Economics, Complexity and Agent Based Models

Francesco LAMPERTI [1,2],

[1]Institute of Economics and LEM, Scuola Superiore Sant'Anna (Pisa)

[2]Université Paris 1 Pathéon-Sorbonne, Centre d'Economie de la Sorbonne and CNRS

RAMP Macroeconomics

January 8th, 2016

Many thanks to A. Roventini and G. Fagiolo for part of the material used here

Research supported by Horizons 2020 FET, DOLFINS project.

Economics and Complexity

A revalant issue: Price Formation mechanisms

The Brock and Hommes Model

Economics and Complexity

What is Economics about?

Economics and Complexity

What is Economics about?

Explaining emergence of order from disorder...
...in social phenomena

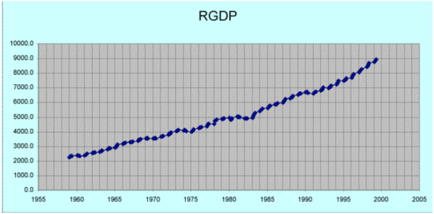
- Disorder: self-interested and interacting agents
- Order: some *stable* and *persistent* behaviour

Economics and Complexity

- Examples
  - How do market prices and interest rates emerge?
  - How do some technological standards manage to dominate the market?
  - How do GDP, employment and inflation move together along economic cycles?
  - Why real and financial economy do not correlate across time but across episodes?

Economics and Complexity: from Disorder to Order

Macro Level



Feedback to Micro Level

Micro Level

- Firms competing in turbulent markets
- Undertaking strategic decisions (output, investments, marketing, R&D, innovation, etc.)

Complex Systems

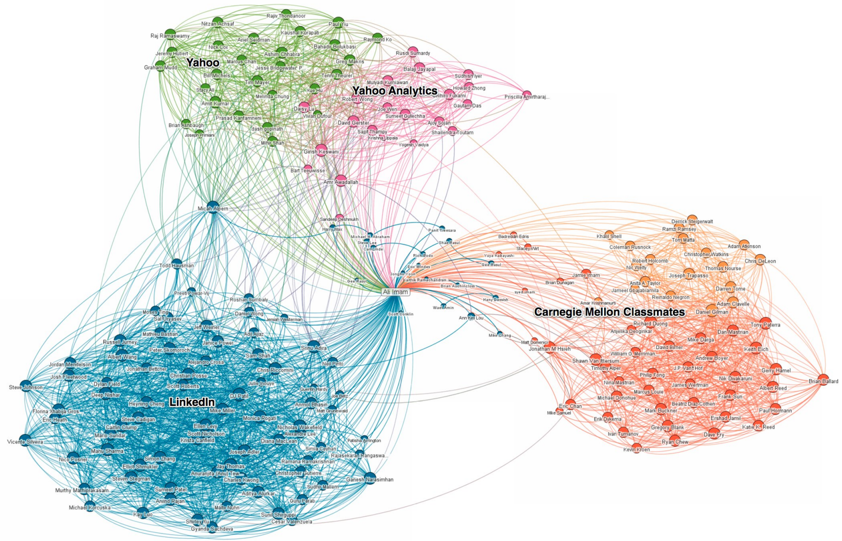
A system is typically defined to be **complex** if it exhibits the following two properties

- The system is composed of *interacting* units
- The system exhibits *emergent* properties,

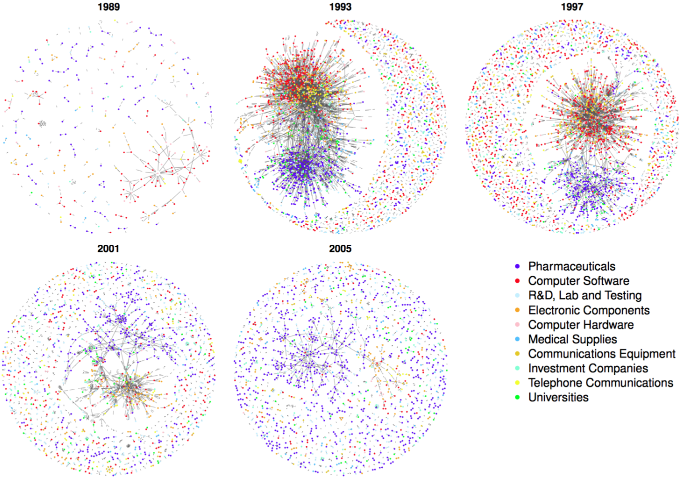
that is, properties arising from the interactions of the units that are not properties of the individual units themselves.

(Flake, 1998; Tesfatsion and Judd, 2006)

Complex Systems - Labour Market: Search



Complex Systems - Firms R&D alliances

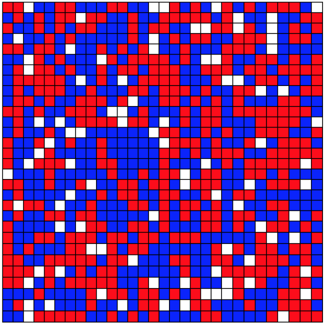


Complex Systems in Social Sciences: an Example

- Schelling segregation model (Schelling, 1971)
  - reds and blues live in a grid
  - they are happy if enough neighbours of same color, unhappy if not
  - at each period, one agent is randomly chosen:
    - if unhappy, moves in another place where she is happy
    - if happy, stays there
  - process repeats until everybody is happy or no more movements are possible

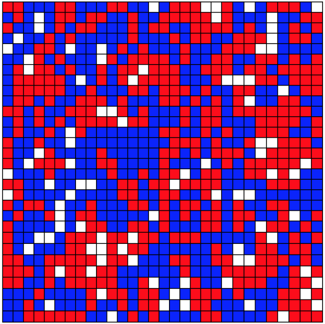
Schelling's model - very tolerant people

- to be happy: 10% of neighbours of the same color



Round 0

Satisfied 0 %

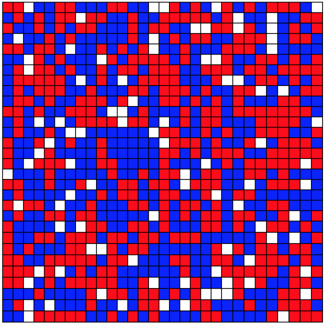


Round 6

Satisfied 100 %

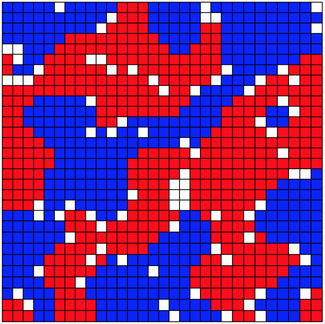
Schelling's model - moderately tolerant people

- to be happy: 50% of neighbours of the same color



Round 0

Satisfied 0 %

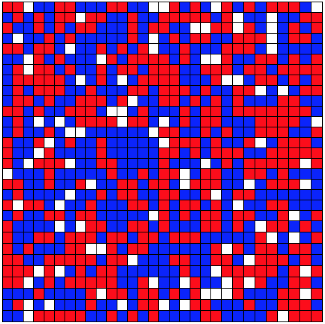


Round 13

Satisfied 100 %

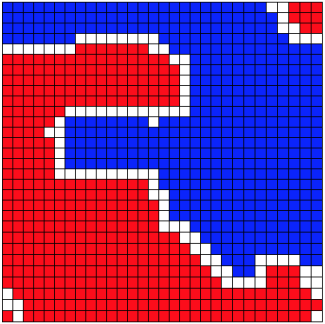
Schelling's model - moderately intolerant people

- to be happy: 70% of neighbours of the same color



Round 0

Satisfied 0 %

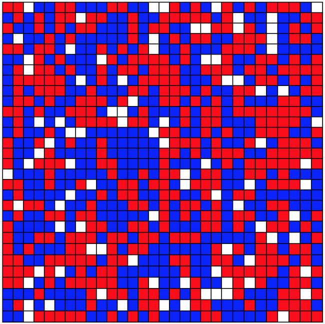


Round 75

Satisfied 100 %

Schelling's model - very intolerant people

- to be happy: 90% of neighbours of the same color

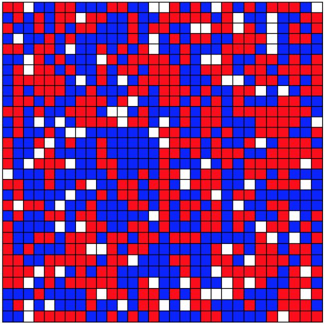


Round 0

Satisfied 0 %

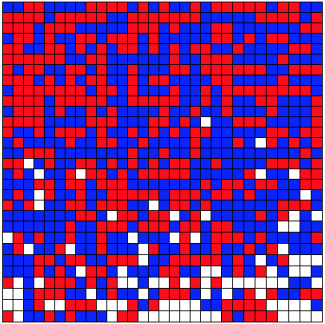
Schelling’s model - very intolerant people

- to be happy: 90% of neighbours of the same color



Round 0

Satisfied 0 %



Round 100

Satisfied 1.8 %

Simple Lesson from Schelling

Micro Properties $\not\Leftrightarrow$ Macro Properties

- for moderate level of tolerance, segregation appears robustly
- for extreme level of (in)tolerance, segregation absent

Complex Systems in Economics

The economy, both in broad and strict sense, is a complex system!

Features of (Social) Complex Systems

- Many micro entities
  - relatively simple and routinised behaviour

- People decisions might be affected by
  - Inherent difficulty in dealing with uncertainty and probability (risk)
  - Framing and Context matters
  - Adaptive (Trial & Error) and Simple Behavioral Rules
  - Problem decomposition (Rubik's Cube)

Features of (Social) Complex Systems

- People exchange **locally** information, knowledge, goods
- Interaction Structures as **non-trivial networks**
  - Who owns who, boards of directors, ...
  - Patent citations, collaboration citations, ...
  - R&D joint-ventures, knowledge spillovers, ...
  - Banks' liabilities
- Persistently heterogeneous economic agents

How to model complex systems

Agent Based Models

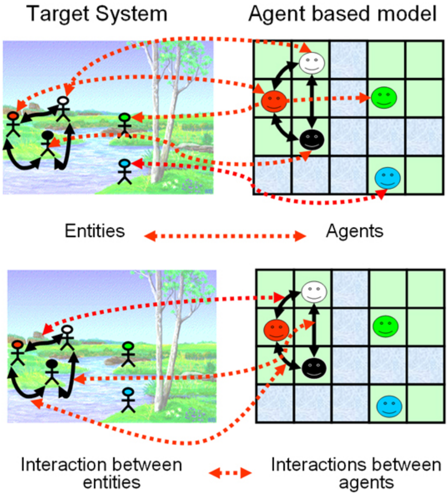
How to model complex systems

Agent Based Models

An Agent Based Model (ABM) is a computational tool used to study the behaviour of complex systems composed by multiple agents that are

- possibly heterogenous in all their characteristics
- boundedly rational (especially in economic applications)
- interacting among each other

Agent Based Models



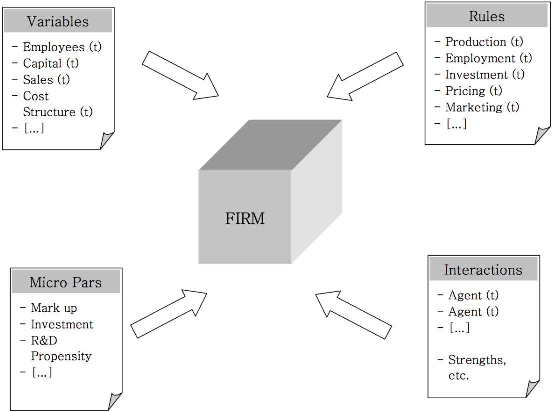
Why ABM?

Economics focus

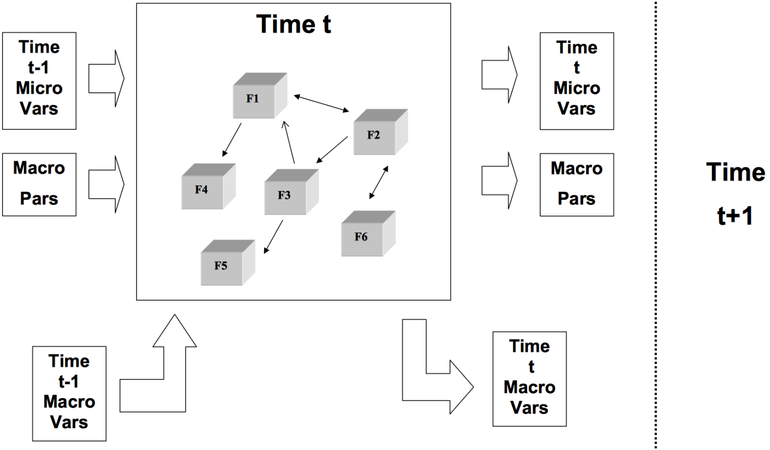
Agents of change

Conventional economic models failed to foresee the financial crisis. Could agent-based modelling do better?

Agent Based Models: an Agent



Agent Based Models: an Economy

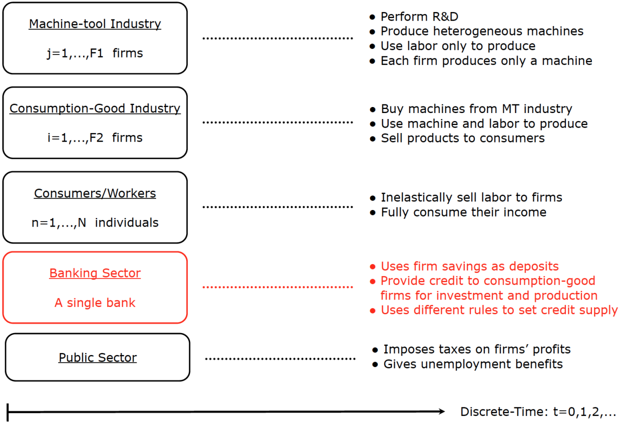


Some Macro-oriented ABM

1. **Schumpeter meeting Keynes model** - Pisa Group
2. **EURACE**- Bielefeld/Genoa Groups
3. **CATS** - Milan/Ancona Group
4. **Housing Market Model** - Axtell et al.
5. **ENGAGE** - Darthmouth/Pisa Groups
6. **Macro-Finance model** - Brown Group

Schumpeter meeting Keynes (K+S)

- **objective**: study growth and business cycles dynamics
- **number of agents**: >500
- **number of parameters**: >30
- **time scale**: quarters



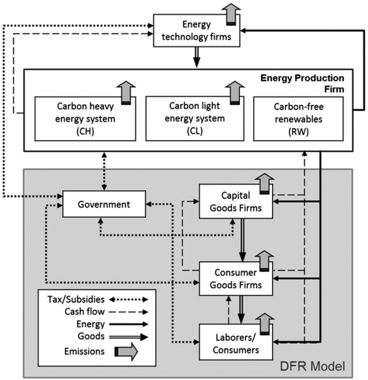
EURACE@UniBi

- **objective**: study of business cycles dynamics of EU economy (with spacial structure)
- **number of agents**: >1600
- **number of parameters**: >50
- **time scale**: months

Agent	Context	Role	Messages
Household	Consumption goods market	Buyer	units demanded
	Labour market	Worker	application, accept/reject job
	Credit market	Depositor	cash holdings
	Financial market	Investor	index share orders
Firm	Investment goods market	Buyer	units demanded
	Consumption goods market	Seller	price, quality
	Labour market	Employer	vacancy, job offer
	Credit market	Borrower	loan request
Investment Goods Firm	Investment goods market	Seller	price, productivity
	Labour market	Employer	vacancy, job offer
Bank	Credit market	Lender	credit conditions
Government	Public sector		tax payments
Central Bank	Credit market	Regulator	base interest

ENGAGE

- **objective**: study the transition towards a "green" economy and emissions paths
- **number of agents**: >600
- **number of parameters**: >40
- **time scale**: years



Simulation time

- Models are usually stochastic
- Monte Carlo runs of size at least 50 are typically required

- Simulation time for a complete MC exercise vary from:
  - few seconds
  - more then a week

Challenges with ABM

- computational time
- calibration/estimation
- validation

Calibration

- **Calibration** $\simeq$ find a parameter vector that minimize some distance between real data and simulation output

"Even in our extremely simple model, with one parameter only, simulation time accounts for more than 50% of all estimation (calibration) time."

Grazzini et al. (2015)

Calibration

- **Calibration** $\simeq$ find a parameter vector that minimize some distance between real data and simulation output

> "Even in our extremely simple model, with one parameter only, simulation time accounts for more than 50% of all estimation (calibration) time."

Grazzini et al. (2015)

- the time required to estimate the model in Grazzini et al. (2015) is about **800 hours** on a 36 cores machine

Computational Time

- If a model has to be used by policy makers or regulators
  - ECB, FED
  - United States Securities and Exchange Commission

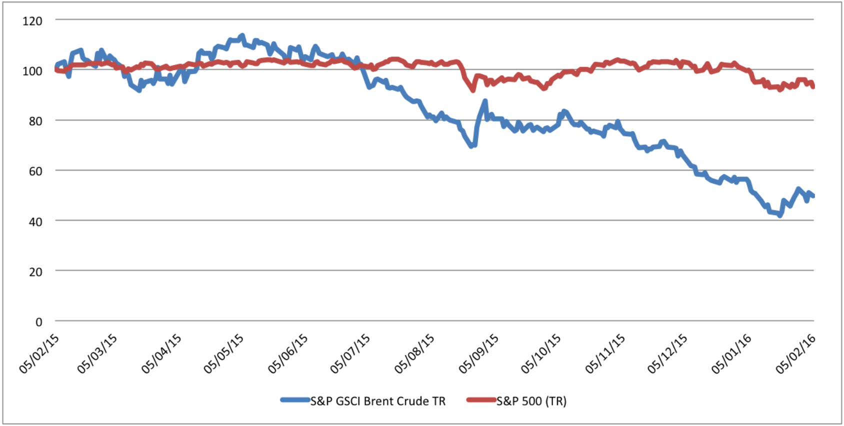
Computational Time

- If a model has to be used by policy makers or regulators
  - ECB, FED
  - United States Securities and Exchange Commission
- it has to provide **timely insight** into the problem

Computational Time

- If a model has to be used by policy makers or regulators
  - ECB, FED
  - United States Securities and Exchange Commission
- it has to provide **timely insight** into the problem
- Models that take **too long** to run and produce data that is **too large** are of limited interest for such users

Our issue: Behaviour of Prices



Price Behaviours - some questions for an economist

- Can we model a pricing system such that returns show some of the observed behaviours ?

Price Behaviours - some questions for an economist

- Can we model a pricing system such that returns show some of the observed behaviours ? IF YES
- Can we link price dynamics to traders attitudes?

Price Behaviours - some questions for an economist

- Can we model a pricing system such that returns show some of the observed behaviours ? IF YES

- Can we link price dynamics to traders attitudes? IF YES

Price Behaviours - some questions for an economist

- Can we model a pricing system such that returns show some of the observed behaviours ? IF YES
- Can we link price dynamics to traders attitudes? IF YES
- Can we detect early-signal predictors of crashes and busts from traders behaviours?

Price Behaviours - some questions for an economist

- Can we model a pricing system such that returns show some of the observed behaviours ? IF YES
- Can we link price dynamics to traders attitudes? IF YES
- Can we detect early-signal predictors of crashes and busts from traders behaviours? IF YES

Price Behaviours - some questions for an economist

- Can we model a pricing system such that returns show some of the observed behaviours ? IF YES
- Can we link price dynamics to traders attitudes? IF YES
- Can we detect early-signal predictors of crashes and busts from traders behaviours? IF YES
- Can we regulate the market in a way to reduce the likelihood of crashes?

Price Behaviours - some questions for an economist

- Can we model a pricing system such that returns show some of the observed behaviours ? IF YES
- Can we link price dynamics to traders attitudes? IF YES
- Can we detect early-signal predictors of crashes and busts from traders behaviours? IF YES
- Can we regulate the market in a way to reduce the likelihood of crashes? IF YES

Price Behaviours - some questions for an economist

- Can we model a pricing system such that returns show some of the observed behaviours ? IF YES
- Can we link price dynamics to traders attitudes? IF YES
- Can we detect early-signal predictors of crashes and busts from traders behaviours? IF YES
- Can we regulate the market in a way to reduce the likelihood of crashes? IF YES
- **We are going to win the Nobel prize**

Price Behaviours - some questions for an economist

- Can we model a pricing system such that returns show some of the observed behaviours ? IF YES
- Can we link price dynamics to traders attitudes? IF YES
- Can we detect early-signal predictors of crashes and busts from traders behaviours? IF YES
- Can we regulate the market in a way to reduce the likelihood of crashes? IF YES
- **We are going to win the Nobel prize or make a lot of money**

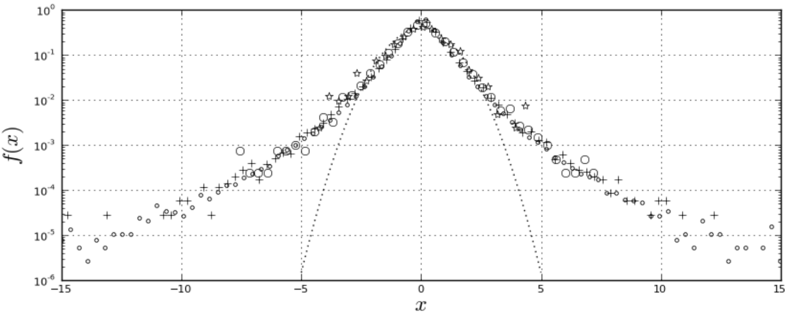
Prices and Returns: basics

- Let $p(t)$ be the **price** of an asset at time t, then
- $r_\tau(t) = [p(t+\tau) - p(t)]/p(t) \simeq \ln p(t+\tau) - \ln p(t)$ is the **return** over the period τ
- $r_\tau(t) - m\tau$, where $m\tau$ is the mean return at scale τ, is the **normalized return** over the period τ.

Behaviour of Price is Complex

- linear growth of variance with time scale:
  $\langle [r_\tau(t) - m\tau]^2 \rangle \simeq \sigma^2 \tau$

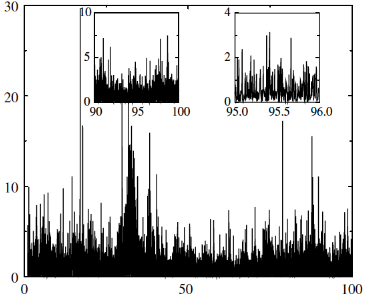
- distribution of returns has power law tails: $|r|^{-1-\mu}$



(Ibex35 data at different time scales); y-axis in log

Behaviour of Price is Complex

- volatility clustering



(absolute value of SP500 returns for 100, 10, 1 year)
Source: Borland et al. (2005)

- and a lot of others features (multifractality, leverage effects...)

Price Behaviour

- Random Walks and Brownian Motion (Bachelier, 1900)
  - returns are i.i.d.; the underlying distribution is normal

Price Behaviour

- Random Walks and Brownian Motion (Bachelier, 1900)
  - returns are i.i.d.; the underlying distribution is normal
- Eugene Fama
  - Efficient Markets
    - (strong form) all information is reflected by prices
    - implicit rationality of traders

Price Behaviour

- Random Walks and Brownian Motion (Bachelier, 1900)
  - returns are i.i.d.; the underlying distribution is normal
- Eugene Fama
  - Efficient Markets
    - (strong form) all information is reflected by prices
    - implicit rationality of traders
  - The joint hypothesis
    - market equilibrium hypothesis $\Leftrightarrow$ market efficiency
    - a challenge for the price formation mechanism!

A simple asset pricing model

The Brock and Hommes model

- Key references:
  - William A. Brock, Cars H. Hommes, Heterogeneous beliefs and routes to chaos in a simple asset pricing model, Journal of Economic Dynamics and Control, Volume 22, Issues 8–9, Pages 1235-1274, 1998.
  - William A. Brock, Cars H. Hommes, A Rational Route to Randomness, Econometrica, vol. 65, issue 5, pages 1059-1096, 1997.

Basic structure and time-line of events

- 1 risky asset, 1 risk-free asset, N traders of different type

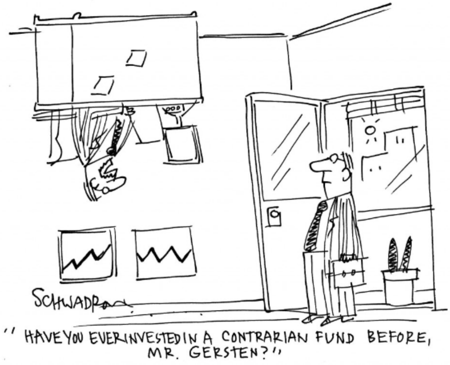
1. history of prices and dividends is observed
2. agents form their expectation on next period prices
3. each agent submit her sell/buy orders
4. market clears and asset prices are determined in equilibrium
5. dividends are paid to stockholders

The BH model - trader types

- trend followers

The BH model - trader types

- trend contrarians



The BH model - trader types

- both types might have a bias towards some value

The BH model

- Agents' trading strategy is determined by a function $f_h(\cdot)$

- rational: $f_{Rt} = x_{t+1}$
- all other types: $f_{ht} = g_h x_{t-1} + b_h$
  - trend chasers $g_h > 0$
  - trend contrarians $g_h < 0$
  - fundamentalists $g_h = b_h = 0$

The BH model

- Agents' trading strategy is determined by a function $f_h(\cdot)$
- rational: $f_{Rt} = x_{t+1}$
- all other types: $f_{ht} = g_h x_{t-1} + b_h$
  - trend chasers $g_h > 0$
  - trend contrarians $g_h < 0$
  - fundamentalists $g_h = b_h = 0$
- agents might switch their type according to accumulated past profits and a switching parameter
  - $n_{ht} = exp[\beta U_{h,t-1}] / \sum_h exp[\beta U_{h,t-1}]$

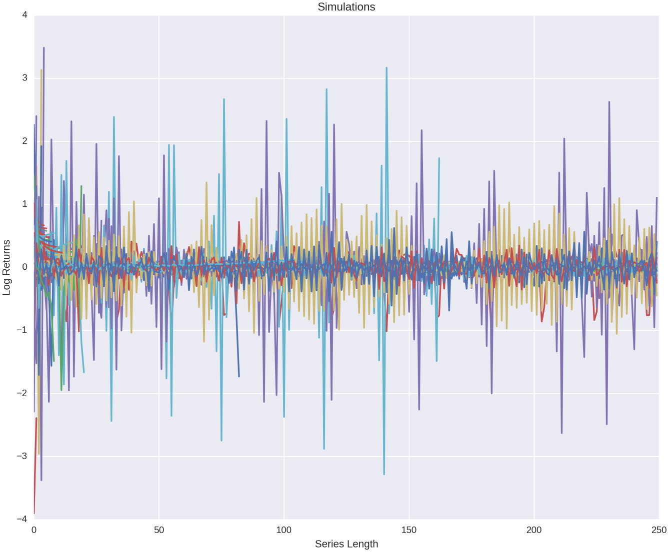
The BH model - I

- agents' wealth evolves according to
  - $W_{t+1} = RW_t + (p_{t+1} + y_{t+1} - Rp_t)z_t$

The BH model - I

- agents' wealth evolves according to
  - $W_{t+1} = RW_t + (p_{t+1} + y_{t+1} - Rp_t)z_t$
- Equilibrium of demand and supply implies (no supply of external shares)
  - $Rp_t = \sum n_{ht} E_{ht}(p_{t+1} + y_{t+1})$, where
- agent of type h forms expectations on future price and dividend
  - $E_{ht}(p_{t+1} + y_{t+1}) = E_t(p^*_{t+1}) + f_h(x_{t-1}, ..., x_{t-L})$, where
  - p^* denotes the fundamental price
  - $f_h(\cdot)$ is a *deterministic function* depending on the agent's type
  - $x_t = p_t - p^*_t$ denotes the price deviation from the fundamental

The BH model - returns dynamics

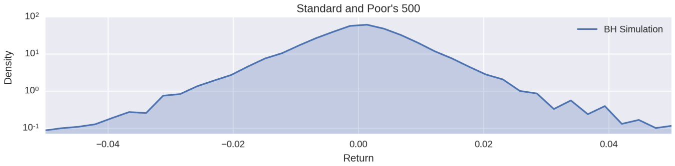


Challenge

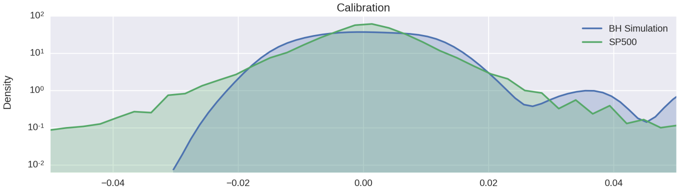
Can we calibrate the model in a way that it resembles real-world return dynamics?

Our target: S&P 500 - long run dynamics

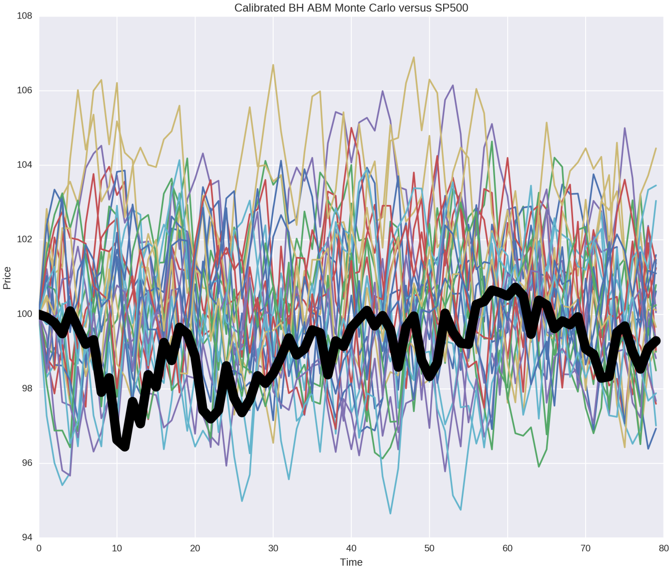
Our target: distribution of last year returns



Distribution of returns: “calibrated” model vs. real data



MC runs of “calibrated” model



Challenge

Can we do better?

Can we calibrate avoidind/reducing the computational burden of simulations?

THANKS !!!