Complexity

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June 9, 2021

Overview

What is complexity?

- No clear definition.
- Any system that doesn't **converge/limit/explode**
- **Emergent/evolutionary** properties (stable/structural features of complete system)
- Nonlinearity
- We'll focus on **Agent Based Models**

Presentation

- Intro to ABM
- New Keynesian ABM = HANK
- Post-Keynesian ABM = SFC-AB
- Taking stock
- Some modelling considerations

Introduction

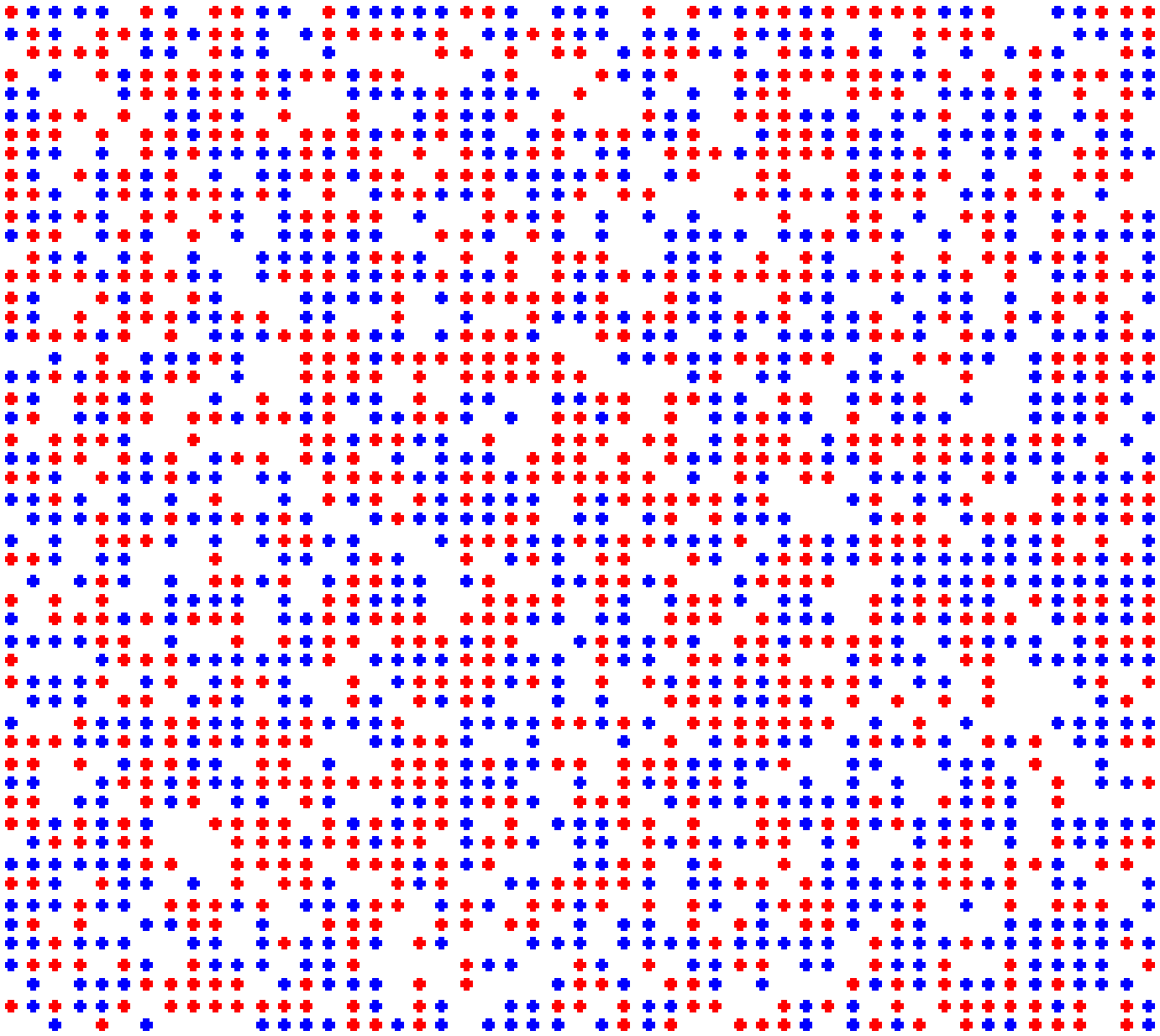
Classic agent based models

- Schelling Model
- Boids
- Pandemic spread

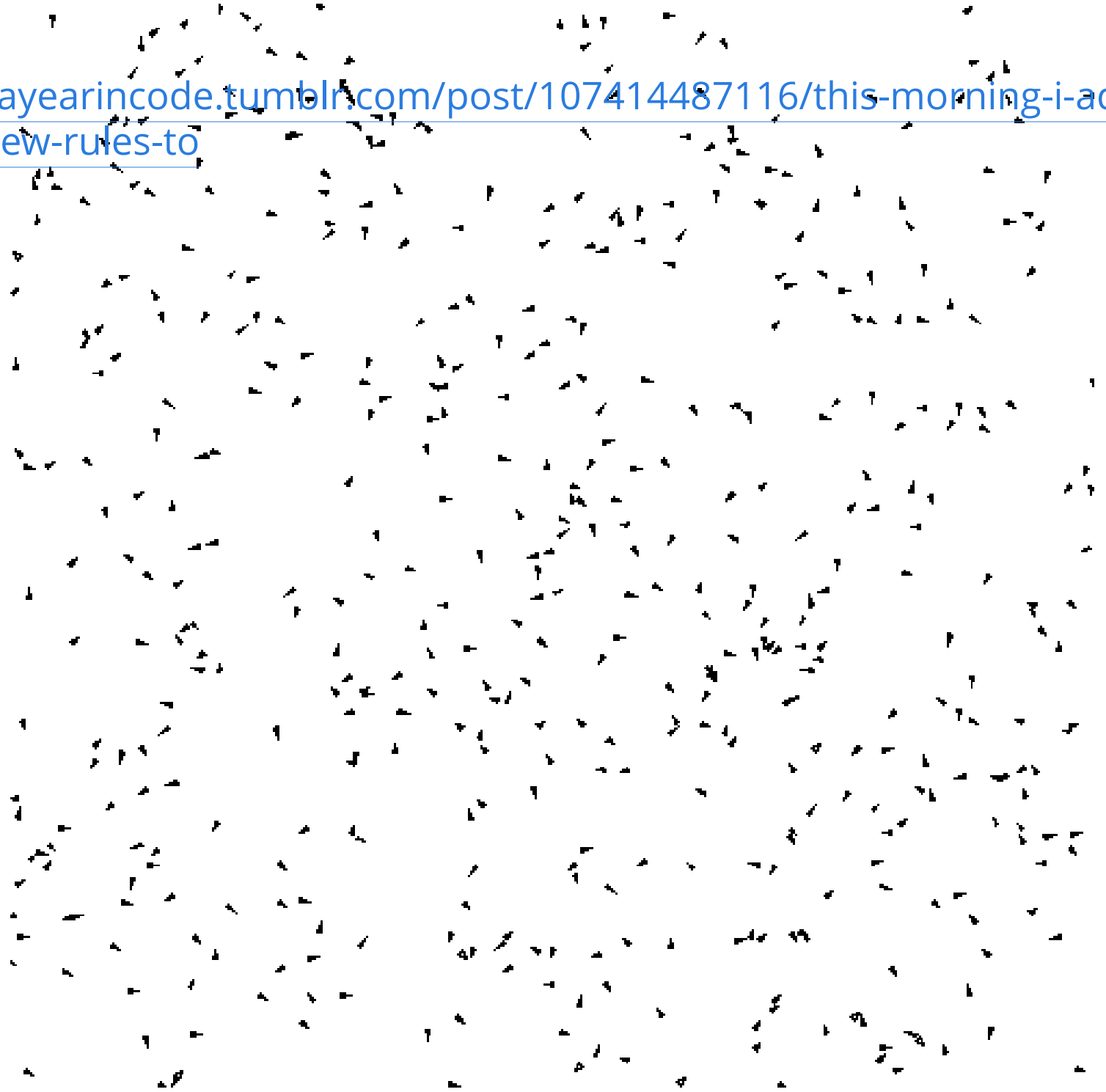
Schelling model

- Lay out coins in a row or grid with spaces
- Coins can be heads or tails
- Coins prefer to be close to another with same side showing
- Repeatedly move a coin that is “unhappy”

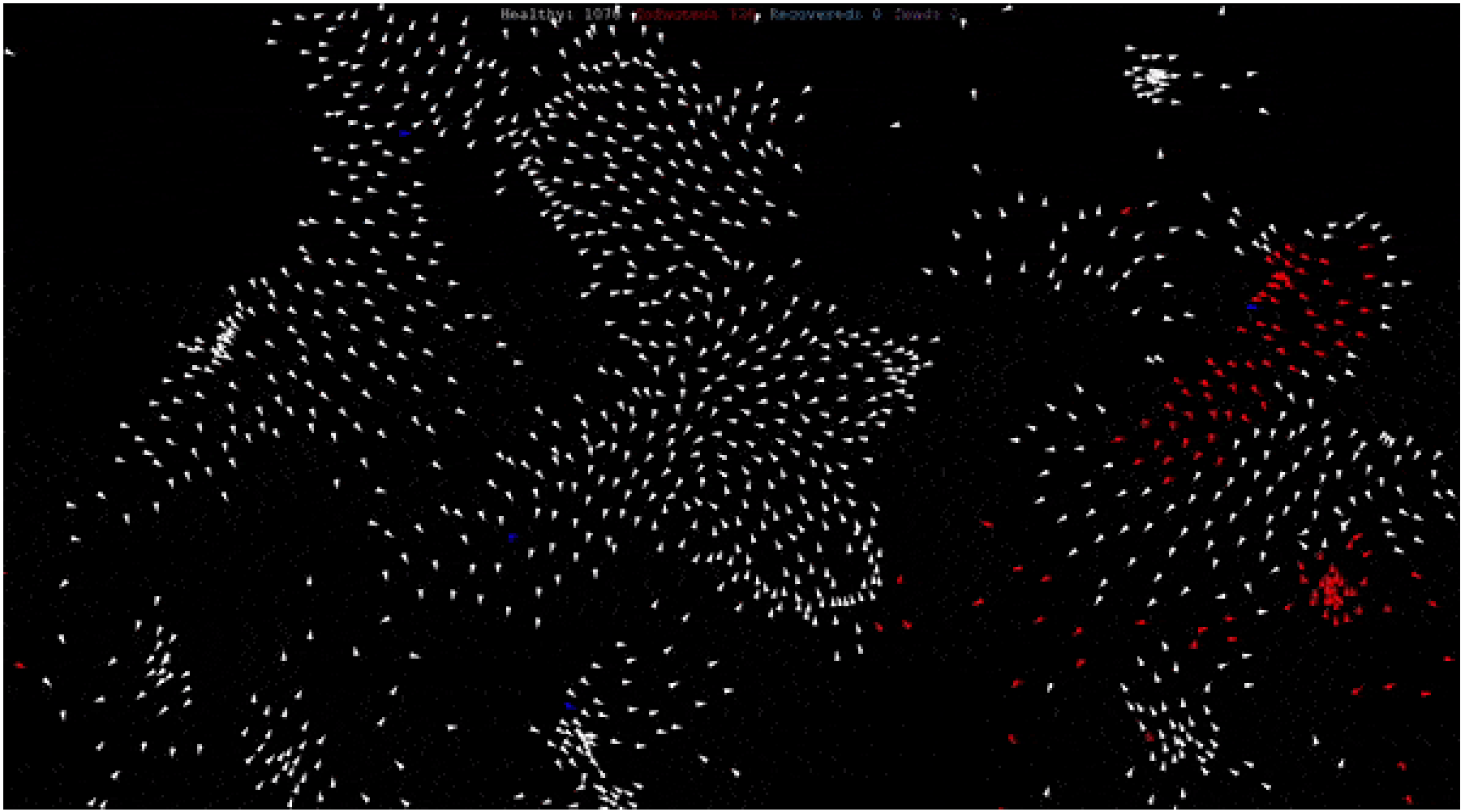
Step 1



https://ayearincode.tumblr.com/post/107414487116/this-morning-i-added-some-new-rules-to



https://github.com/IvanHornung/Pandemic-Simulator



Common features

- “Agents” follow rules
- Agents react to their environment
- The “environment” changes as a result of agents’ behaviour
- State switching, e.g. behaviour change from fundamental trader to chartist
- Matching – agents interact locally
- Emergent properties
- Equilibrium either absent or emergent

AB in macro

- (non-AB) macro models solved and/or simulated as system of simultaneous equations
  - Inter-temporal price equilibrium in NK models
  - Current period S = I equilibrium condition in PK models, LR stock-flow equilibrium from simulation.
- AB macro models usually simulated incrementally (no short-run equilibrium)
- Some progress on analytical AB, both NK and PK

AB macro design

- (Additional) decisions on:
  - Types of agents, (e.g. different type of households/firms)
  - Distributions of e.g.
    - agents
    - endowments (skills, capital, technology)
    - income
    - financial assets and liabilities
  - Sequencing of actions and transactions
  - Aggregation and feedback from environment to agents (markets, government)

Example: Standard Keynesian cross

- $$C = cY$$
- $$Y = C + I$$
- $$Y = \frac{I}{1 + c}$$

Example: AB Keynesian cross

- N discrete consumers with consumption functions $C_i = c_i \alpha_i Y$, with i in $1, 2 \dots N$
- Propensities to consume c_1, c_2, … , c_n
- shares of national income α_1, α_2, … , α_n
- E.g. if consumer 3 has propensity to consume $c_3 = 0.7$ and share of income $\alpha_3 = 0.1$ then $C_3 = 0.07Y$

Example: AB Keynesian cross

$$C = \hat{c}Y$$

$$\hat{c} = \sum_{i=1}^{N} c_i \alpha_i$$

$$Y = \frac{I}{1 + \hat{c}}$$

Example: AB Keynesian cross

- Total consumption depends on distributions of income and propensities to consume
- Changes to agent behavour (propensity to consume) affects “environment” (aggregate demand).
- Changes in aggregate demand affect all agents behaviour (incomes change)
- This is a trivial example – excludes most “complex” features
- Slight development: make consumption depend on **last period** income
- Model would then adjust gradually towards final state after a change in propensity to consume or distribution

New Keynesian HANK models

HANK vs RANK

- **Heterogeneous agent New Keynesian models** (HANK) developed from **representative agent New Keynesian models** (RANK)
- RANK models
  - Single consumer optimising over lifetime income in GE framework
  - Reacts strongly to interest rate changes, exogenous shocks
  - Reacts little to short run changes in income
  - Ricardian Equivalence
  - Strongly contradicted by the evidence
  - ** No role for inequality **: assumed that macro is not distributional

Where did RANK go wrong

"Approxiate aggregation" result (Krusell and Smith, 1998)

> Approximate aggregation … has led many economists to conclude that aggregate dynamics in representative and heterogeneous agent models are essentially equivalent. This is … innacurate.

> The high sensitivity of consumption to interest rates is not well supported by micro or macro data. … Consumption is not very responsive to changes in interest rates …

(Kaplan and Violante, 2018, p. 171-172)

Where did RANK go wrong

> This collective body of evidence on MPCs points towards 1) sizeable average MPCs out of small unanticipated, transitory income changes; 2) larger MPCs for negative than for positive income shocks; 3) small MPCs in response to announcements about future income gains and 4) substantial heterogeneity in MPCs that is correlated with access to liquidity. None of these four features are in line with the consumption behaviour in representative agent models.

(Kaplan and Violante, 2018, p. 172)

Where did RANK go wrong

> At the core of the RANK stands an aggregate Euler equation whose empirical failure has been widely documented, in particular in a series of celebrated papers by Campbell and Mankiw (1989, 1990, 1991)

(Bilbiie, 2020)

Where did RANK go wrong

- Evidence:
  - Low sensitivity of consumption to interest rates
  - High sensitivity of consumption to income
  - Finance matters: (heterogeneous) balance sheet positions affect behaviour

Here come TANK and HANK

- Two agent (TANK) and heterogenous agent (HANK) NK models
- Heterogenous **households**
- Distribution of MPCs
- Requires additional assumption to prevent all households optimising (infinite) lifetime income by lending/borrowing:
  - some agents are “hand to mouth” (ad hoc)
  - some agents are credit constrained (ad hoc)
- Otherwise, in line with RANK:
  - Rational expectations inter-temporal optimisation
  - Loanable funds (saving determines investment in LR)

What's the difference?

- Higher average MPCs
- Higher sensitivity to short run income changes
- Lower sensitivity to interest rates
- Resonse to change in rates occurs indirectly via Y
- Depends on fiscal policy (no Ricardian equivalence)
- Fiscal multipliers >1 (in short run)
- Otherwise, in line with RANK:
  - Exogenous (preferences-driven) long-run equilibrium path
  - Policy reacts to exogenous shocks
- Rediscovery of (old) Keynesian consumption function, in short run, and Kalecian insight that macro and distribution are co-determined.

PK/heterodox AB-SFC models

Situating AB-SFC

- Part of a broader heterodox agent-based literature including substantial contributions from Dosi, Delli Gatti, Gallegati, Ricetti and co-authors.
- Delli Gatti and Dawid (2018) provide a comprehensive survey
- Dosi et al's "Keynes-Schumpeter" framework.
- Salle and Seppecher's JAMEL (Java Agent Based MacroEconomic Laboratory)
- Richiardi's "JAS-mine" (Java Agent-based Simulation Library)
- Large-scale models such as EURACE, intended for policy use
- Not all explicitly SFC (accounting not always clear), or explicitly PK (role of aggregate demand not always clear)

General approach

- Attempts to integrate PK-SFC models a la Godley and Lavoie with agent-based features.
- Economies are evolutionary systems characterised by emergent properties
- Heterogeneous agents
- Bounded rationality, local information and interaction
- Stochastic elements
- Path dependence
- Emergent properties (macro) as a result of interactions between agents (micro)
- Embedded in SFC monetary accounting framework

Applications

- Inequality
- Financial structure and fragility
- Innovation
- Firm entry-exit
- Market process

Issues

- Analytically very difficult
- Large number of parameters to calibrate
- Numerical simulations hard to analyse systematically
- Presentation of results is challenging
- **Interpretation** of results is challenging

Examples

Example: Caiani et al (2016, 2018)

- Large complex multi-sector model
- Macro structure:
  - Heterogenous sectors
    - Households
    - Firms (two or more types)
    - Banks
  - Government
  - Central Bank

Example: Caiani et al (2016, 2018)

- Markets
  - Consumption goods: HH – Firms
  - Capital goods: firms – firms
  - Labour market: HH – firms/gov
  - Credit market: firms – banks
  - Deposit market: HH – banks

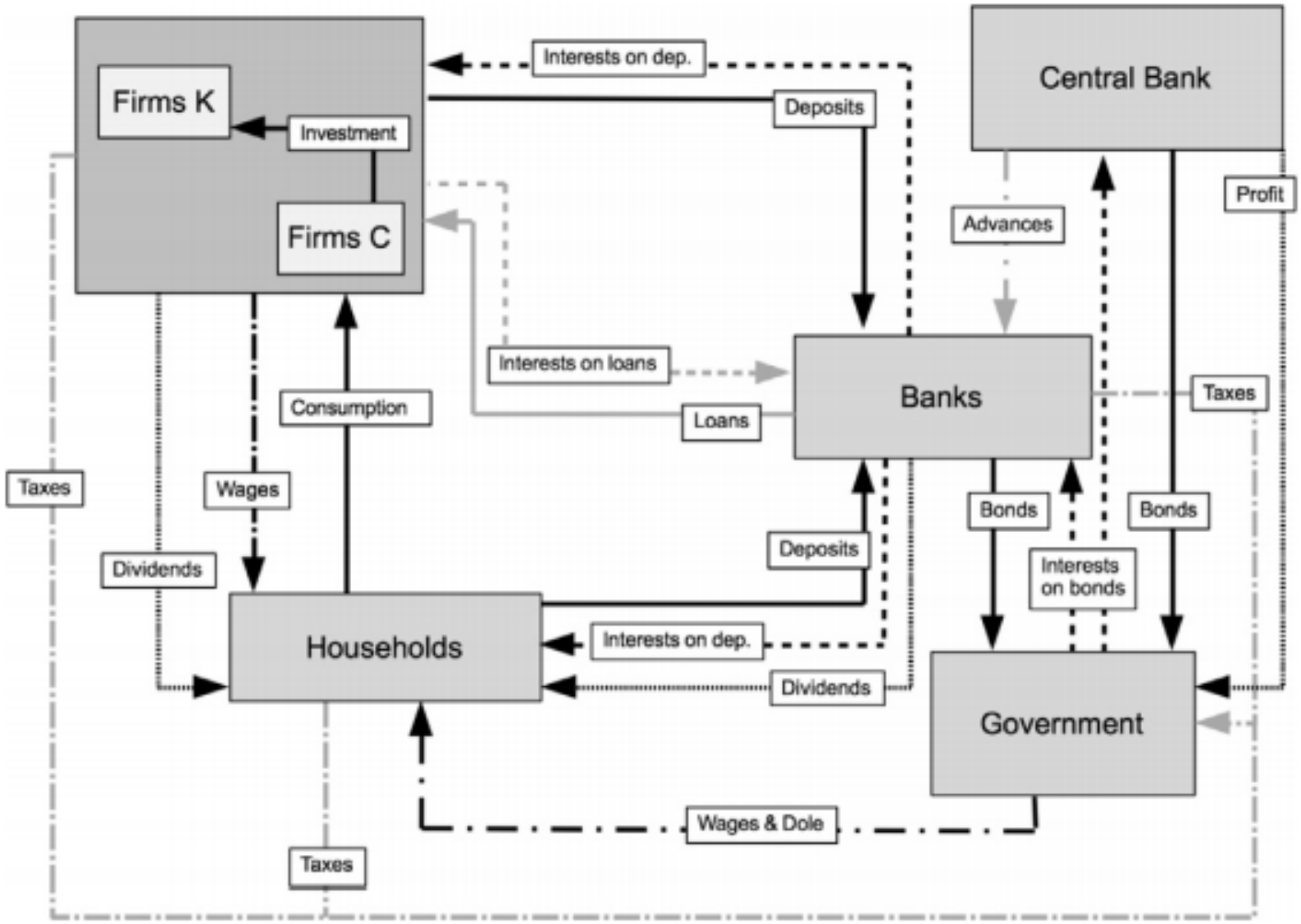


Fig. 1. Flow diagram of the model. Arrows point from paying sectors to receiving sectors.

In each period of the simulation, the following sequence of events takes place:

1. *Production planning*: consumption and capital firms compute their desired output level.
2. *Firms' labor demand*: firms evaluate the number of workers needed to produce.
3. *Prices, interest, and Wages*: consumption and capital firms set the price of their output; banks determine the interest rate on loans and deposits. Workers adaptively revise their reservation wages.
4. *Investment in capital accumulation*: consumption firms' determine their desired rate of capacity growth and, as a consequence, their real demand for capital goods.
5. *Capital good market* (1): consumption firms choose their capital supplier.
6. *Credit demand*: Firms assess their demand for credit and select the lending bank.
7. *Credit supply*: Banks evaluate loan requests and supply credit accordingly.
8. *Labor market*: unemployed workers interact with firms on the labor market.
9. *Production*: capital and consumption firms produce their output.
10. *Capital goods market* (2): consumption firms purchase capital from their supplier. New machineries are employed in the production process starting from the next period.
11. *Consumption goods market*: households interact with consumption firms and consume.
12. *Interest, bonds and loans repayment*: firms pay interests on loans and repay a (constant) share of each loan principal. The government repays bonds and interest to bonds' holders. Banks pay interest on deposits. Cash advances and related interests, when present, are repaid.
13. *Wages and dole*: wages are paid. Unemployed workers receive a dole from the government.
14. *Taxes*: taxes on profits and income are paid to the government.
15. *Dividends*: dividends are distributed to households.
16. *Deposit market interaction*: households an firms select their deposit bank.
17. *Bond purchases*: banks and the Central Bank purchase newly issued bonds.
18. *Cash Advances*: the Central Bank accommodates cash advances requests by private banks.

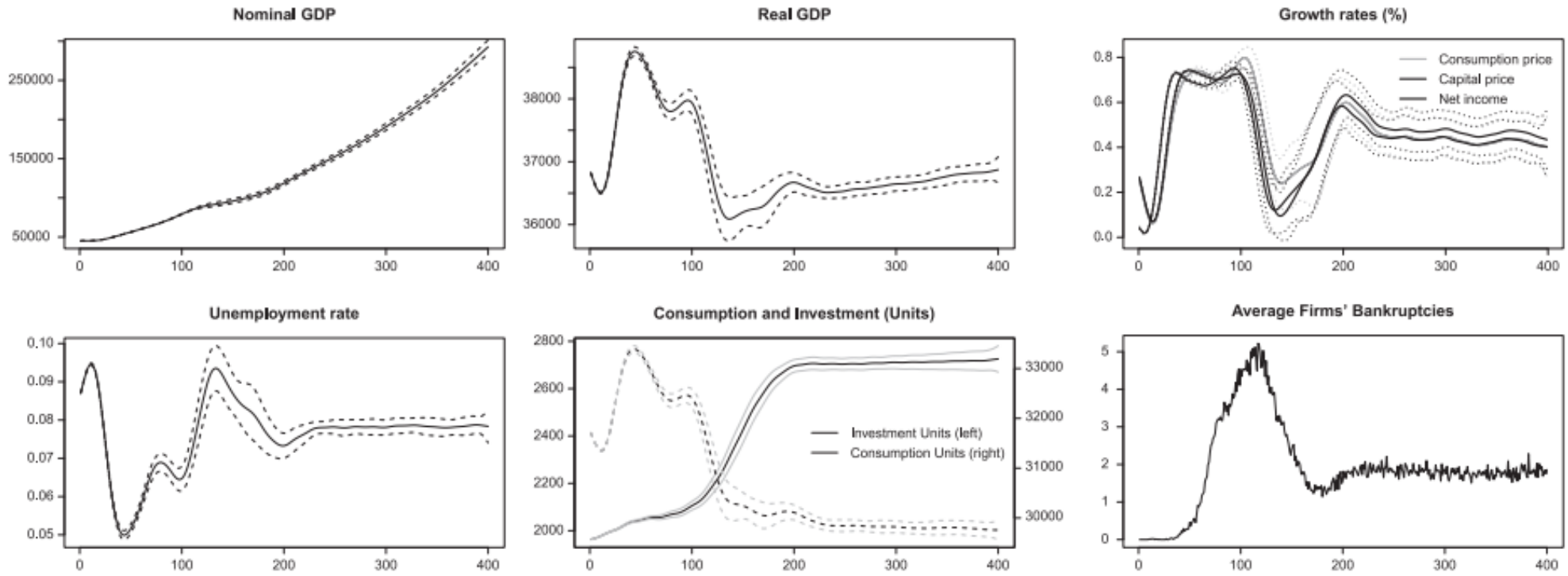


Fig. 2. Top Left: Nominal GDP. Top Center: real GDP. Top Right: net-income, consumption prices, and capital prices rates of growth. Growth rates of prices have been computed using average market prices (weighted for firms' market shares). Bottom Left: Unemployment. Bottom Center: Investment and consumption (real units). Bottom Right: number of firms' bankruptcies. Continuous lines are mean trends over Monte Carlo Simulations. Dashed lines are trends standard deviations across Monte Carlo runs.

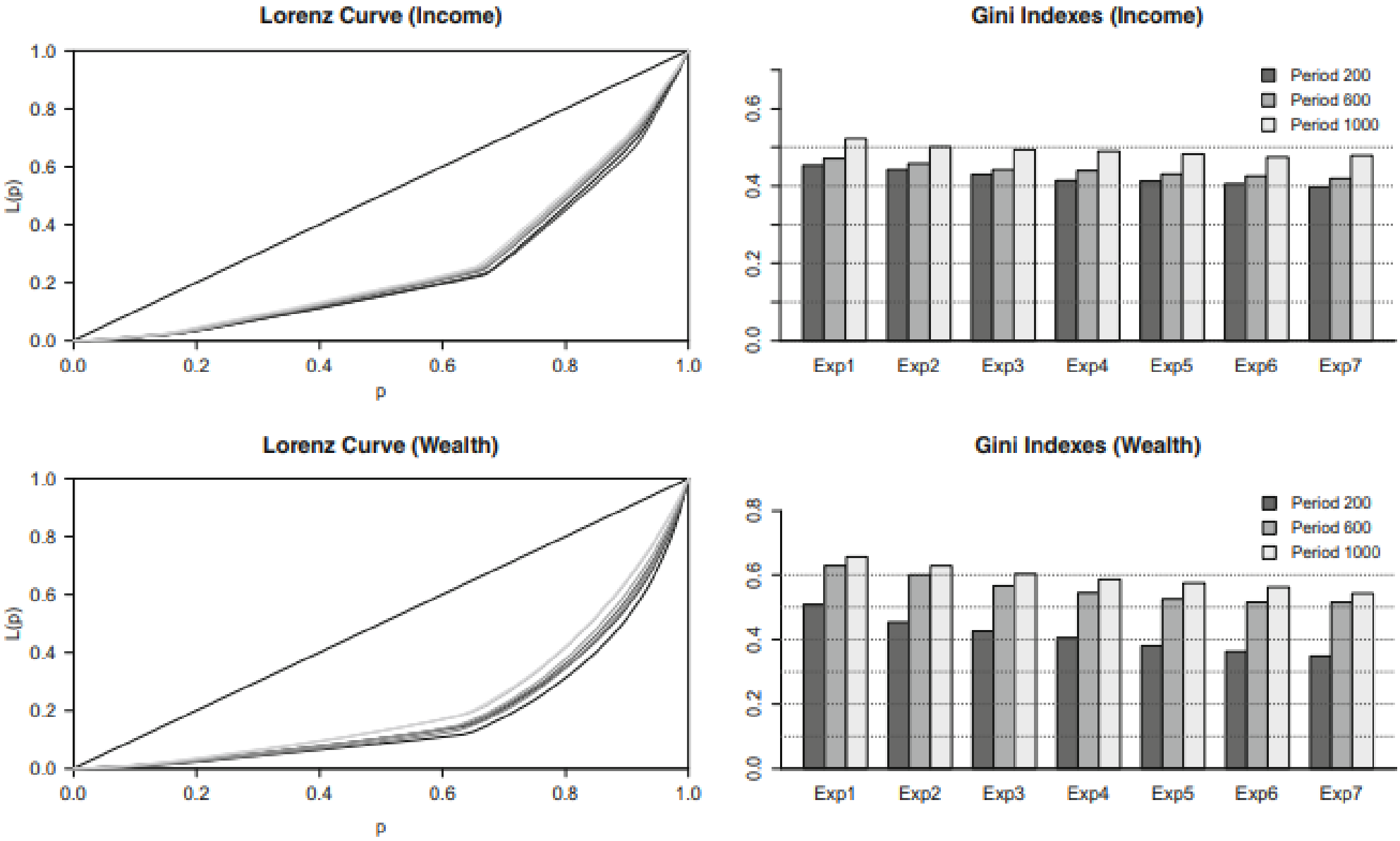


Fig. 6 Different tax schemes: Lighter gray lines correspond to higher values of θ. Top, left: Lorenz curve (income) at period 1000. Top, right: Gini indexes (income) at different simulation time steps. Bottom, left: Lorenz curve (wealth) at period 1000. Bottom, right: Gini indexes (wealth) at different simulation time steps

Example: Michell (2014)

- Simple model
- Heterogenous firms, aggregated household sector and simple horizontalist banking sector
- Kaleckian investment functions
- Monopoly tendency: demand allocated according to size of firm (capital stock)
- Stochastic anti-monopoly process (random reallocation of demand)

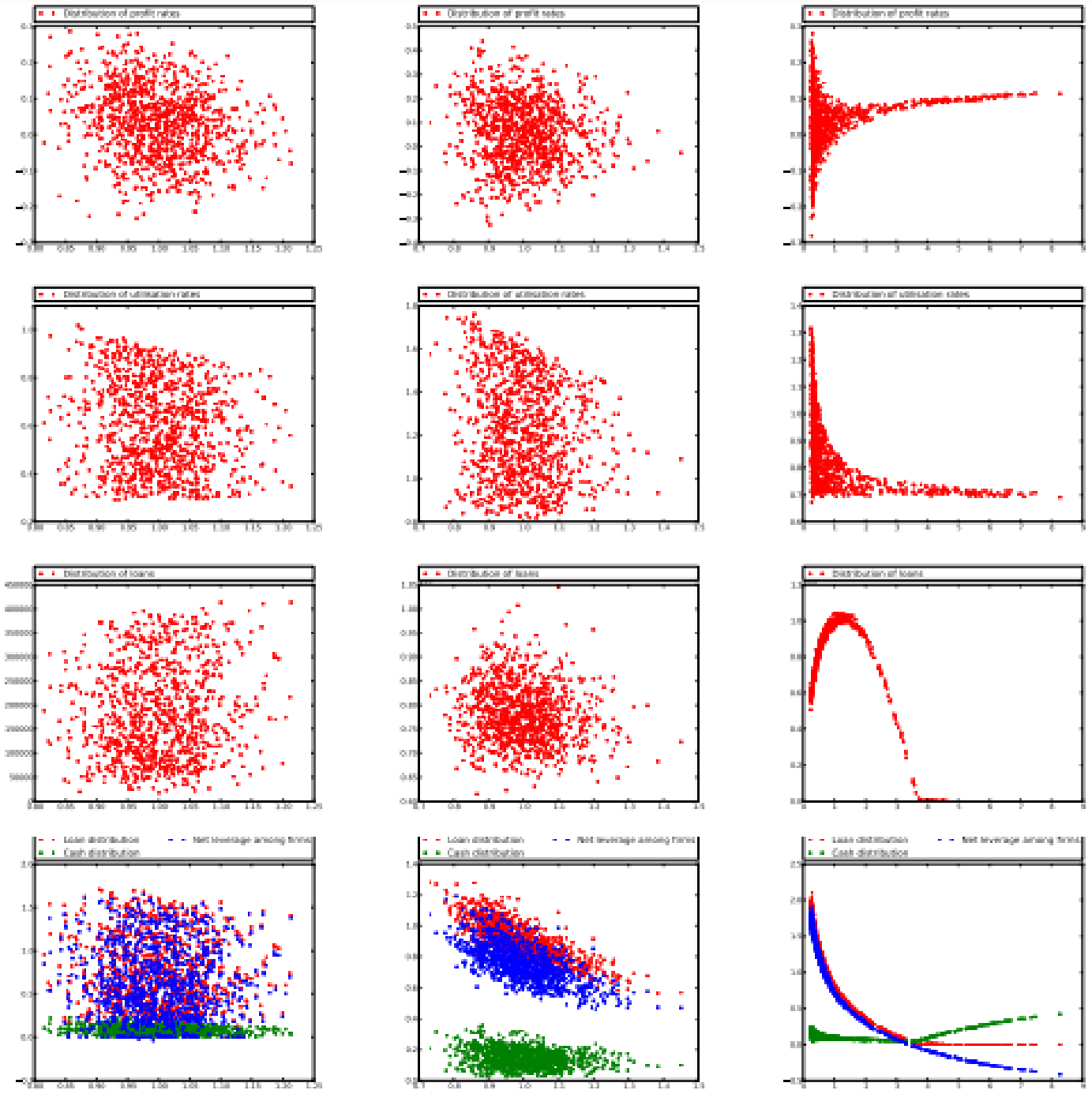


Figure 4 By row from top, distribution of: 1. growth rates; 2. profit rates; 3. capacity utilisation; 4. loans (nominal); 5. loans, deposits, net leverage (% of capital)

Taking stock

Where next for HANK?

- likely to be a highly active research area over next decade:
  - Bounded rationality
  - More frictions
  - Banking sector
  - Alternatives to RE
  - More solution and simulation methods
  - Etc.
- Ongoing commitment to basic approach of inter-temporal optimisation

Where next for PK/heterodox ABM?

- Relatively small number of teams working somewhat independently
- Separate codebases, not yet any unified, standardised accepted framework
- “Black box” problem
- No “killer application” yet
- Barriers to entry: coding, stats, maths, macro theory, vision.

Still want to play?

Considerations for building an ABM

- Which sectors to include?
- Will all sectors be heterogenous, or some aggregated?
- In what way will agents be heterogenous (preference, endowments, balance sheets)
- What distributions will be used, and how will they be applied?
- What kind of matching/transacting will take place?
  - Full agent-agent interaction
  - Hybrid agent-aggregate interactions
- What does finance do?
- What happens with defaults/failures/entry/exit?

Considerations for building an ABM

- Which programming language (Python, R, Matlab, Java, Netlogo etc.)?
- How to deal with the black box issue (Monte Carlo simulation, parameter sweeps, analytical approaches?)
- How to verify and present results?
- **What is the question?**