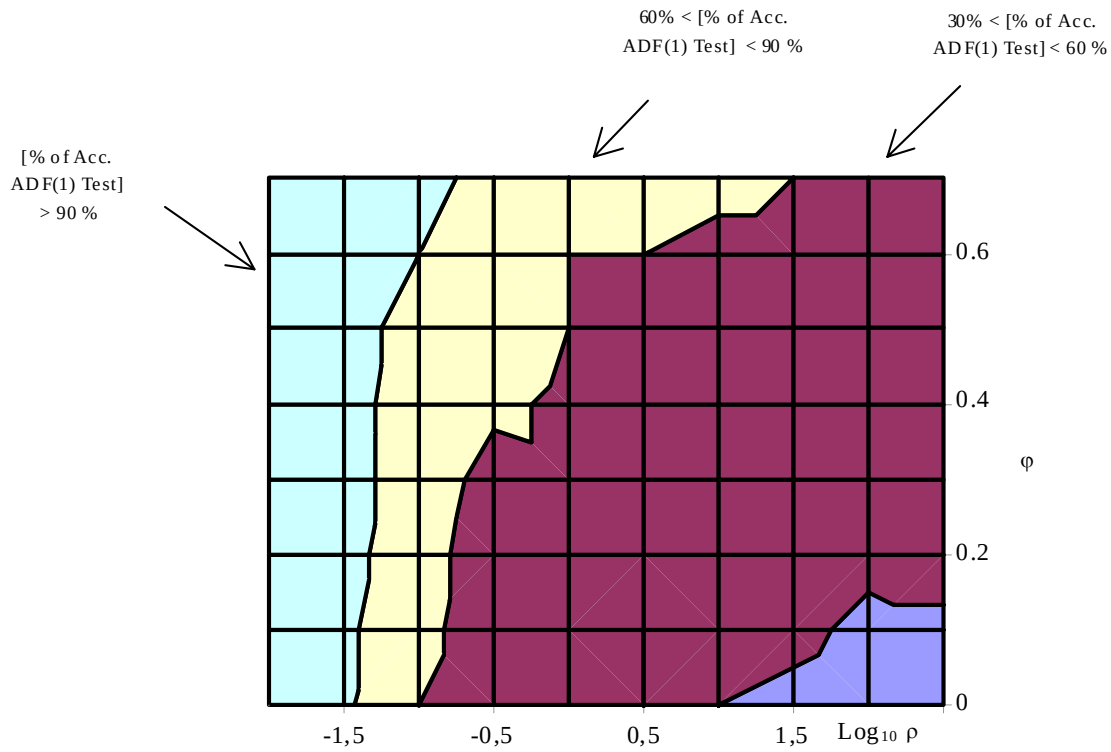
- System parameters
  - ρ globality of information diffusion
  - φ path-dependency in learning
  - λ likelihood of radical innovations
  - π baseline opportunity conditions
  - α increasing returns to scale in exploitation
  - ε willingness to explore
  - N population size
  - T time horizon

The Model: Monte-Carlo Analysis



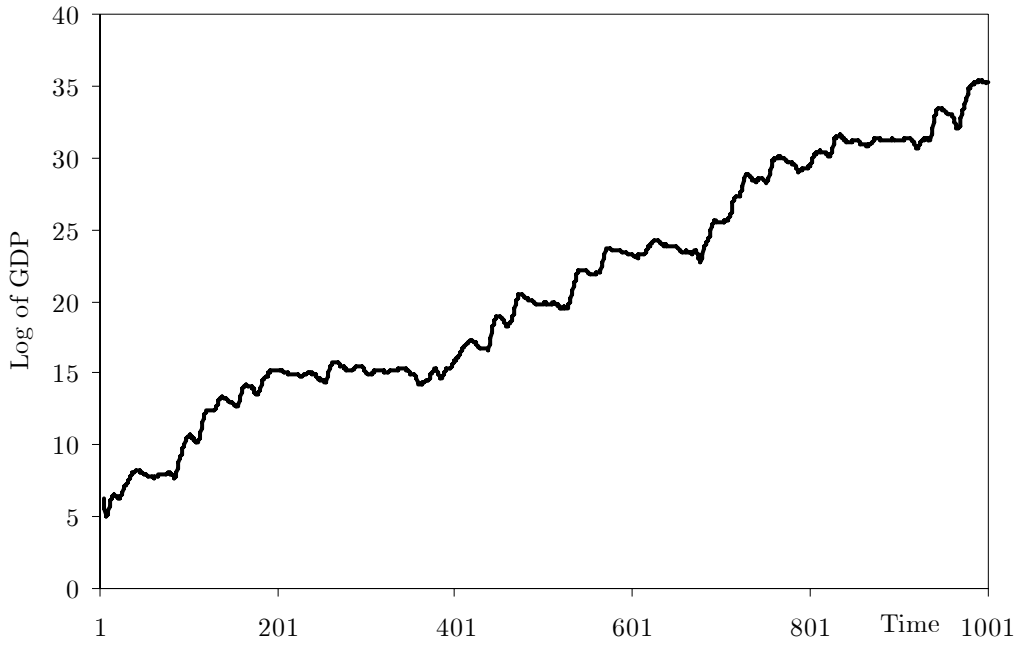
The Model: Some Results (1/5)

- Emergence of self-sustaining growth…
  - Is it possible to find parameters regions (necessary technological and institutional conditions) where self-sustaining growth is a high-probability event?



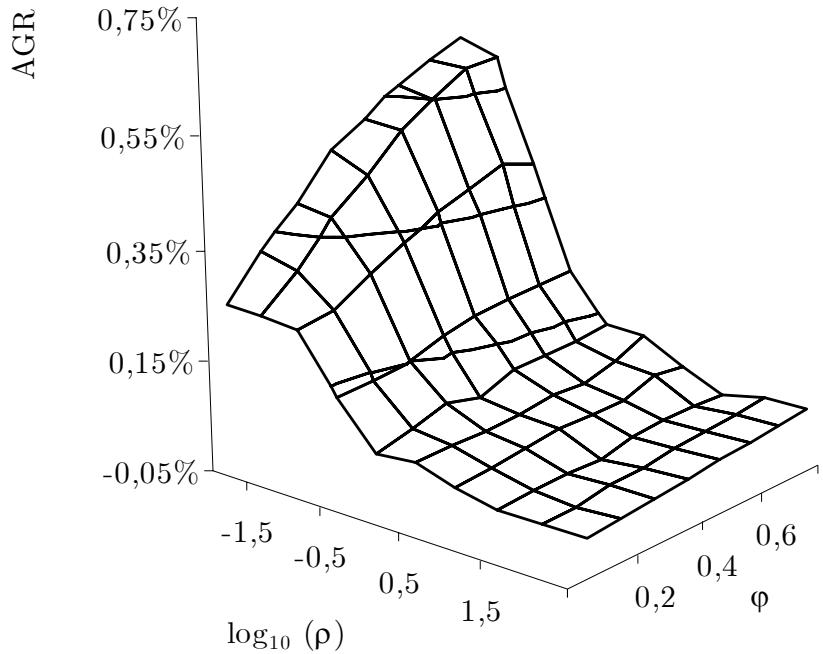
The Model: Some Results (2/5)

- … with the “right” statistical properties
  - Under which technological and behavioral conditions (if any) is the model able to generate log(GNP) time-series with statistical properties similar to real ones?



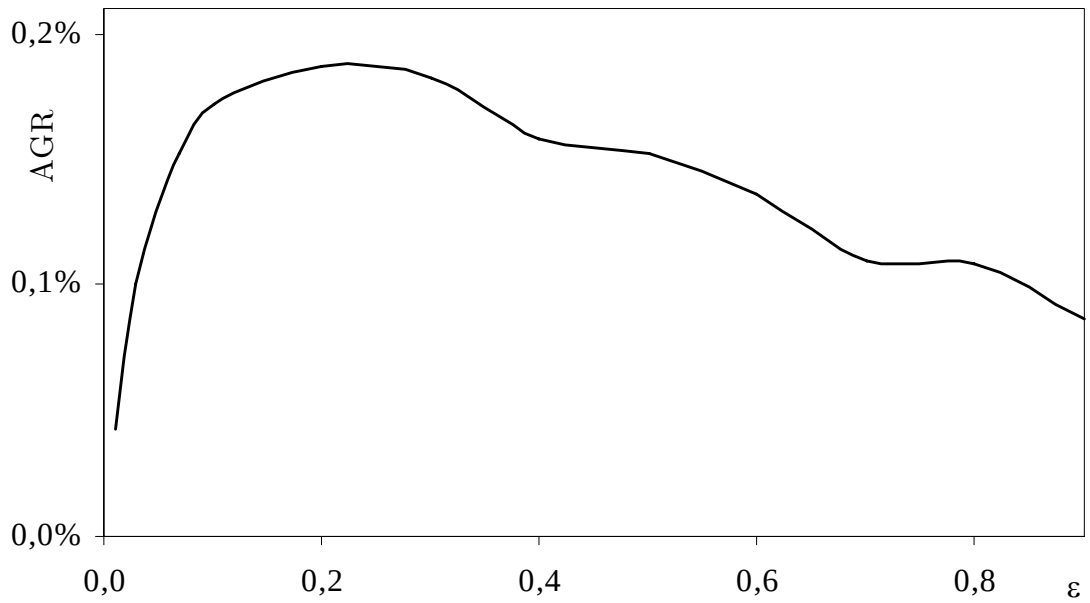
The Model: Some Results (3/5)

- Explaining self-sustaining growth…
  - Mapping parameters (technological and institutional conditions) into average performance (average growth rates) for the economy



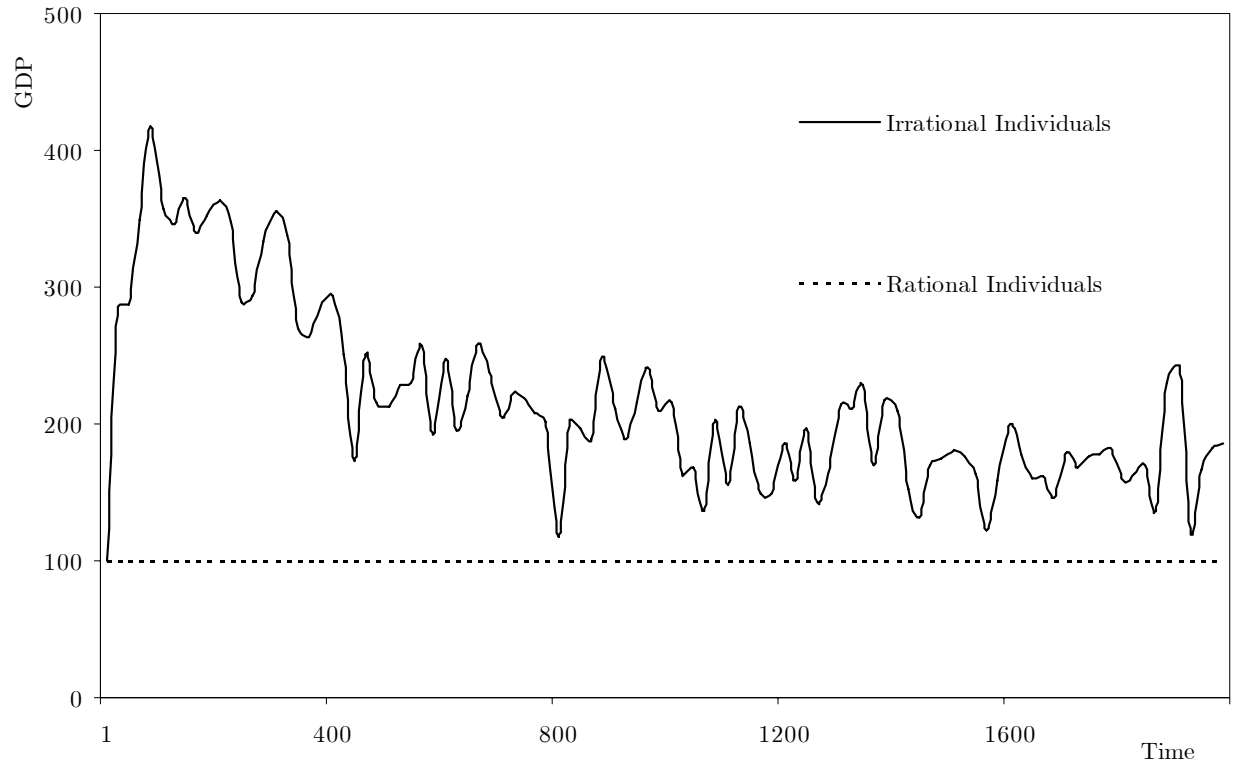
The Model: Some Results (4/5)

- … as solving exploitation-exploration trade-offs
  - Average growth rates vs. propensity to invest in R&D



The Model: Some Results (5/5)

- Irrationality necessary for self-sustaining growth
  - Showing that irrational agents can do better than rational representative-individuals in the aggregate



Concluding Remarks (1/2)

- A whole new way of doing economics?
  - Large community: Ph.D. programs, journals, conferences
  - Still a minority vs. neoclassical economics
  - Characterizing 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

Concluding Remarks (2/2)

- Open issues
  - Fostering empirical validation techniques
  - Pushing policy and design exercises
- Issues in empirical validation
  - Allow for a better and deeper replication of stylized-facts
  - Over-parameterization of agent-based models
  - Developing more powerful calibration 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