Simulation (part 3)

Computational Economics, spring term 2012

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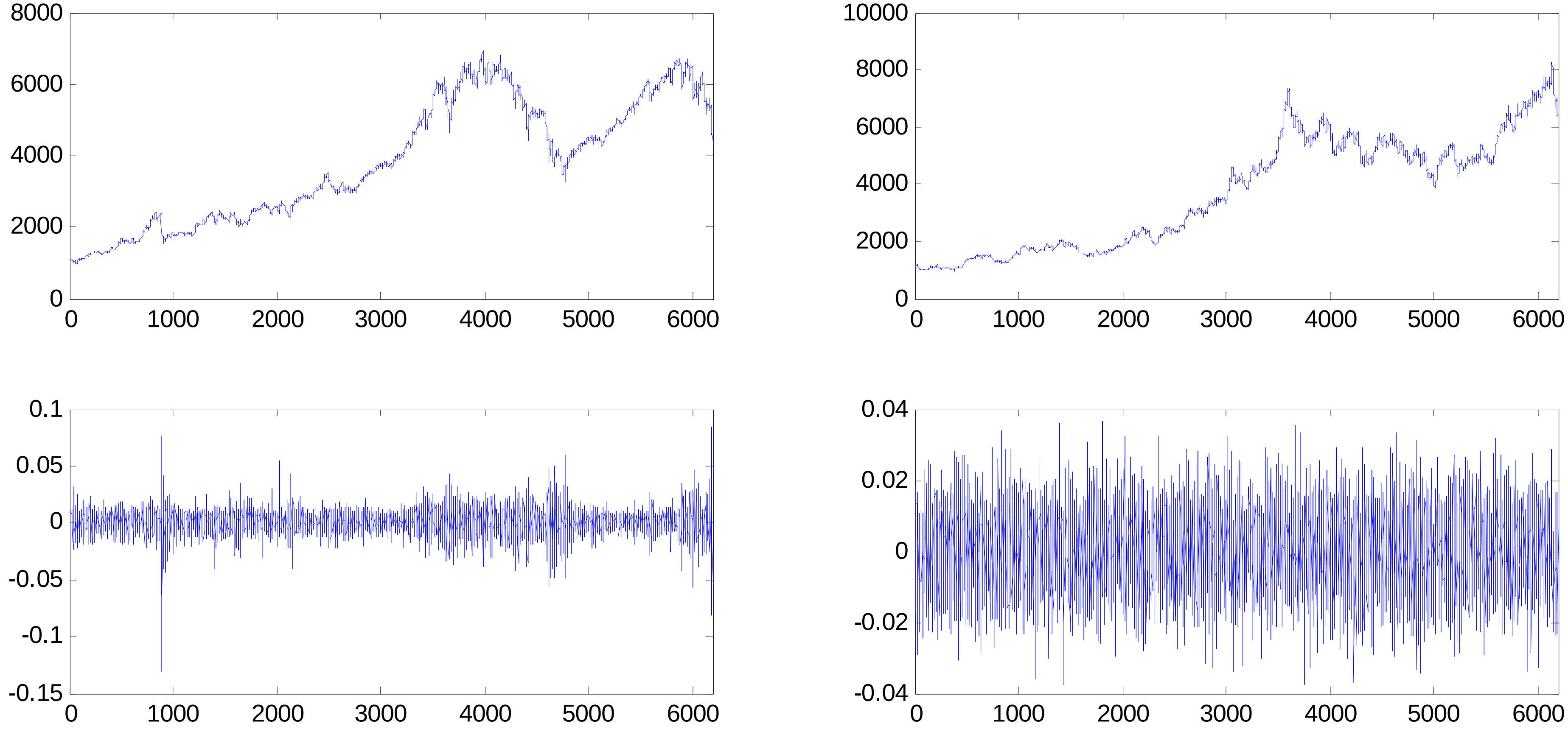
the story so far

- Geometric Brownian Motion
  - FTSE 100 versus simulated data



artificial financial markets

- why artificial markets?
  - EMH & the representative agent
    - rational
    - homogenous expectations
    - information efficiency
    - normal distribution
  - actually …
    - DJA, 23.12.1980 – 5.3.2010, 7’366 daily returns

# std. dev.s	1	2	3	4	5	6	7	8
expected: once every …	*6d*	*2m*	*3y*	*126 y*	*14k y*	*4mio. y*	*3bio. y*	*6trio. y*
expected # days (‘80-’10)	1169	168	10	<1	0	0	0	0
observations	739	164	55	27	14	7	5	2

the story so far

- open questions
  - efficiency ⇔ rationality
  - pricing puzzles
  - causes for stylized facts
  - evolution
  - nonlinear dynamics
  - … and many more
- hence

  "If we restrict ourselves to models which can be solved analytically, we will be modeling for our mutual entertainment, not to maximize explanatory or predictive power."

  Harry M. Markowitz

modelling the aggregate versus micro-structure models

- Kim & Markowitz (1989)
  - puzzle: what caused the 1987 crash?
  - setting
    - wealth depends on cash and risky positions ($w_t = c_t + q_t\, p_t$)
    - types of agents:
      - rebalancers: 50/50 of wealth in risky assets and cash, $c_t = q_t\, p_t$
      - insurers: multiple of "cushion" in risky asset, $q_t\, p_t = k\,(w_t - f_t)$
  - findings
    - higher number of "insurers"
      - extreme price changes happen more often
      - markets become unstable

cellular automata

- basic idea
  - microstructure model
    - agents arranged in a line or regular grid
      - "cells"
      - special case: *torus grid*
    - discrete set of states / actions / etc.
  - new state of cell *j* depends on
    - its own previous state
    - (some of) its neighbours' previous states : $x_{t+1,j} = f(x_{t,j}, x_{t,N(j)}, \theta)$
    - typically:
      - same rules for all cells
      - random initial setting

linear cellular automata

- a simple example
  - 3 cells
  - each cell:
    - two possible actions: {0, 1}
    - compares own and neighbours' actions
  - behaviour:
    - if both immediate neighbours are different: ➔ change action
    - if both immediate neighbours are equal: ➔ change action
    - if exactly one immediate neighbour is equal: ➔ don't change action
  - **extension:**
    what, if there are more than 3 cells (torus grid)?
    - comparison with two adjacent neighbors
    - comparison with more than 2 neighbors

linear cellular automata

- example 2: "Rule 22"
  - possible states: {0, 1}
  - rule for next state depends on neighbourhood structure:

situation	left	self	right	rule 22
0	0	0	0	0
1	0	0	1	1
2	0	1	0	1
3	0	1	1	0
4	1	0	0	1
5	1	0	1	0
6	1	1	0	0
7	1	1	1	0

linear cellular automata

- 4 different classes of behaviour (acc. Wolfram)
  1. convergence to unique, homogenous state
     - e.g., rules “0” or “255”
  2. (separated groups with) periodic patterns
     - e.g., rule “51” (“do the opposite”)
  3. chaotic patterns
     - e.g., rule “22”
  4. complex structures, long transients
     - e.g., rule “110”

- reactions to random alterations
  - classes 1 & 2: little impact
  - classes 3 & 4: can propagate across vast distance

cellular automata

- John Conway's "Game of Life"
  - cells arranged on a grid
  - two states: 0 / 1
  - if a cell is currently alive
    - 2 or 3 living neighbours → stays alive
    - otherwise: dies of overcrowding / boredom
  - if a cell is currently empty
    - 3 living neighbours → becomes alive
    - otherwise: remains empty

cellular automata

- majority model
  - idea
    - cells want to conform with their friends / neighbours
    - peer groups:
      - 8 neighbouring cells (Moore neighbourhood)
  - cells arranged on a grid
  - two possible states: 0 / 1
  - cell
    - copies the state of the majority of its eight immediate neighbours
    - keeps current state if neighbours are equally divided

cellular automata

- gossip model
  - idea
    - news is passed on if neighbours meet
    - once heard, cells can pass it on further
    - encounters with neighbours happen with specific probability

  - cells arranged on a grid
  - two possible states: blue (infected, “in the know”) or red
  - “blue” cell passes infects a “red” cells with probability *p*
  - if cell is blue:
    - version a: stay blue
    - version b: with small probability, change to red

cellular automata

- desert island holiday resort
  - if deserted, attracts holiday makers
  - if there are too many visitors, it's no longer attractive and people leave
  - setting: two states, visiting or not

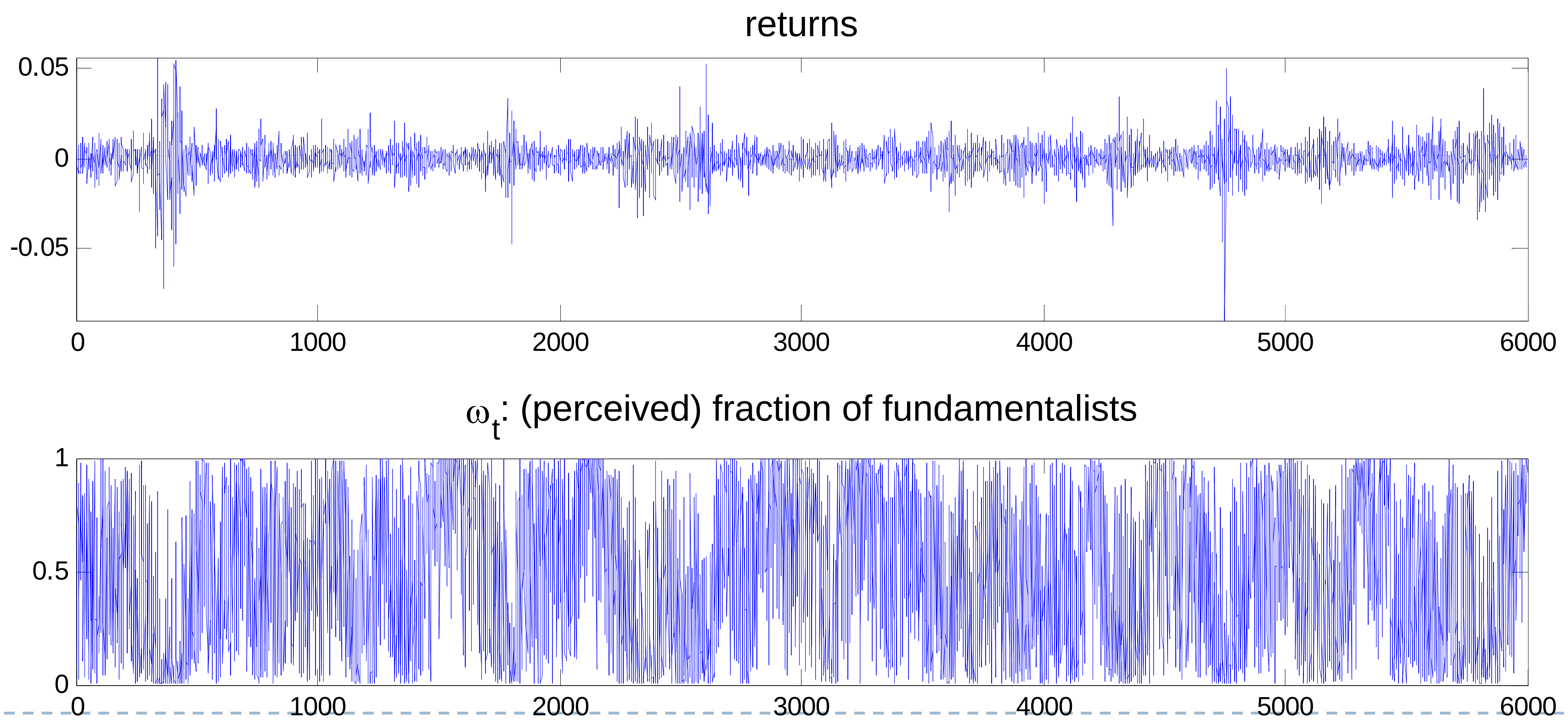
- variants
  - instead of / in addition to changing state, agent can also change position:
    - move to favorable areas
      e.g., towards thinly populated areas, like-minded inhabitants, etc.
    - move away from undesirable areas
      e.g., away from over-populated, unattractive areas, opponents, etc.

agent-based computational economics

- idea
  - complex dynamic situations
  - agents
    - individual decision makers
    - connectedness (networks)
    - interaction
    - operate within a framework (rules, regulations, infrastructure, etc.)
- main goals (Tesfatsion and Judd (2006), Leigh Tesfatsion's website)
  - empirical understanding
  - normative understanding
  - qualitative insight and theory generation
  - methodological advancements

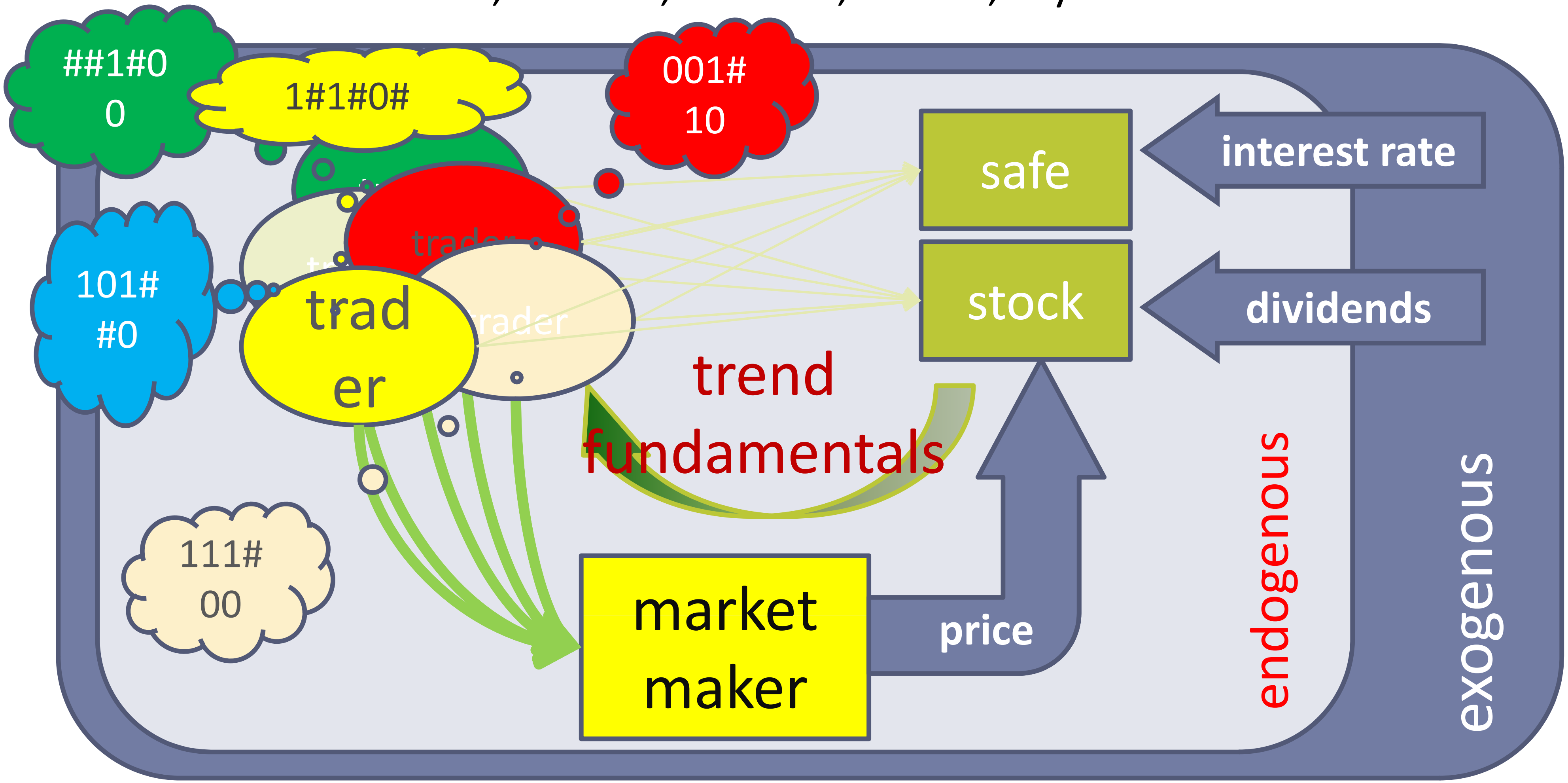
a simple agent-based model

- Kirman's FX market
  - *types of agents*
    - trend follower, $E^C(\Delta p_t) = g \cdot (p_{t-1} - p_{t-2})$
    - fundamentalists, $E^F(\Delta p_t) = \nu \cdot (\bar{p} - p_{t-1})$
    - noisy market signal
  - *dynamics*
    - agents can change type
      - randomly (prob. ε)
      - direct interaction (prob. δ)



a typical artificial stock market

- the Santa Fe ASM
  - authors: Arthur, Holland, LeBaron, Palmer, Taylor



a typical artificial stock market

- important findings
  - heterogeneity
    - aggregate v representative agent
    - learning
      - adaptive behaviour
      - social learning
  - generates stylized facts
    - memory / swings
    - excess kurtosis
    - regime switches
  - design issues
    - variants to address specific aspects
    - improved modelling of agents

how to build an ASM

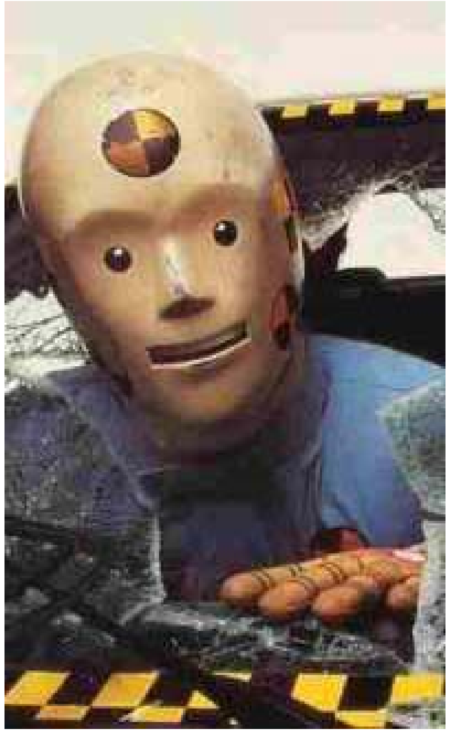
- agents
  - level of sophistication
    - zero intelligence, noise traders
    - adaptive / interacting / social learning
    - investigative learning & exploring
  - strategies
    - few ⇔ many types of strategies
    - selecting ⇔ creating strategies
      - trend followers / contrarians / chartisis
      - fundamentalists
      - individually generated
  - heterogeneity
    - risk preferences
    - “intelligence” and adaptability
    - time horizon
    - liquidity

how to build an ASM

- framework
  - price determination
    - endogenously, complete market
    - exogenous factors
    - market segment
  - market design
    - self contained ASM
    - link to real data
  - clock & rhythm
    - synchronized trading
    - (a)synchronous learning

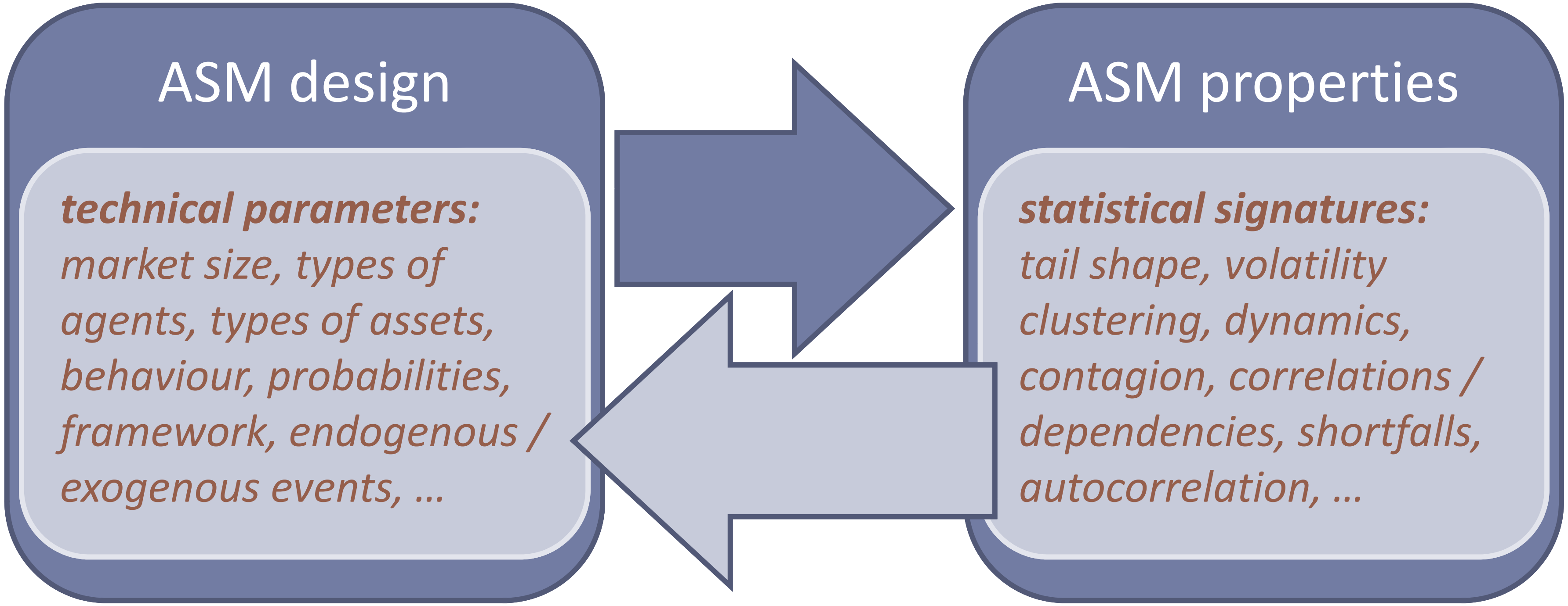
how to build an ASM

- objectives and aims
  - "random number generator"
    - Monte Carlo approaches
    - pricing
    - stress tests
  - improved understanding
    - dynamics v static equilibrium
    - extreme events
    - investors' behaviour
  - wind tunnel testing
    - algo trading
    - institutional framework



how to build an ASM

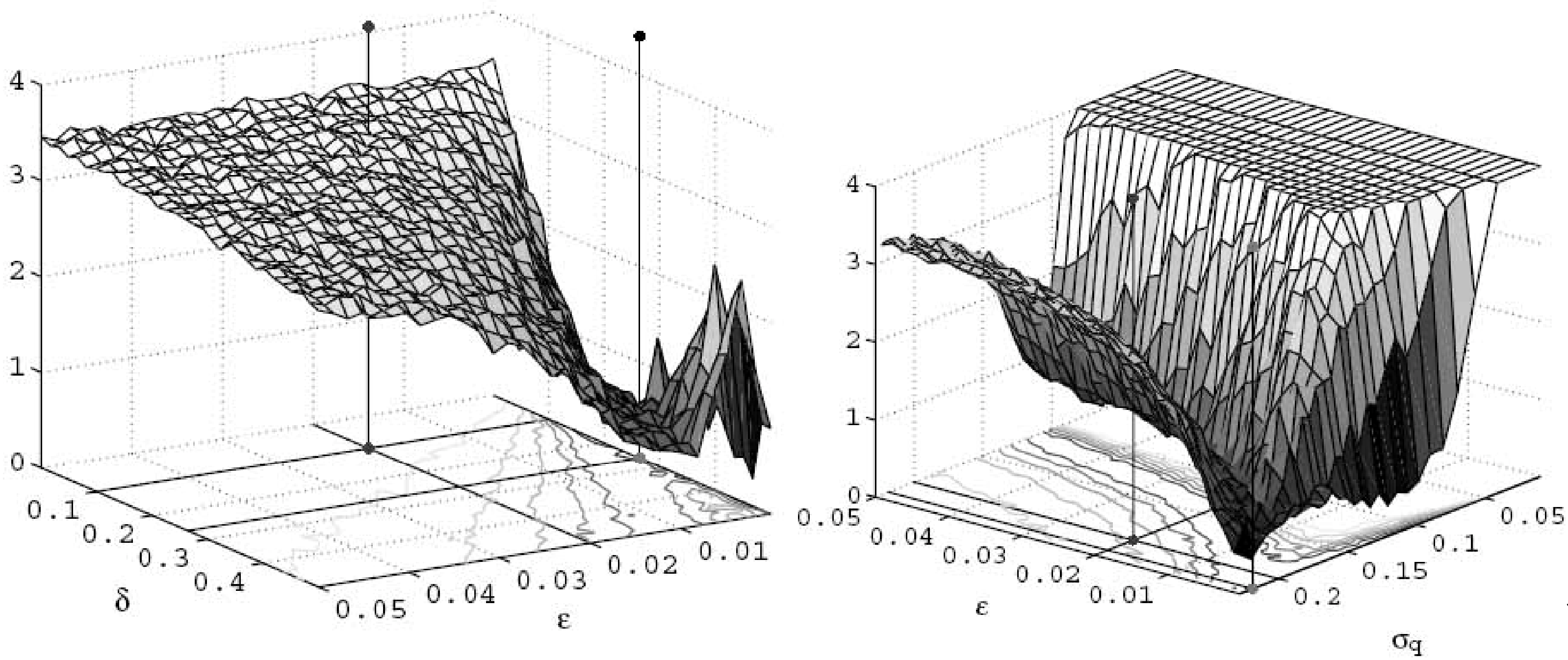
- evaluation & calibration



how to build an ASM

- evaluation & calibration for Kirman's FX model
  - statistical signatures, μ_s:
    central moments, Hill estimator, GARCH parameters
  - objective: agents' and true signatures should be close

$$f([\nu,\epsilon,\sigma_q,\ldots]) = \sum_s \lambda_s \left| \mu_s^{\text{ag}} - \mu_s^{\text{emp}} \right| \rightarrow \min$$



source:
Gilli & Winker,
CSDA 2003

the road ahead

- current and future research areasa
  - realistic modelling
    - underlying assumptions
    - stylized → explicit market microstructures
      - behavioural finance
      - institutions
  - comprehensive models
    - core model + environment
    - holistic approaches
    - caveats:
      - calibration issues
      - reliability
  - sound and consistent evaluation
    - application & objective driven
    - systematic calibration, testing, and validation

literature

- additional reading

  - Nigel Gilbert and Klaus G Troitzsch,
    Simulation for the Social Scientist,
    Open University Press 2005; Chapters 1 and 4
  - Blake LeBaron,
    Agent-based Computational Finance,
    working paper (2005); see also: L Tesfatsion and K Judd (eds.), *Handbook of Computational Economics, Vol. 2: Agent-Based Computational Economics*, 2006:1187-1232, chapter 24.
  - Nigel Gilbert,
    Agent-Based Models,
    Quantitative Applications in the Social Sciences Series, vol. 153, Sage Publications, 2008
  - Leigh Tesfatsion, Kenneth Judd
    Handbook of Computational Economics, Vol. 2: Agent-Based Computational Economics,
    North-Holland 2006.

  - Leigh Tesfatsion's website offers a comprehensive introduction & literature links