The endogenous dynamics of markets:

price impact, feedback loops and instabilities

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The Sacred Lore of Efficient Markets

- Why and how do market prices move?

- Efficient market theory:

  ▷ Rational Agents and Market in "Equilibrium"

  ▷ Prices reflect faithfully the Fundamental Value of assets and only move because of exogenous, unpredictable news.

- Platonian markets that merely reveal fundamental values without influencing them

  ▷ or is it a mere tautology??

  ▷ If we had a way to check, we would not need markets

The Sacred Lore of Efficient Markets

- Markets are fundamentally stable: any mispricing is arbitraged away by those who "know"

  ▷ but who exactly is supposed to know the price??

  (An efficient market is such that prices are correct to within a factor 2 ✓ – Fisher Black)

- Crashes can only be exogenous, not induced by markets dynamics itself – really??

- *Market stability is trivial and not even an interesting question* (M. Friedman) – when feedback loops and instabilities are everywhere

Eyes Wide Shut

- I think that calls for a radical reworking of the field go too far. [...] The financial crisis did not discredit the usefulness of economic research and analysis by any means,

  still: The crisis should motivate economists to think further about their modeling of HUMAN BEHAVIOUR. Most economic researchers continue to work within the classical paradigm that assumes rational, self-interested behavior and the maximization of expected utility,

  and: Another issue brought to the fore by the crisis is the need to better understand the determinants of LIQUIDITY in financial markets. The notion that financial assets can always be sold at prices close to their fundamental values is built into most economic analysis...

  – Ben Bernanke, Princeton, September 2010

Indeed...(Human behaviour)

- `My convinction: we, humans, are lost in the dark`

  – swamped by noisy/superabundant information and *radical uncertainty*. We make mistakes, are subject to biases

- We rely on heuristic rules to make suboptimal decisions

  ▷ We are strongly influenced by the behaviour of others (who might have more information) – panic feeds panic

  ▷ We are strongly influenced by past patterns (that might repeat) – trends feed trends

- Theories that treat these effects consistently are still at an early stage – see below

Indeed...(Liquidity)

- `Liquidity and impact of trades`

  ▷ Empirical fact: Trading, even with relatively small volumes in usual market conditions, moves prices in a measurable way – see below

  ▷ This is called PRICE IMPACT

- Impact transforms trades into price changes: this is a key ingredient to understand *market dynamics and stability*

- Impact also contributes to costs and limits the size of trading strategies

Indeed...(Liquidity)

- Efficient market story: Informed agents successfully forecast short term price movements and trade accordingly. This results in correlations between trades and price changes, but uninformed trades should have no price impact – prices must stick to "Fondamental Values"

- An empirically rooted story: since there is no easy way to distinguish "informed" from "non-informed" traders, all trades do statistically impact prices (✓)

  ▷ Agents believe/fear that trades might contain useful information they don't have

  ▷ Even silly/random trades do impact market prices: a transmission belt for feedback loops and avalanches

Some questions with empirical answers

- Financial markets offer Terabytes of information (daily) to try to investigate why and how prices move, and offer an ideal test bed for some fundamental questions in economics/finance
  – `e.g. market stability`

- A) Exogenous vs. Endogenous dynamics

  `Are news really the main determinant of volatility?`

- B) How do trades impact prices?

  `How sensitive is the market to trades?`

A) Exogenous or endogenous dynamics?

- `Accumulating body of observations`

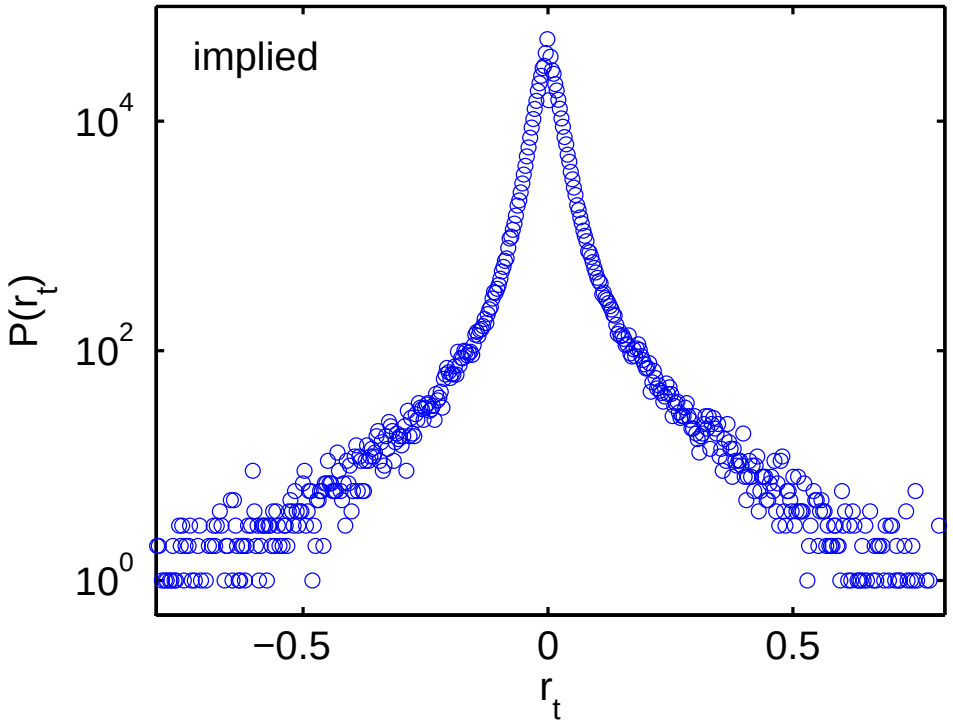
  ▷ Power-law distribution of jump sizes: crises of all scales (like earthquakes)

  ▷ Most jumps are unrelated to news and look endogenous

  ▷ Excess volatility, with long range memory – looks like endogenous intermittent noise in complex systems (turbulence, Barkhausen noise, earthquakes, etc.)

- To a large extent: Universal observations in time, space & assets – details may evolve, but main features remain

Power-law tails



Distribution of daily volatility moves on option markets or *any other traded stuff*: $\approx$ inverse cubic law

Endogenous jumps

- Yes, some news make prices jump, sometimes a lot, but jump freq. is much larger than news freq.

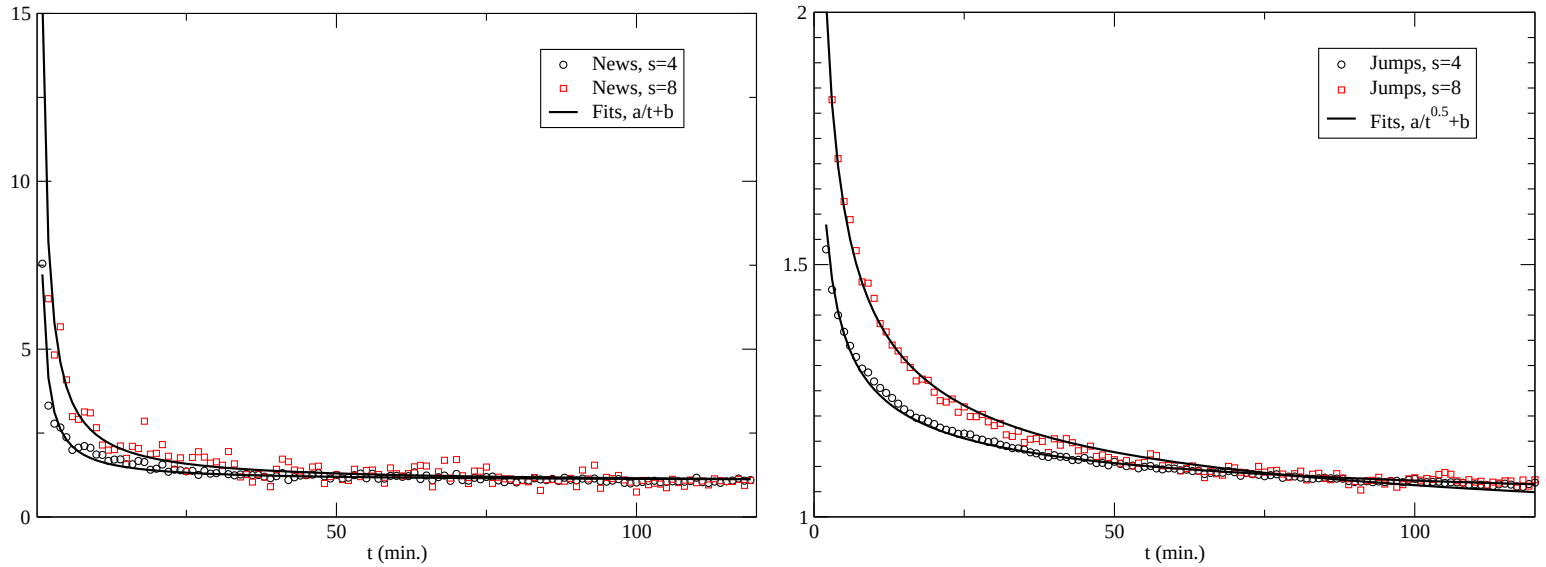
- On stocks, only $\sim 5\%$ of $4-\sigma$ jumps can be attributed to news, most jumps appear to be endogenous

- Similar conclusions on daily data in seminal papers (Cutler, Poterba, Summers; Shiller; Fair)

- NB: Private information should not induce jumps! (Kyle)

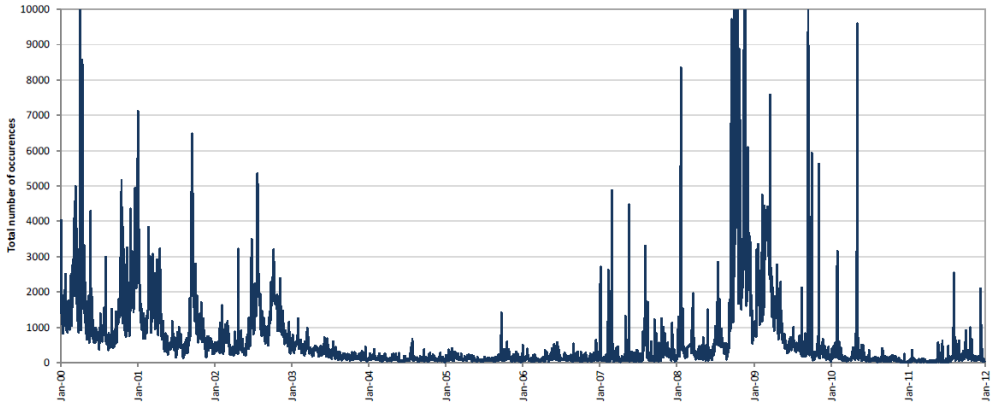
- Return distributions and 'aftershocks' (volatility relaxation) are markedly distinct

Two jump types: Aftershocks



Volatility relaxation after news (t^{-1}, left) and endogenous jumps ($t^{-1/2}$, right). With A. Joulin, D. Grunberg, A. Lefevre

Multiscale intermittency

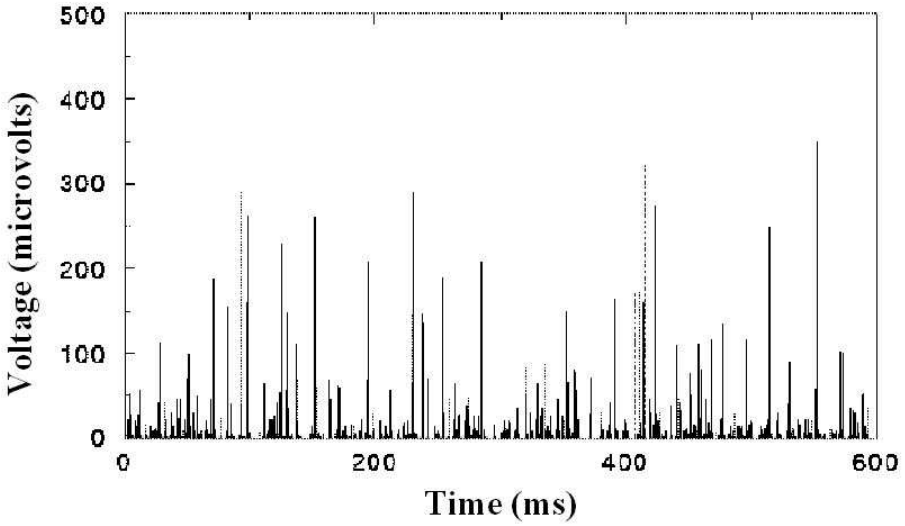


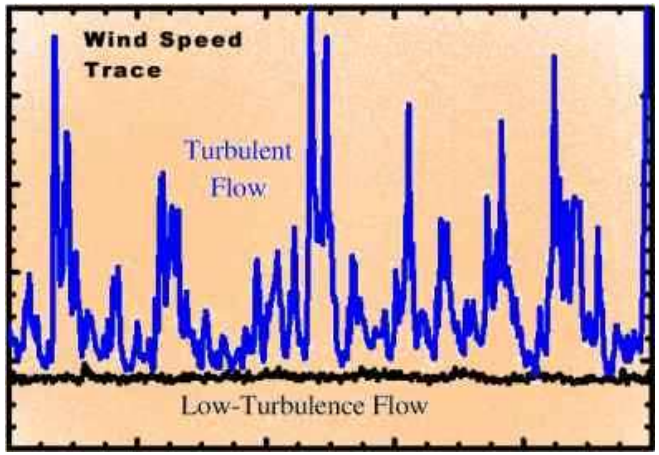
Excess volatility, with long range memory

– looks a lot like endogenous noise in complex systems

(Number of weekly 1% jumps/min on S&P stocks)

Intermittency: Barkhausen noise, Turbulence





Slow, regular and featureless exogenous drive $\longrightarrow$
Intermittent endogenous dynamics

A) Exogenous or endogenous dynamics?

- These UNIVERSAL observations and analogies strongly suggest that endogenous dynamics is the solution to the excess volatility puzzle – NOT DUE TO FUNDAMENTALS

  ▷ Calibration of models suggests at least $\approx 80\%$ of volatility is due to self-reflexive feedback of activity onto itself

  ▷ We need models for endogenous crises and discontinuities

B) How do trades impact prices?

- The fundamental paradox of liquid markets: very small instantaneous liquidity but rather large daily volume

  ▷ Total liquidity immediately accessible on large US stocks: $\sim 10^{-6}$ of market cap.

  ▷ Total daily traded volume: 5,000 times larger!

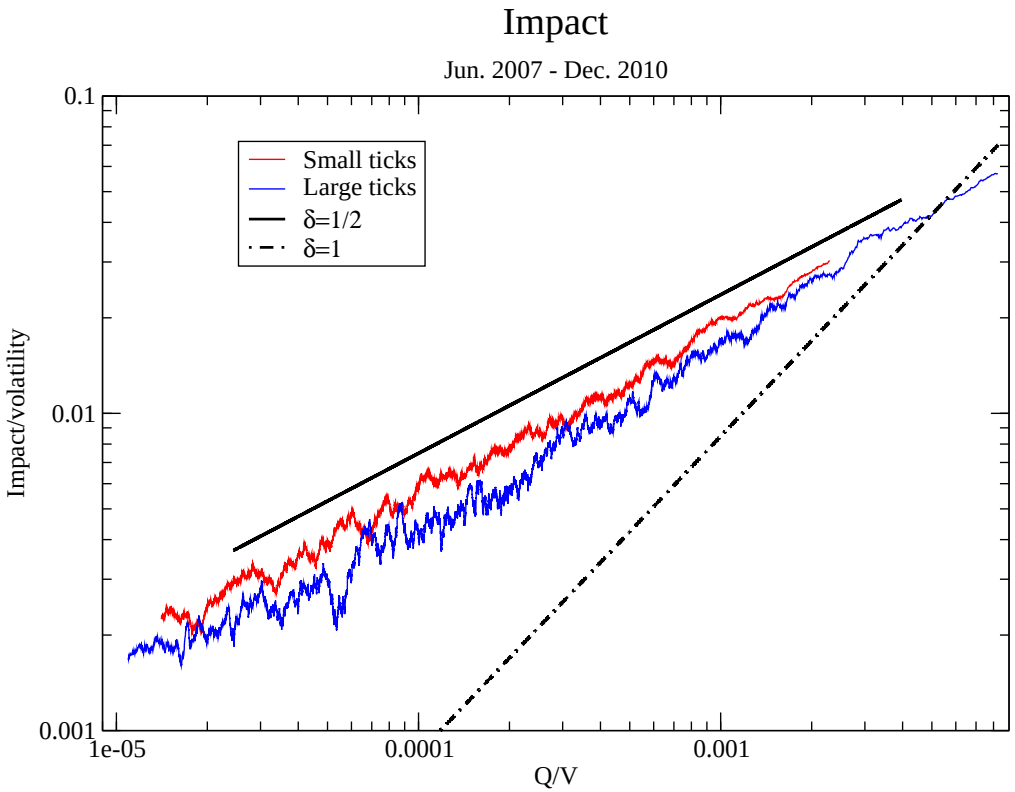
  ▷ Trades must be executed incrementally $\rightarrow$ "metaorders"

- The (average) impact of a metaorder of size Q is singular

$$I(Q) \sim \sigma \sqrt{\frac{Q}{V}}$$

  ▷ Again: A universal observation (BARRA, Almgren, Engle, JPM, DB, LH, CFM): different strategies, markets, tick sizes, limit/market orders, periods (1995 – 2012)...

The square-root impact law



From ca. 500,000 CFM trades on futures markets

B) How do trades impact prices?

- A non trivial impact law:

  ▷ Impact is concave (not additive): $1 + 1 = 1.4142 < 2$

  ▷ Anomalously large impact of small trades: 1% of ADV pushes the price by 10% of its vol

  ▷ Important: impact is usually small compared to volatility itself

- Why is impact so large (singular) and liquidity so small?

B) How do trades impact prices?

- Why is impact so large (singular) and liquidity so small?

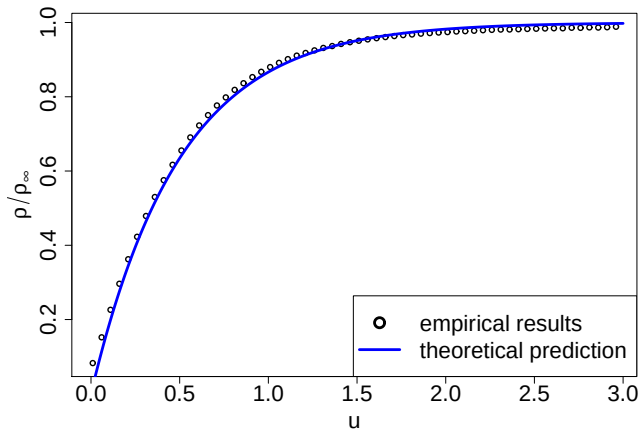
- A statistical theory of liquidity:

  ▷ Even with "zero-intelligence" agents: provided the price makes a random walk, and for generic order flow, the probability to have unexecuted orders close to the current price is linearly small

  ▷ An analytical theory based on the diffusion equation

  ▷ + Agent-based numerical simulations

A linear liquidity profile



▷ Consequence: square-root impact!

$$Q = \int_p^{p+I} \alpha\, u\, du = \frac{\alpha}{2} I^2 \to I \propto \sqrt{Q}$$

As price moves up, more and more sellers oppose further up moves and reduce impact → concavity

B) How do trades impact prices?

- Intrinsic Market Fragility!

  – `Markets are NOT obviously stable, Pr. Friedman`

- Liquidity around current price is vanishingly small

  ▷ Liquidity fluctuations are bound to play a crucial role in explaining micro-crises and jumps in prices without news (cf. above)

  ▷ Regulation must engineer stabilizing feedback loops

  – favoring liquidity when it is most needed (cf. debate about HFT)

A cartoon model for self-referential behaviour

- People do not make decision in isolation but rely on the choice/opinion of others: many direct empirical evidence.

- Very strong distortion/amplification phenomena due to imitation: fads & fashion (e.g. love-locks), bubbles & crashes

  ▷ Difficult to understand without imitation

- Many important situations in practice: vaccines, hygiene, fertility, driving, crime, tax evasion, technology, etc.

Love-locks on Pont Des Arts

The madness of crowds (Newton)

A cartoon model for self-referential behaviour

- The RFIM: a unifying framework for many phenomena, for example Barkhausen noise – Sethna et al. "Crackling Noise", Birth rates, Cell phones, Clapping...(with Q. Michard)

- N heterogeneous agents, influenced by the behaviour of others

  ▷ Binary decision of agent i: $S_i = \pm 1$ (to buy/sell/lend/trust or not to buy/sell/lend/trust, etc.)

  ▷ Aggregate demand: $\mathcal{O} = N^{-1} \sum_i S_i$

A cartoon model for self-referential behaviour

- Influence factors:

  ▷ personal opinion, propensity or utility ϕ_i – heterogeneous with probability P, width σ

  ▷ public information (price, technology level, news, zeitgeist) $F(t)$, – for illustration purposes, smooth

  ▷ social pressure or imitation effects $\sum_j J_{ij} S_j$

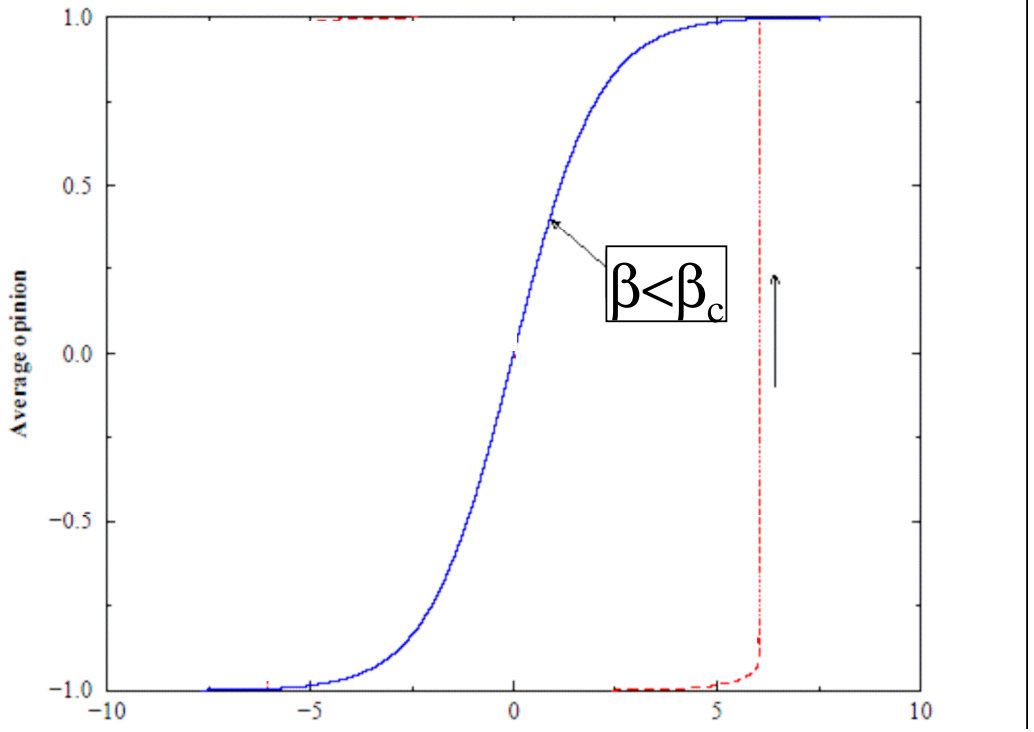
- The RFIM update rule:

$$S_i(t) = \text{sign}\left[\phi_i + F(t) + \sum_{j \in \mathcal{V}_i} J_{ij} S_j(t-1)\right],$$

  The globally coupled case: $J_{ij} = \beta/N$, $\forall i \neq j$ – only the aggregate opinion/consumption matters

Soft landing or crash?

Fraction of ‘‘pessimists’’ as a function of time



Breakdown of Representative Agent; Spontaneous discontinuities

Cartoon model of self-referential behaviour

- $\beta < \beta_c$: personal choices dominate, smooth demand curve

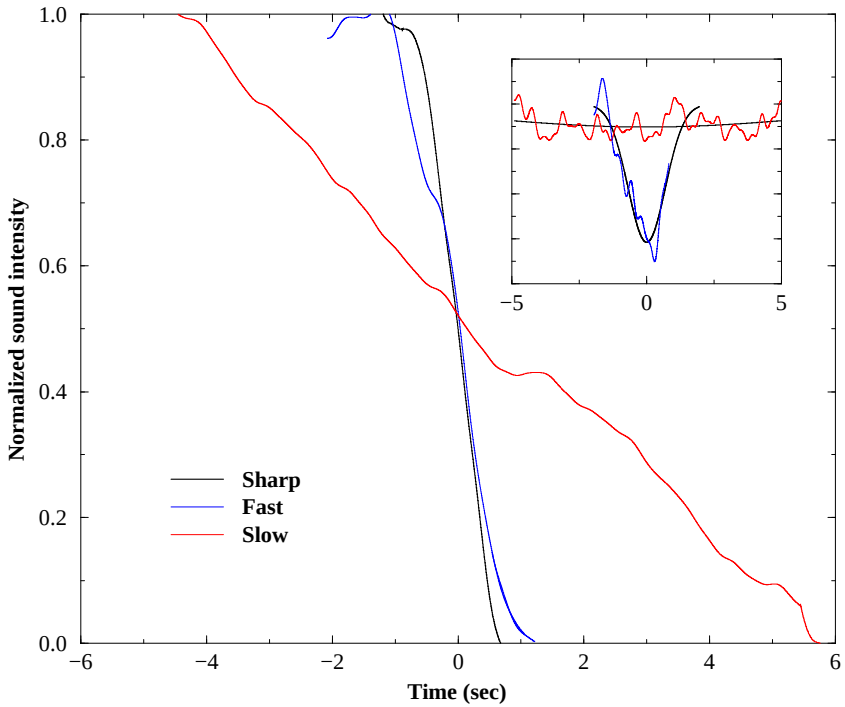
- $\beta > \beta_c$: herding dominates, strong distortion/amplification of the fundamental demand curve: discontinuities appear at the macro level – imitations induced panic/crashes/mistrust

  $\triangleright$ Hysteresis in and out of the crisis

- $\beta \approx \beta_c$: avalanche dynamics (power-law distribution of sizes)

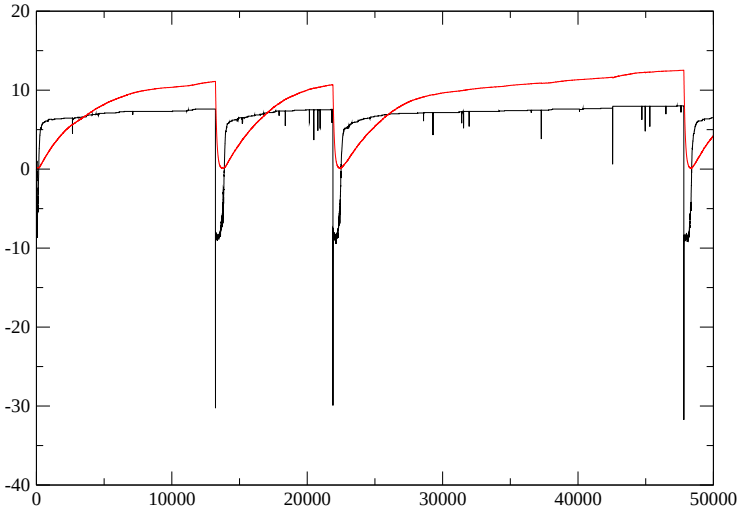
- $\beta_c \propto \sigma$: More dispersed opinions avoid polarisation and stabilizes the system

Cartoon model of self-referential behaviour



End of clappings

Application: spontaneous evaporation of trust



Number of trust bonds and average trust as a function of time

I trust you because he trusts you because I trust you

As trust builds up, the system becomes more fragile

cf. Battiston et al., Kirman et al., etc.

Conclusion – Endogenous crises?

- Financial markets, the economy, many other social phenomena exhibit crises, ruptures, sudden discontinuities that resemble far-from-equilibrium phenomena in complex systems

  ▷ Accumulating empirical evidence for positive feedback loops, self-reflexivity and endogenous crises

  → Most price jumps appear unrelated to any news at all

  → Market statistics share features with slowly driven, heterogeneous interacting systems with many equilibria

  ▷ Markets are critical (they operate in a regime of vanishing liquidity), making them particularly fragile

Conclusion, lessons for agent based modelling

- Surprises on the way from micro to macro: interactions can generate discontinuities at the macro level, even in a smoothly evolving world

- Equilibrium analysis is not enough: one can be dynamically stuck in the "wrong" state

- Increased efficiency generically means more instabilities

  ▷ Critical fragility to external perturbations and small changes of parameters – small local shocks *may* trigger large systemic effects (a definition of complexity !)

References

- This talk is based on the following papers:

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▷ A. Joulin, A. Lefevre, D. Grunberg, J.-P. Bouchaud, *Stock price jumps: news and volume play a minor role*, Wilmott Mag., Sept/Oct 2008; arXiv:0803.1769

▷ J.-P. Bouchaud, *Crises and collective socio-economic phenomena: cartoon models and challenges*, arXiv:1209.0453