Agent-based macroeconomics: Methods, myths and models

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Outline

- Alphabet soup
- MABM: A primer
- Policy issues
- The geography of MABM
- A tentative taxonomy
- Hybrid MABM
- To do

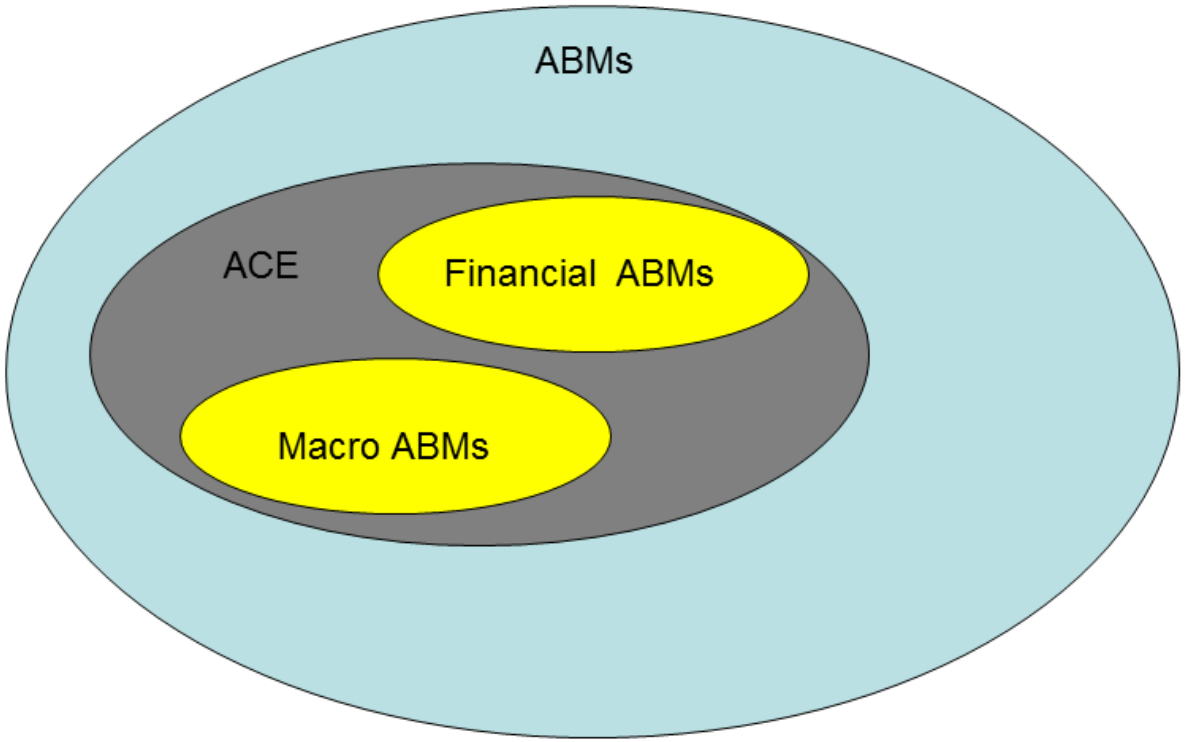
Alphabet soup

- **ABM** *(Agent Based Models)*: Models of complex adaptive systems in which a *multitude of (heterogeneous) objects interact* with each other and the environment.
- **ACE** *(Agent based Computational Economics)*: "The computational study of economic processes modelled as dynamic systems of interacting agents" (Tesfatsion, 2006).
- **FABM** *(Financial ABM)*: ABM of an "artificial market" – typically a stock market – in which agents (investors) use a few competing heuristics to form expectations (fundamentalists, trend followers, noise traders) (aka HAM in finance, see Hommes, 2006).

Alphabet soup (cont'd)

- **MABM** *(Macroeconomic ABM)*: ABM of the *macroeconomy,* conceived as a *complex adaptive system* in which a *multitude of (heterogeneous) agents* (firms, households, banks) *interact* with each other and the environment.
- Heterogeneity comes from a variety of sources: skill, productivity, size, leverage, wealth...
- Aggregate (macroeconomic) variables such as GDP, consumption etc. are computed *"from the bottom up"*, i.e. summing individual quantities across agents.
- The bottom-up approach to macroeconomics consists therefore in "deducing the macroscopic objects and their phenomenological complex ad-hoc laws in terms of a multitude of elementary microscopic objects interacting by simple fundamental laws." (Solomon)

The alphabet soup in a picture

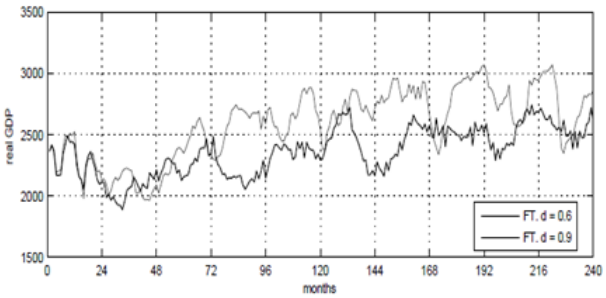


How to do MABM

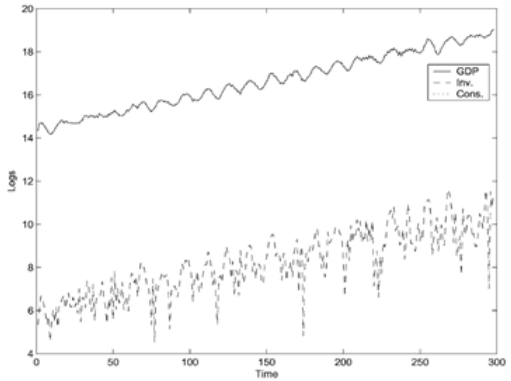
- *Starting point:* consider a population of heterogeneous agents (households, firms, banks,...).
- *Theory*: write behavioral rules (e.g. demand and supply of goods, labour, credit).
- *Codification*: translate the rules into code lines.
- *Validation*:
  - calibrate the parameters
  - run simulations
  - analyze the *emerging properties* of the simulated data, both at the cross-sectional level (e.g. firms' size distribution) and at the macroeconomic level (GDP growth and fluctuations, inflation/unemployment trade off)
  - compare these properties with real world "stylized facts".

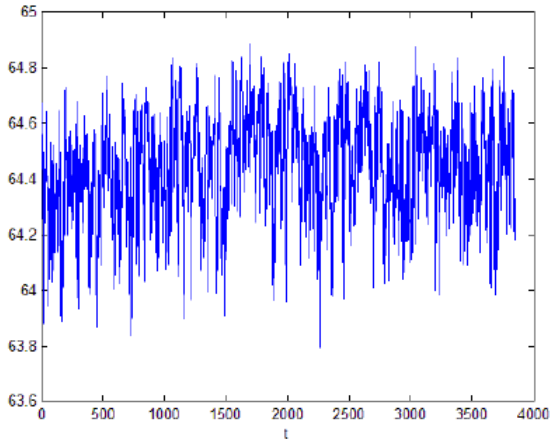
In MABM GDP tends to *self-organize* towards a quasi-steady state or steady growth equilibrium

Cincotti-Raberto et al.



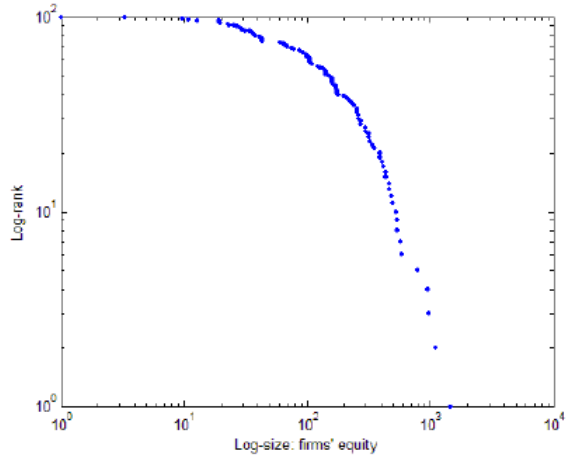
Dosi-Fagiolo et al.





Delli Gatti
Gallegati
Et al.

MABM can reproduce also the cross-sectional evidence. This is out of the reach of standard macroeconomic models



Delli Gatti
Gallegati
et al.

Dosi
Fagiolo
et al.

MABMs are characterized by

- *externalities* and *non-linearities* (due to interaction),
- *autocatalytic processes:* dynamic processes with *positive feedbacks.*

Autocatalyticity

- Autocatalyticity insures that the behaviour of the entire system is dominated by the elements with the highest auto-catalytic growth rate rather than by the typical or average element (Solomon).
- As a result, "much of the real world is controlled as much by the 'tails' of the distributions as by the average; by the exceptional, not the mean; by the catastrophe, not the steady drip; by the very rich, not the 'middle class'. We need to free ourselves from 'average' thinking" (Anderson).

Autocatalyticity (cont'd)

- Autocatalytic dynamics is key to understanding the emergence of *scale-free distributions (power laws)* at an aggregate level.
- The relevance of scale free distributions in economics (e.g. of firm size, wealth, income, etc.) is now extensively recognized
  - in the econophysics literature (Mantegna and Stanley, 2000)
  - in macroeconomics (Gabaix, 2011)

Policy issues that can be explored using MABMs and are out of the reach of standard macro models: #1

- Due to auto-catalicity, **idiosyncratic shocks may have aggregate consequences.**
- In other words, an agent specific negative shock may turn into a macroeconomic recession, provided the agent is "big" enough or "connected" enough.
- Hence MABM can generate business fluctuations due to the percolation of an idiosyncratic shock to the "tail" of the distribution (e.g. firms'size or net worth distribution) in the absence of aggregate shocks.

Policy issues that can be explored using MABMs and are out of the reach of standard macro models: #2

- Due to heterogeneity, **aggregate shocks may have idiosyncratic consequences.**
- In other words, a negative aggregate shock may affect different agents in different ways. An aggregate shock affects not only the mean but also the variance (and higher moments) of the distribution.
- This heterogeneity of individual reactions to aggregate shocks may then affect the aggregate repercussions of the aggregate shock
- Hence MABM can generate business fluctuations of different magnitudes in the presence of the same shock depending on the distribution of agents' specific responses.

2 important remarks on MABM

1. **Behavioural equations may or may not be derived from optimization.** If not, one can think of behavioural equations as being based on "rules of thumb".
2. **No equilibrium condition required (out-of-equilibrium dynamics).**

Bounded rationality and adaptive behavior

- AB modellers generally prefer to assume that agents are characterized by *bounded rationality*; they are "not global optimizers, they use simple rules *(rules of thumb)* based on local information" (Epstein).
- In principle, however, behavioural rules can be either grounded in bounded rationality *(rules of thumb)* or can be derived from specific optimization problems *(optimal rules).*

Out-of-equilibrium dynamics

- AB modellers generally prefer to assume that markets are systematically in disequilibrium.
- In principle, however, at least some markets may be in equilibrium or converge to a statistical equilibrium.
- Generally, aggregate variables in MABM (e.g. GDP) show a tendency to *self-organize* towards a stable aggregate configuration (quasi-stationary equilibrium).

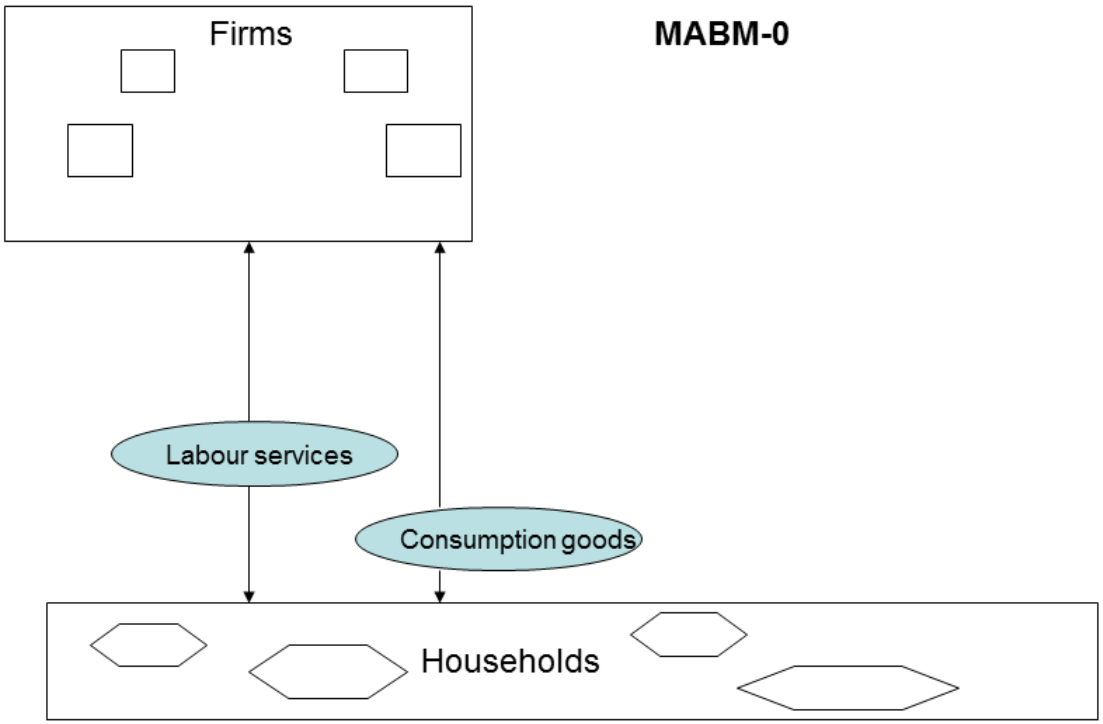
A sparse network of researchers

- There is a network of MABM researchers based predominantly in Europe but present also in the US. To name just a few examples:
  - MABM in which *"financial factors"* play a major role in business fluctuations: Howitt et al., Delli Gatti-Gallegati et al., Cincotti-Raberto et al. (Eurace-Genoa);
  - MABM in which *capital accumulation and embodied technical progress* generate growth and fluctuations: Dosi-Fagiolo et al.;
  - MABM for the analysis of the interplay of the labour market and technical progress: Dawid et al. (Eurace-Bielefeld);
  - MABM for the analysis of the macroeconomic impact of learning: Yildizoglu (Bordeaux) - Salle (Amsterdam).

Dublin
Essex-Sussex
London-Oxford
Amsterdam (Hommes-Salle)
Potsdam
Paris
Bielefeld (Dawid)
Bordeaux (Yildizoglu)
Milan (Delli Gatti)
Genoa (Cincotti)
Aix-Marseille-Nice
Ancona (Gallegati)
Pisa (Dosi-Fagiolo)
Castillon

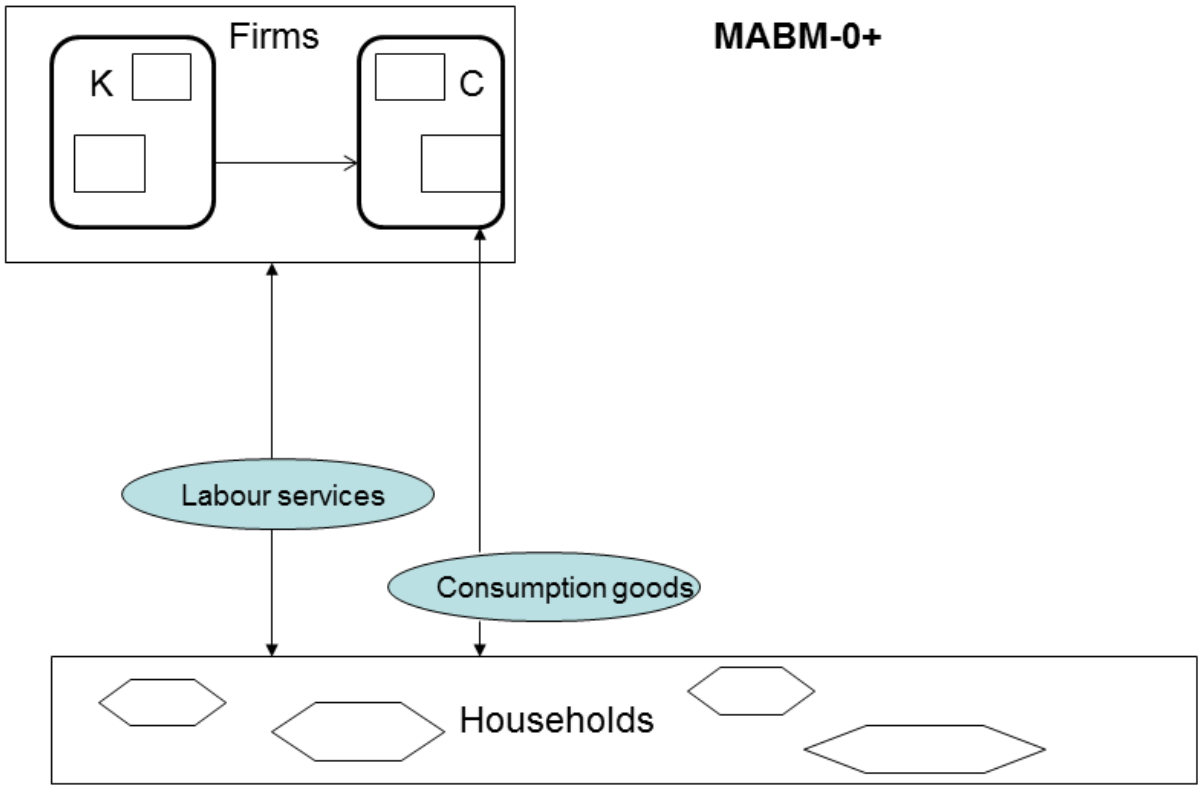
MABM Mark 0

- Agents: households, firms
- Markets: goods, labour
- In the simplest version:
  - only consumption goods,
  - technology uses only labour to produce consumption goods.
- Artificial time series shows irregular fluctuations.


Firms
MABM-0
Labour services
Consumption goods
Households

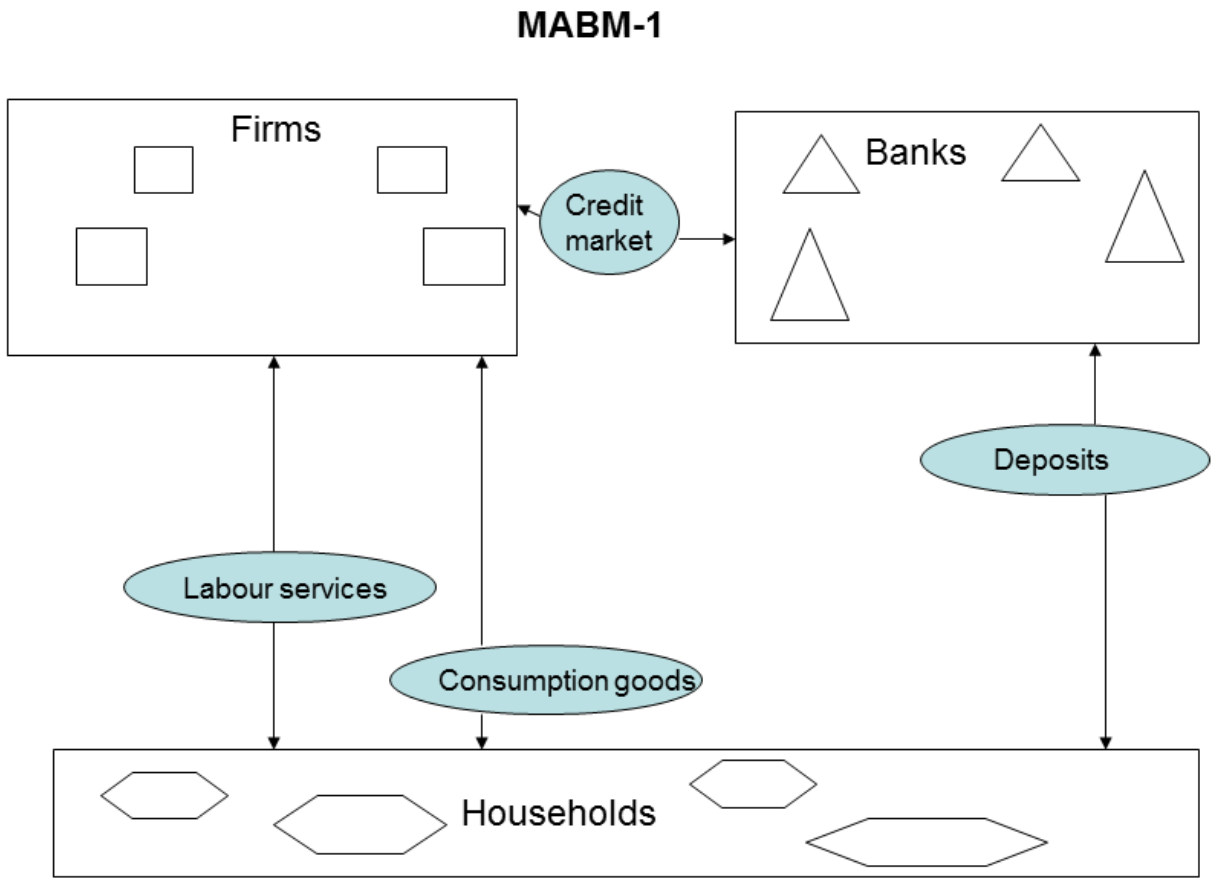
MABM Mark 0 (cont'd)

- In a more sophisticated version:
  - investment goods and consumption goods,
  - investment goods and labour used to produce consumption goods,
  - labour used to produce investment goods,
  - with investment and innovation/imitation, R&D and/or complementarities among inputs (workers'skills and qualities of investment goods) one can have growth and fluctuations.
- This is essentially the original Pisa S.Anna model aka "Schumpeter meeting Keynes" (Dosi, Fagiolo et al.)...
- ...but also the EURACE-Bielefeld model (Dawid et al.).


Firms
K
C
MABM-0+
Labour services
Consumption goods
Households

MABM Mark 1

- Agents: households, firms, banks
- Markets: goods, labour, credit
- In the simplest version:
  - only consumption goods,
  - technology uses only labour to produce consumption goods.
- Artificial time series shows irregular fluctuations driven by financial fragility of firms.
- This is essentially the core model of Macroeconomics from the Bottom Up (MBU) (Delli Gatti, Gallegati and co-authors).


MABM-1
Firms
Banks
Credit market
Deposits
Labour services
Consumption goods
Households

MABM Mark 1 (cont'd)

- In a more sophisticated version (say mark 1.1):
  - part of retained profits are used to finance R&D expenditure,
  - R&D expenditure increases the productivity of labour.
- In this context one can have growth and fluctuations. This is the simplest extension of MBU.

MABM Mark 1 (cont'd)

- In a more sophisticated version (say mark 1.2):
  - investment goods and consumption goods,
  - investment goods and labour used to produce consumption goods;
  - labour used to produce investment goods,
- durability enhances the persistence of fluctuations (but there is no growth).
- This is the CRISIS MABM mark 1+...

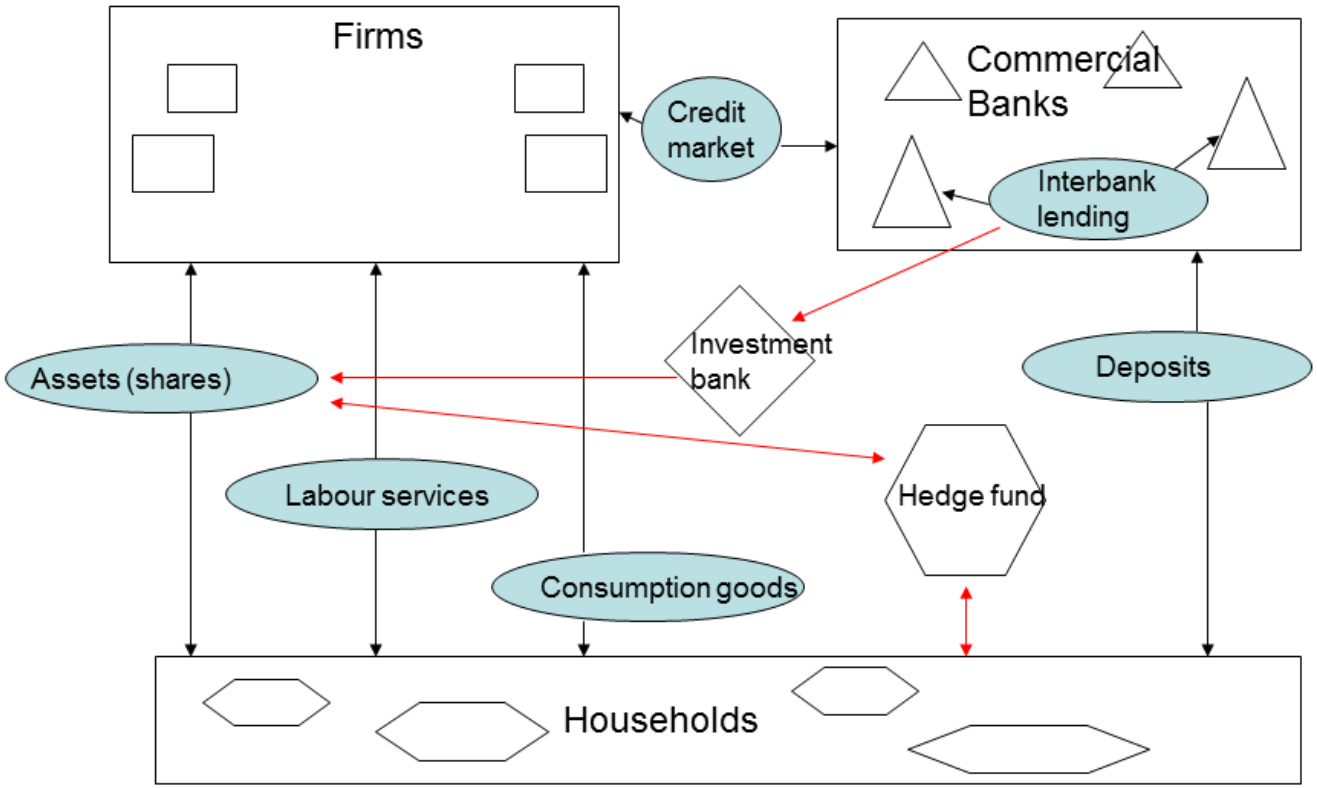
MABM Mark 2

- Agents: firms, banks, households (as workers and investors),
- Markets: goods, labour, credit, a financial market (typically: a Stock market)
- This is a reasonably complete macro-financial ABM (a combination of MABM and FABM).
- In principle, you can analyze the entire range of transmission mechanisms of shocks and feedbacks that arise in the presence of heterogeneity...

MABM Mark 2 (cont'd)

- Generally, however, there are
  - investment goods and consumption goods;
  - investment goods and labour used to produce consumption goods;
  - labour used to produce investment goods,
- durability enhances the persistence of fluctuations but there is no growth.
- This is the CRISIS MABM mark 2...

MABM-2


Firms
Credit market
Commercial Banks
Interbank lending
Investment bank
Assets (shares)
Deposits
Labour services
Hedge fund
Consumption goods
Households

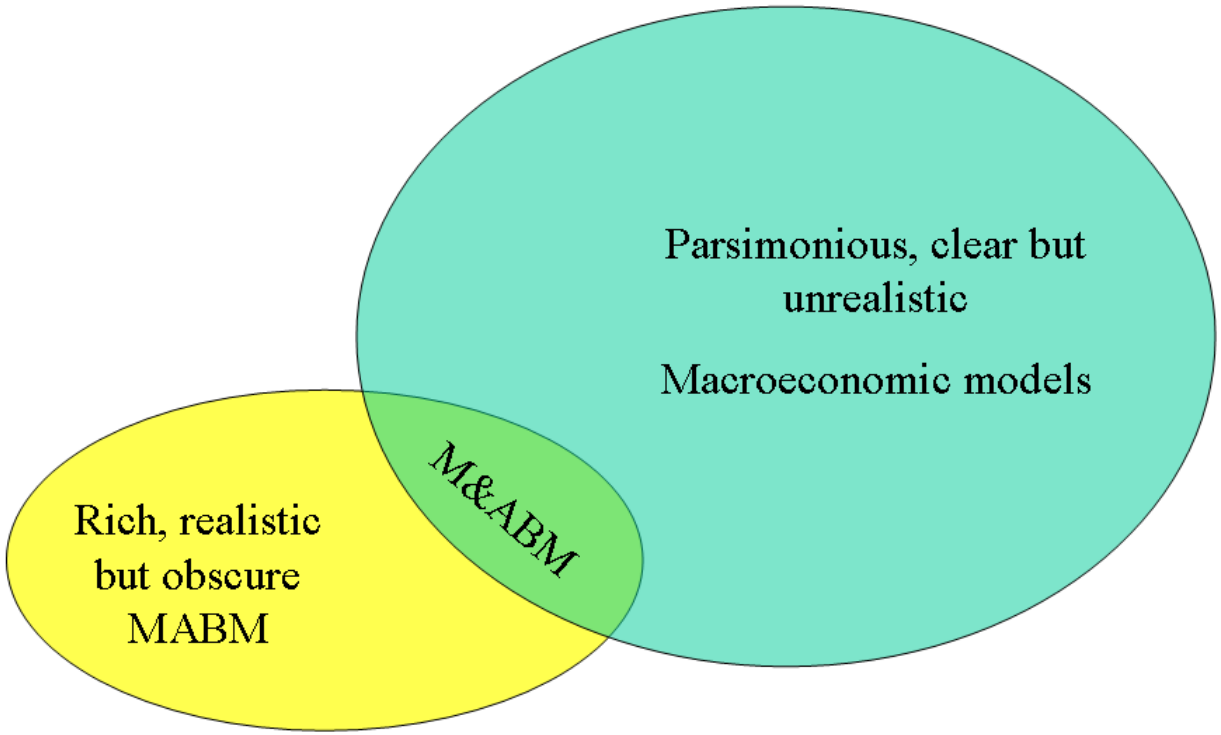
MABMs as black boxes

- MABMs can reproduce the empirical evidence, both at the aggregate and at the cross sectional level
- For instance: irregular fluctuations (puntuated by "great contractions") of GDP (determined from the bottom up)...
- ...but the *interpretation is difficult and somehow arbitrary*
- This is the standard criticism: ABMs are *"black boxes".*

A hybrid Macroeconomic and AB Model (M&ABM)

- To *reconcile macroeconomic thinking and AB modelling*, in Assenza-Delli Gatti 2013 we propose to nest an ABM into a standard macro model, therefore building a hybrid macroeconomic and agent based model **(M&ABM)**
- We want to gain clarity in the conclusions we can get from M&ABM. In order to reach this goal we sacrifice – at least in part – the richness of the macroeconomic representation of MABMs.

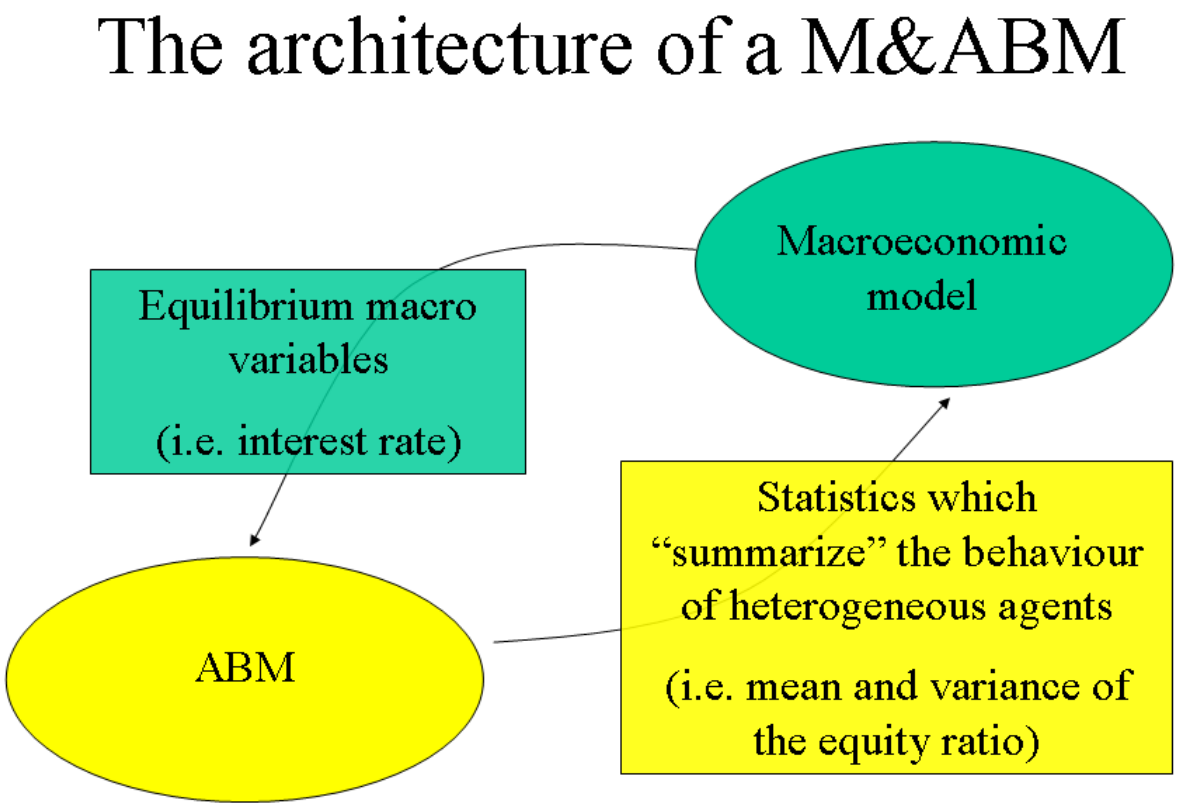
The trade off between "clarity" and "realism"



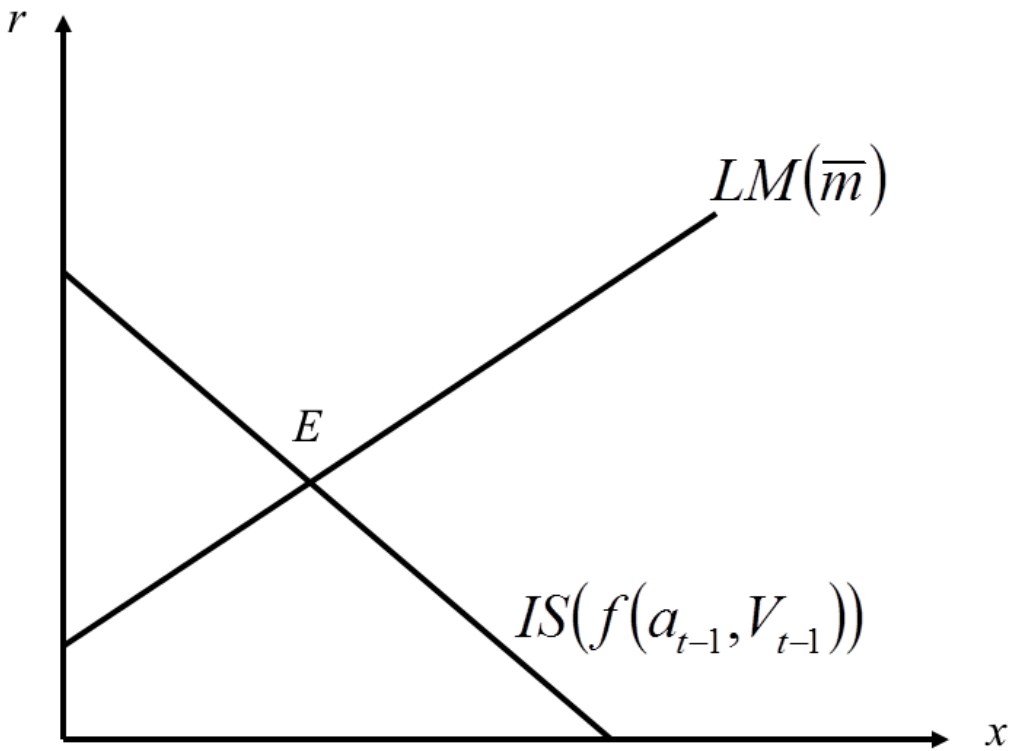
The architecture of a M&ABM

- There is a *two way feedback* between the macroeconomic model and the ABM:
  - from the macroeconomic equilibrium$\longrightarrow$aggregate variables $\longrightarrow$ micro-state variables;
  - Averaging the micro-state variables$\longrightarrow$macro state variables $\longrightarrow$macroeconomic equilibrium.

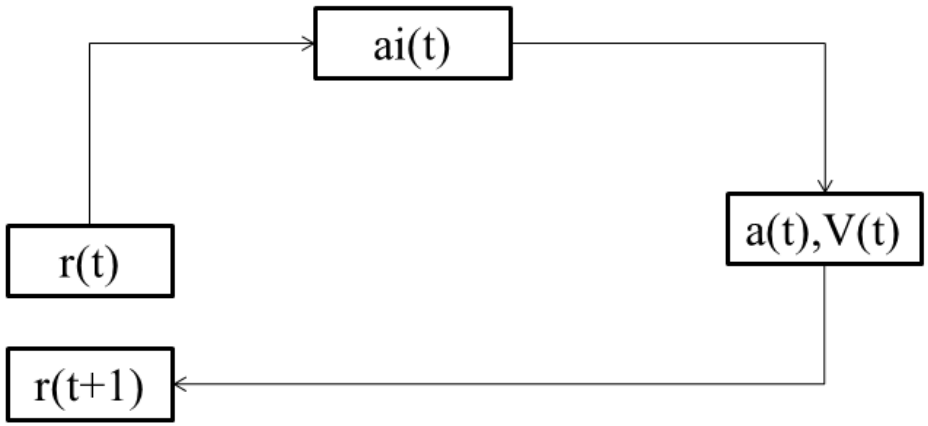
The architecture of a M&ABM



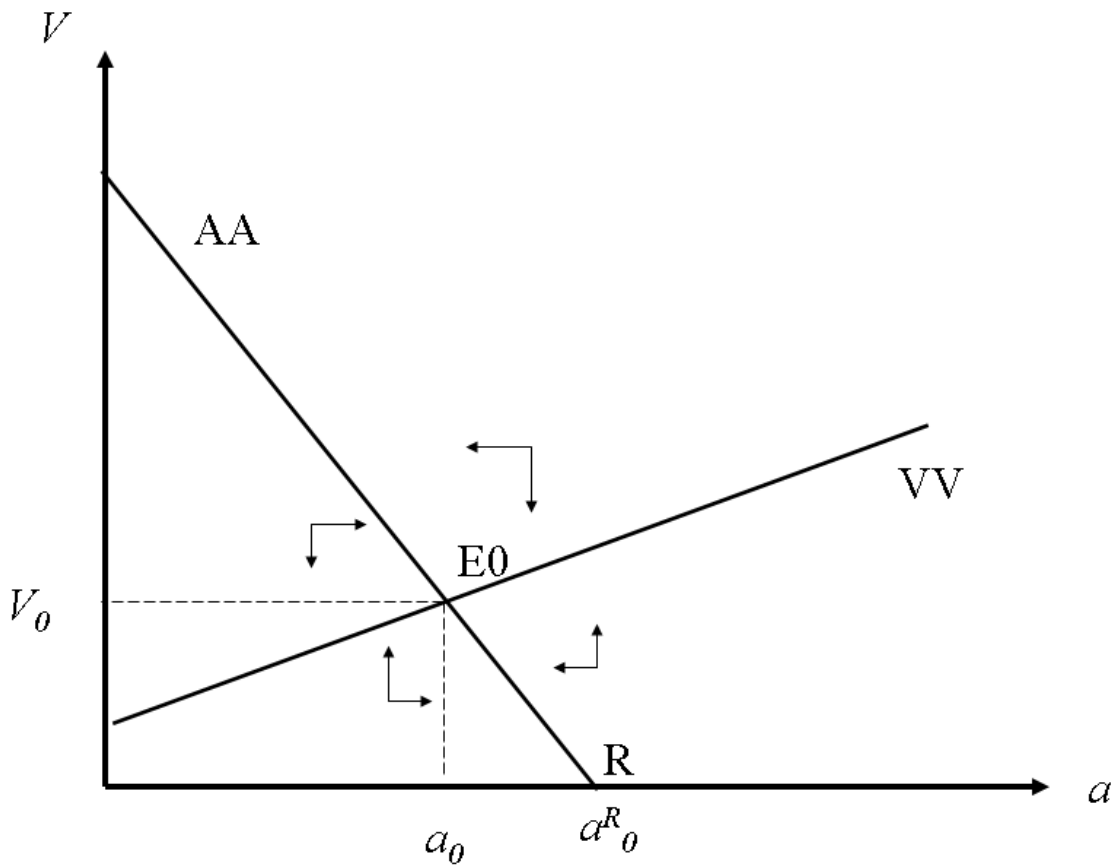
The "moments augmented" IS-LM model



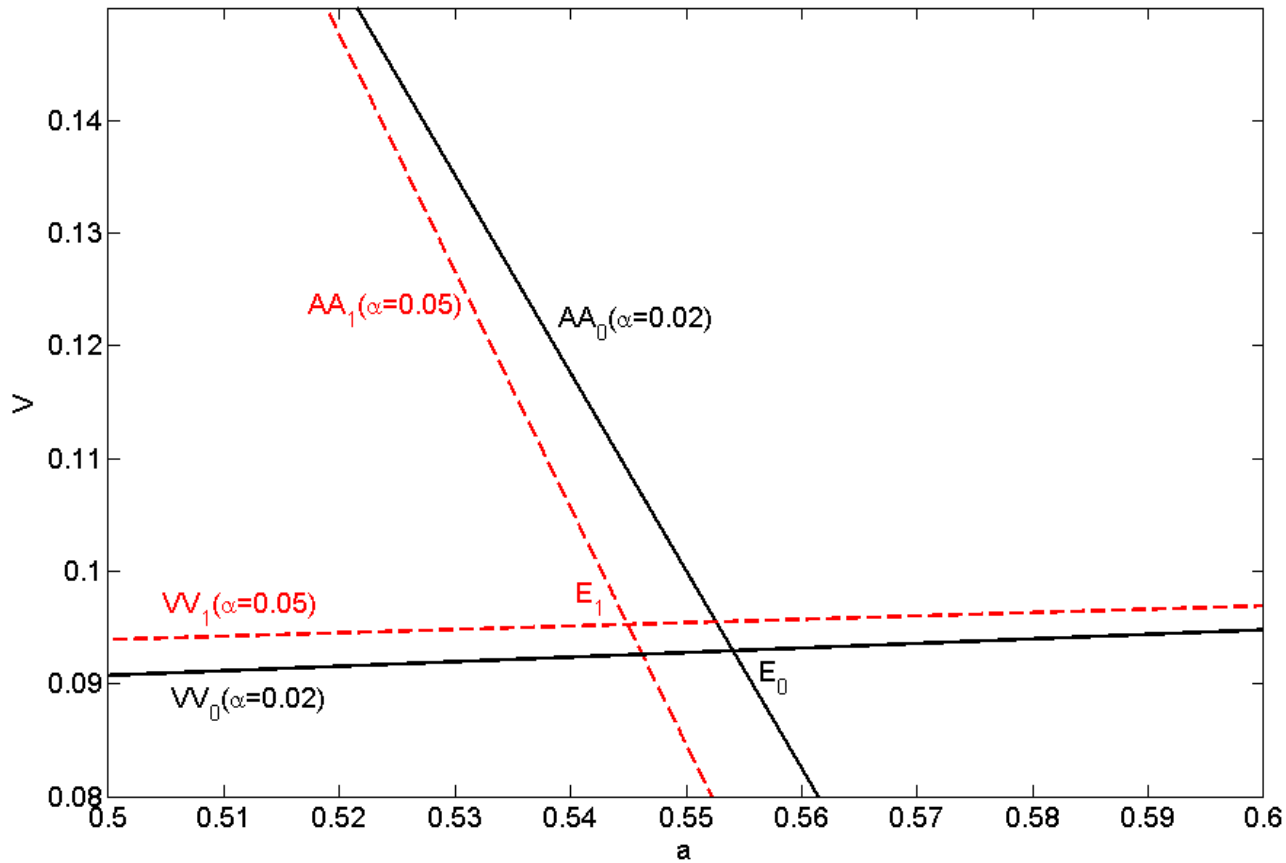
The nested ABM and the macroeconomic externality



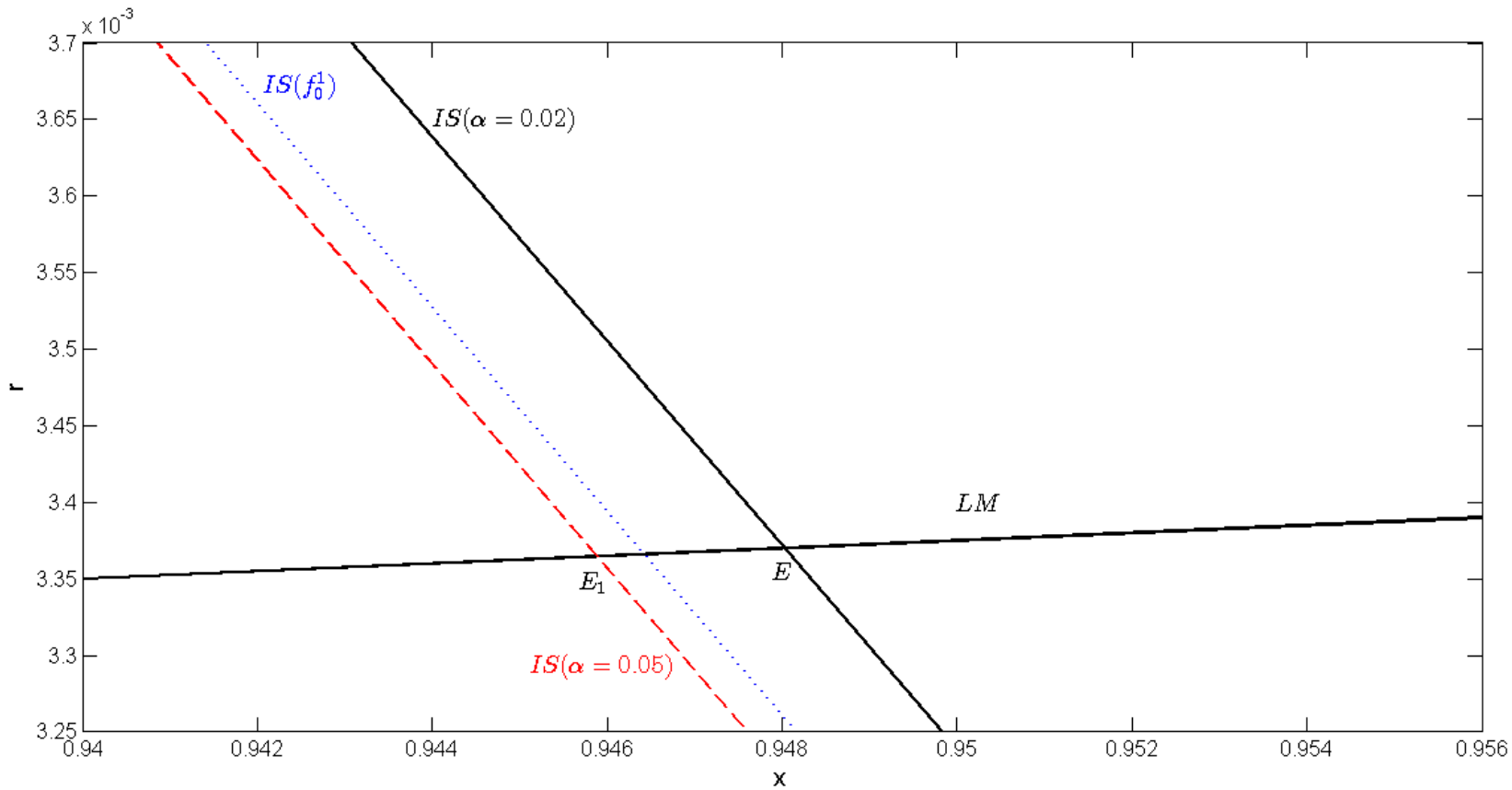
The trajectories of the distribution



A negative financial shock: effects on trajectories of the distribution



A negative financial shock: effects on the macroeconomic equilibrium



3 important remarks on M&ABM

1. Behavioural equations are derived from optimization (but one can build a M&ABM from rules of thumb).
2. **The equilibrium condition is necessary to "solve the macroeconomic model (i.e. to compute the reduced form).**
3. **The dynamics of GDP is determined "in equilibrium",** i.e. through the reduced form of the macroeconomic component of the model, instead of through the procedure "from the bottom up".

To do

- Expectation formation in a complex environment with heterogeneous agents
- Meaningful policy experiments
- Bring MABM to the date to make quantitative *predictions of macroeconomic variables*