The Endogenous Dynamics of Markets: Price Impact, Feedback Loops and Instabilities

Twenty years in financial markets

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Why and how do market prices move?

- Efficient market theory:

  ▷ 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

  ▷ Crashes can only be exogenous, not induced by markets dynamics itself

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

  ▷ This is no trifle debate: many real world consequences (investment decisions, economic policy, market regulation, etc.)

Fama/Shiller: a very ambiguous 2013 Nobel Prize

- Fama (2010): *The word 'bubble' drives me nuts, frankly. I don't even know what a bubble means.*

- Shiller (2013): *Market prices are esteemed as if they were oracles. This view grew to dominate much professional thinking in economics, and its implications are dangerous. It is a substantial reason for the economic crisis we have been stuck in for the past five years, for it led authorities in the United States and elsewhere to be complacent about [...] the instability of the global system*

- Black, in *Noise* (1986): *We might define an efficient market as one in which price is within a factor two of value, i.e., the price is more than half of value and less than twice value.* —
  `But this leaves a lot of room for markets to err around!`

Bernanke's research agenda after the crisis

- *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*.

  ▷ *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*,

  ▷ *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 (2010), see also A. Greenspan, `The map and the territory`.

Human behaviour

- Let's face it: we, humans, are lost in the dark – we over/underreact, make mistakes, are subject to biases, have regrets...

- We rely on "fast and frugal" rules (Gigerenzer) to make sub-optimal decisions (experimental psychology, neuroscience)

  ▷ 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`

  ▷ We are strongly risk adverse and intuitively cope with unknown unknowns – `Survival instinct and risk limits`

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

Liquidity

- `Liquidity and impact of trades`

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

  ▷ All trades do statistically impact prices (✓)

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

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

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

Some questions with empirical answers

- 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) The Endogenous Dynamics Hypothesis

- Quality data has become "easily" available, e.g.

  ▷ All transactions on all stocks and other traded quantitities in the last 10 years (Petabytes)

  ▷ Daily data on US stocks since 1962 + some "fundamental" info

  ▷ Some prices (stock indices, grains, etc.) since 1800, rates, price and production indices over 100 years...

- Accumulating evidence of universal "anomalies" and "stylized facts" suggesting that the dynamics of financial markets is mostly endogeneous, and *only very weakly driven by fundamentals*

A) The Endogenous Dynamics Hypothesis

- Universal "anomalies"

  ▷ "Momentum" (absolute & relative) over very long periods (`trend feeds trend`)

  ▷ Most market jumps occur in the absence of any news, but are the result of 'micro-crises'* (`panic feeds panic`)

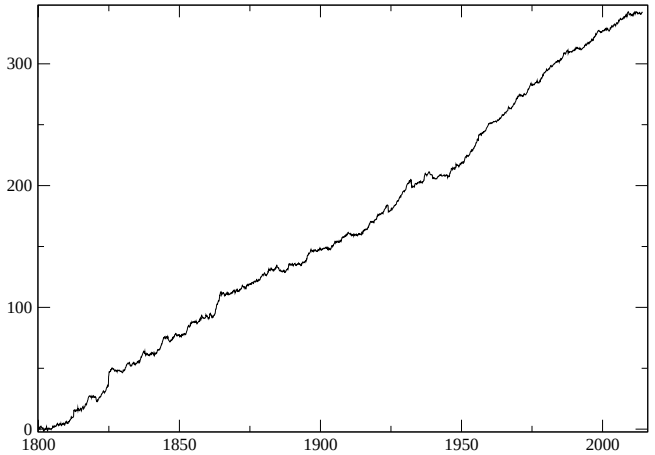
  ▷ Pareto continuum between daily 'jumps' and decennial crashes

  ▷ Excess volatility, with intermittent dynamics and long range memory

  ▷ Many, many more anomalies...("AOA" is just a rough approximation)

*with 'flash crashes' – 1962, 2010, etc. – as epitome

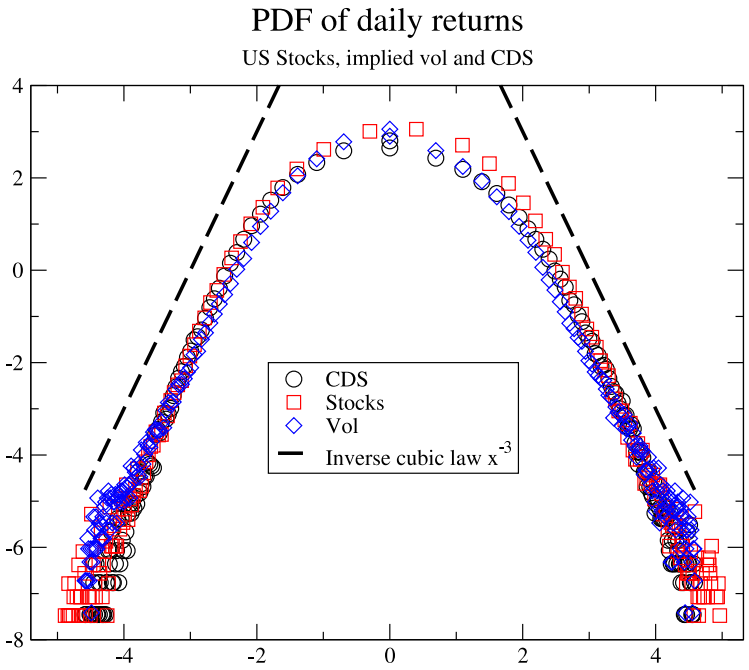
Two centuries of Momentum



T-stat ≈ 10, over all periods and all instruments (FX, Commo, IDX, BND). Y. Lempérière et al.

Universally: Past six month returns tend to persist (weak but highly significant) – *prices do not reflect all public information!*

Pareto tails



Universal distribution: daily stocks, implied volatility, CDS moves or *any other traded stuff*: $\approx$ inverse cubic law. With J. Bonart

A) Exogenous or endogenous dynamics?

- Yes, some news make prices jump, sometimes a lot, but...

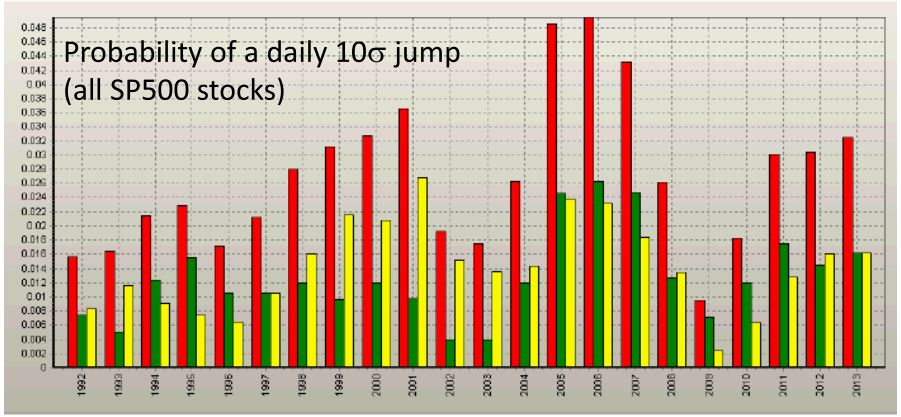
- On stocks, only $\sim 5\%$ of 1 min. 4σ-jumps can be attributed to news, most jumps appear to be endogenous – cf "flash crashes" that have always existed (i.e. May 28th, 1962)

  ▷ Similar conclusions on daily data in seminal and more recent papers (Cutler et al.; Shiller; Fair; Cornell): *The evidence that large market moves occur on days without identifiable major news casts doubts on the view that price movements are fully explicable by news...*

  ▷ Private information should not induce jumps! (Kyle)

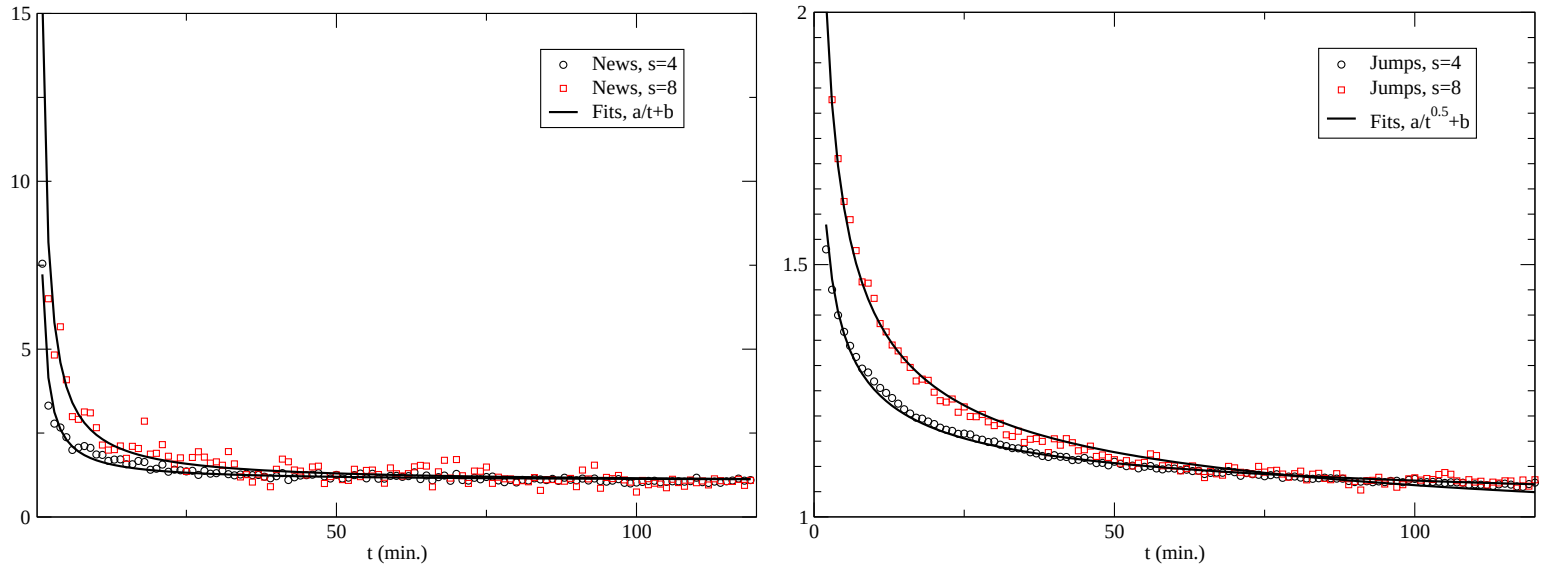
- Return distributions and 'aftershocks' (volatility relaxation) are markedly distinct

Jumps



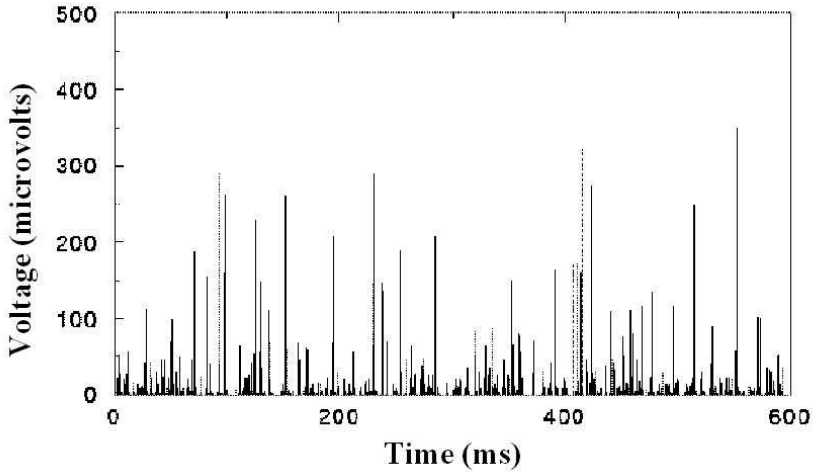
A very old phenomenon! With S. Ciliberti

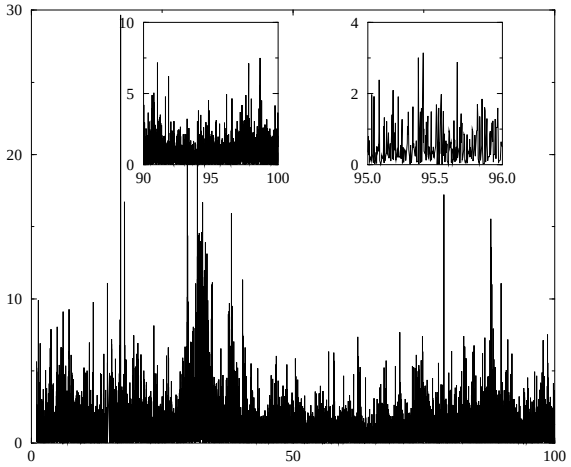
Two jump types: Aftershocks



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

Intermittency: Volatility, Barkhausen, Turbulence





Slow, featureless exogeneous drive but intermittent endogeneous dynamics

A) The Endogenous Dynamics Hypothesis

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

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

- These features strongly suggest that the endogenous dynamics hypothesis explains Shiller's excess volatility puzzle – NOT DUE TO FUNDAMENTALS

  ▷ Calibration of "GARCH" or "Hawkes" models indeed suggest that $80 \rightarrow 100\%$ of volatility is due to self-reflexive feedback of activity!!

- Trades impact prices and price changes influence future trades – this leads to excess volatility and to unstable feedback loops

A) The Endogenous Dynamics Hypothesis

- Excess volatility in economic systems – the "business cycle" conundrum

  ▷ Large economic systems should "average-out" idiosyncratic shocks: $\sigma \sim n^{-1/2}$

  ▷ But: "aggregate" volatility (GDP growth/IPI/...) is high (YOY IPI in the US since 1950: $\sigma \approx 4\%$!)

- *What shocks are responsible for economic fluctuations? Despite at least two hundred years in which economists have observed fluctuations in economic activity, we still are not sure.*

  – John Cochrane (1994)

  ▷ EDH probably also relevant for (some) economic crises

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!

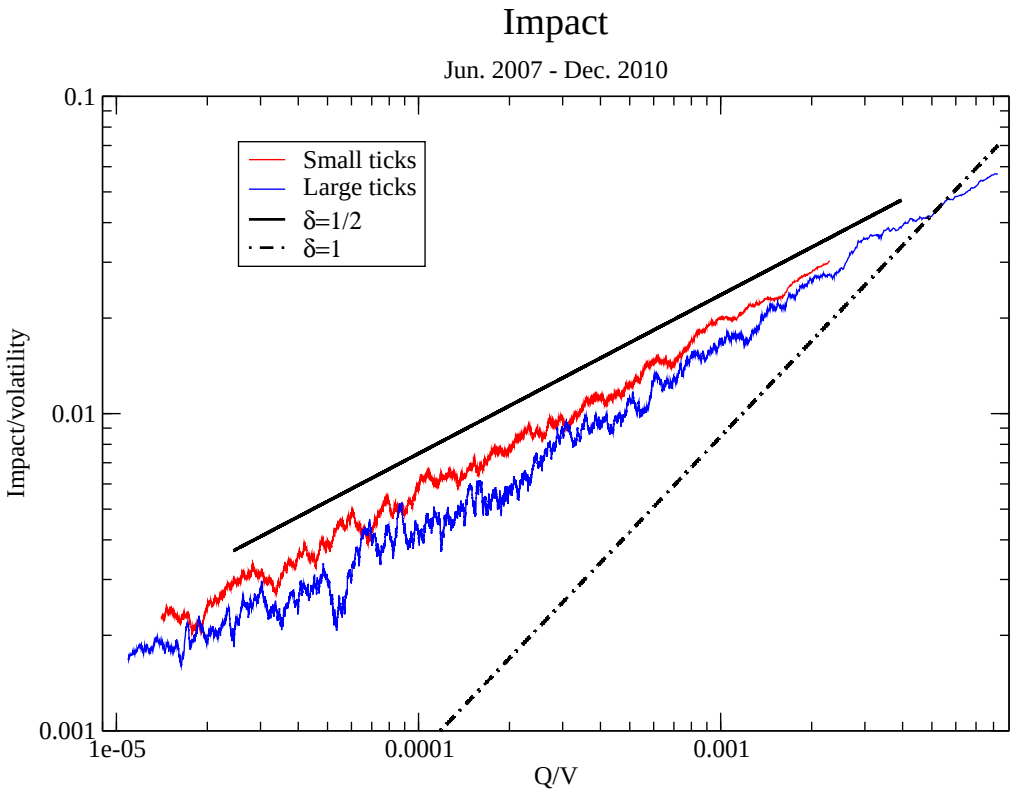
  ▷ Trades must be executed incrementally $\rightarrow$ "metaorders"

- 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, periods (1995 – 2012)...

The square-root impact law



From ca. 500,000 CFM trades on futures markets; more recent results are still perfectly in line – with I. Mastrosmatteo, B. Toth et al.

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?

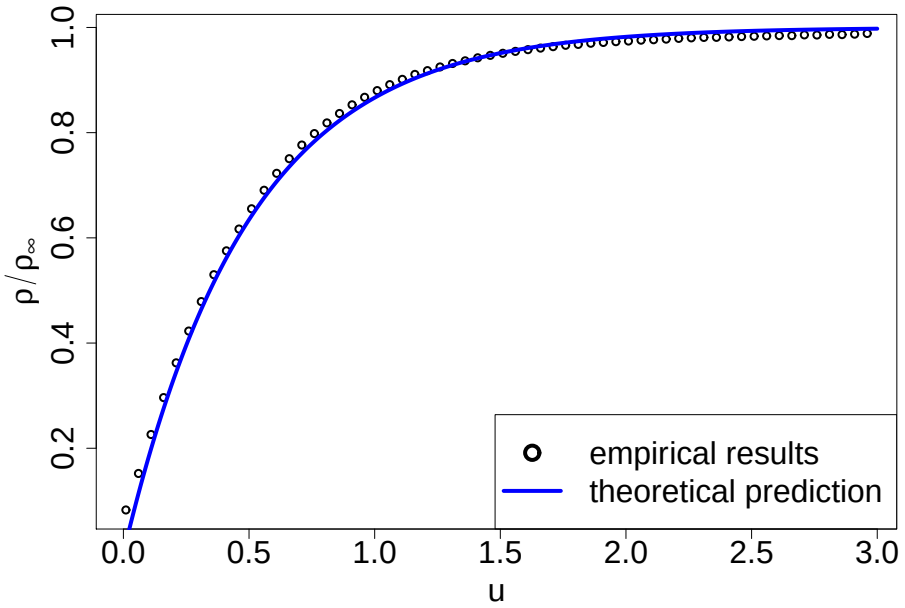
- Why is impact so large (singular) and liquidity so small?

- A statistical theory of liquidity: (B. Toth et al., I. Mastromatteo, JPB)

  ▷ 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

  ▷ Analytical results + Agent-based numerical simulations

A linear liquidity profile



A generic result (e.g. $A + B \to \emptyset$) – with B. Toth, I. Mastromatteo, etc.

B) How do trades impact prices?

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

- A statistical theory of liquidity:

  ▷ The probability to have unexecuted orders close to the current price is linearly small

  ▷ `Consequence: square-root impact!`

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

  ▷ This can be made fully rigorous within diffusion-reaction models $A + B \to \emptyset$ (with J. Donier, J. Bonart, I. Mastromatteo, B. Tóth)

B) How do trades impact prices?

- Critical liquidity and Intrinsic Market Fragility

  – `Markets are NOT obviously stable` (M. Friedman)

- Liquidity around current price is vanishingly small (eaten by the diffusive motion of prices): `Market makers are needed!`

  ▷ Liquidity fluctuations are bound to play a crucial role: 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)

Endogenous crashes: Impact-induced instabilities

- Impact-induced feedback loops that can and do lead to crises:

  ▷ Trend induced feedback loops: bubbles and crashes (cf. e.g. Wyart, JPB on a impact based model for self-fulfilling trends)

  ▷ Model induced feedback loops: e.g. the BS feedback loop in 1987, the CDO feedback loop in 2008,...

  ▷ Risk/Regulation induced feedback loops: mark to market, risk limits, margin calls, (catastrophic) deleveraging: prices are only meaningful for *infinitesimal transactions*.

  ▷ Contagion, spill-over: the 2007 quant crunch; ...

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.

  When men are in close touch with each other, they no longer decide randomly and independently of each other, they each react to the others. Multiple causes come into play which trouble them and pull them from side to side, but there is one thing that these influences cannot destroy and that is their tendency to behave like Panurges sheep

  (Poincaré 1900, on Bachelier's thesis!)

Love-locks on Pont Des Arts

The madness of crowds (Newton)

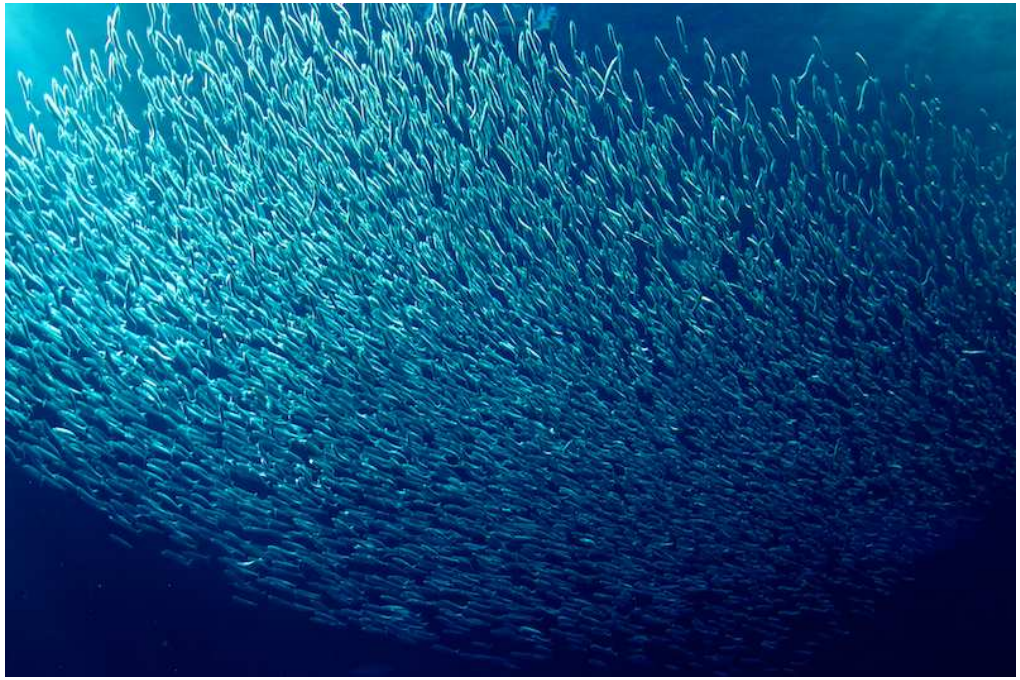
A cartoon model for self-referential behaviour

- 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.

Starlings in Rome and Fish Schools



A. Cavagna et al.

Cartoon models for collective behaviour

- A simple framework: N homogeneous agents with "mean-field" interactions (i.e. only influenced by the aggregate decision)

  ▷ Binary decision of agent i: $D_i = 0, 1$ (to buy/lend/trust or not to buy/lend/trust, etc.)

  ▷ Aggregate decision: $\phi = N^{-1} \sum_i D_i$

Cartoon model for collective decisions: RFIM

- 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)

- Agents are both heterogeneous and influenced by the behaviour of others

  $\Rightarrow$ the RFIM update rule (mean-field):

$$D_i(t) = \frac{1}{2}\left(1 + \text{sign}\left[\psi_i - \alpha(t) + \beta\phi(t)\right]\right),$$

Cartoon model for collective decisions: RFIM

- the RFIM update rule (mean-field):

$$D_i(t) = \frac{1}{2}\left(1 + \text{sign}\left[\psi_i - \alpha(t) + \beta\phi(t)\right]\right),$$

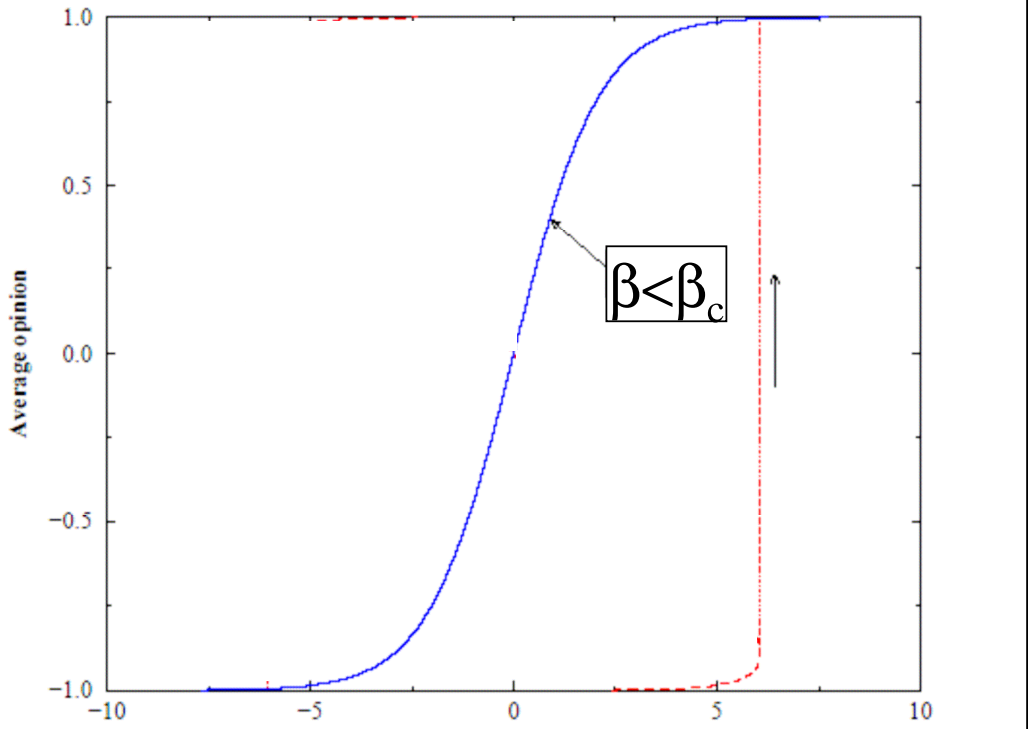
  ▷ personal opinion, propensity or utility ψ_i – heterogeneous with probability P with rms σ

  ▷ public information (price, technology level, news, zeitgeist) $-\alpha(t)$ (for illustration purposes, smooth in time)

  ▷ social pressure or imitation effects $\beta\phi(t)$

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

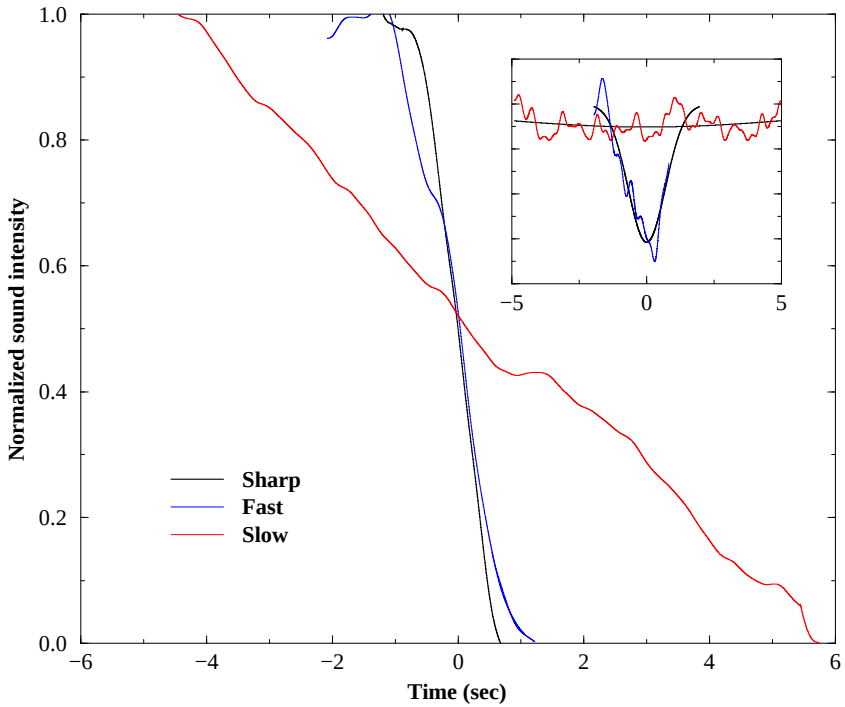
- $\beta > \beta_c$: herding dominates, strong distortion/amplification of the fundamental demand curve: discontinuities appear at the macro level – imitations induced panic/crashes/mistrust, rushing for the exit...

  $\triangleright$ Hysteresis in and out of the crisis

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

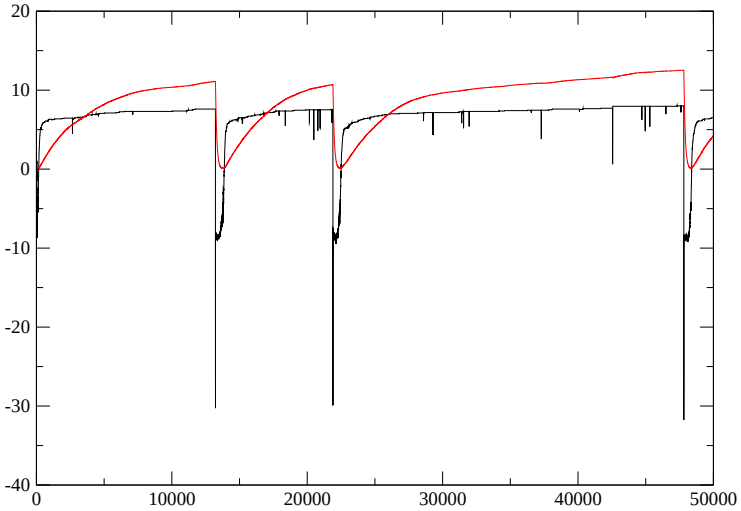
- $\beta_c \propto \sigma$: More dispersed opinions avoid polarisation and stabilizes the system

Cartoon model of self-referential behaviour



End of clappings

Application: spontaneous evaporation of trust



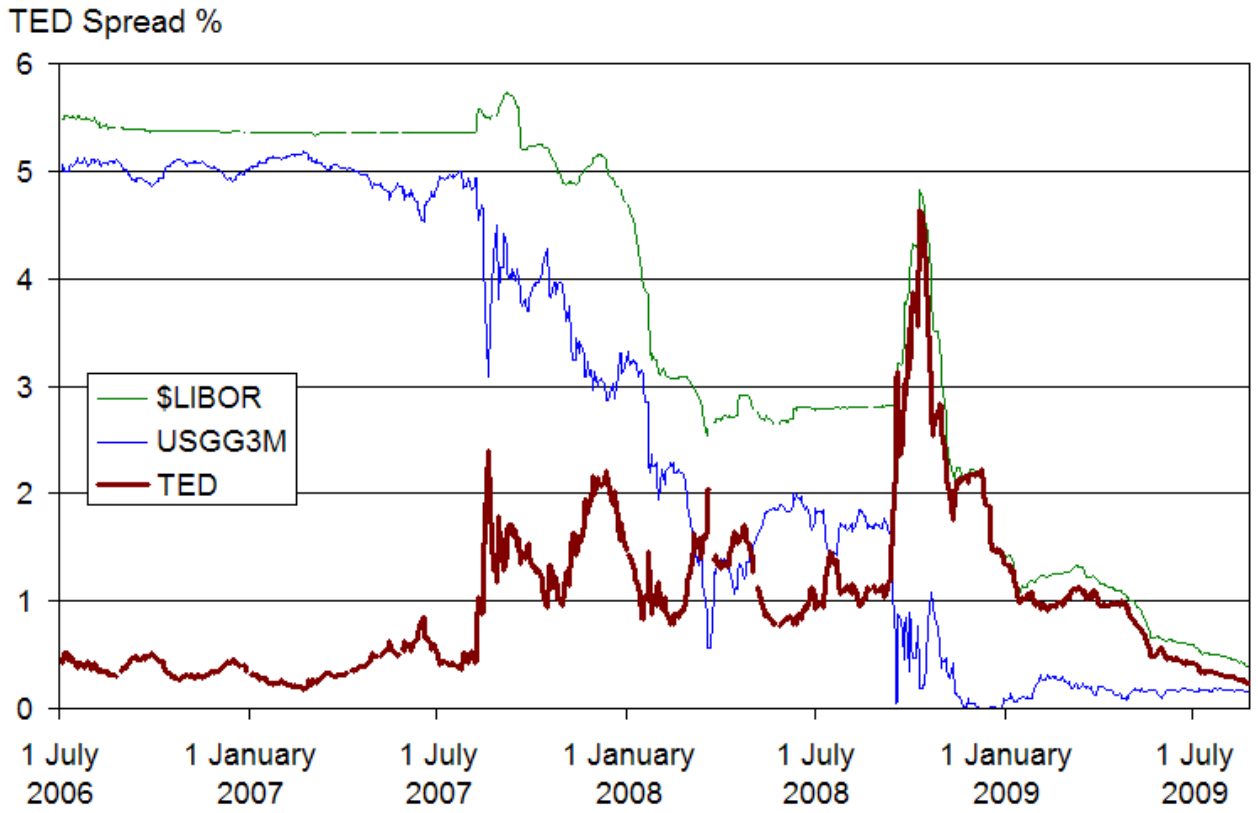
Number of trust bonds and average trust as a function of time

I trust you because he trusts you because I trust you

As trust builds up, the system becomes more fragile

Battiston et al., Kirman et al., Batista et al.

Evaporation of trust and money market freeze



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

Conclusion – Endogenous crises?

Financial markets seem to operate close to criticality, making them particularly fragile (cf. square-root impact)

- Many tensions in markets try to equilibrate in a "tug of war"
  - ▷ Buyers vs. Sellers
  - ▷ Trend followers vs. mean reverters (Lux-Marchesi, Giardina-JPB)
  - ▷ Liquidity providers vs. liquidity takers (Wyart at al.)
- A recent theoretical framework: learning necessarily pushes the system towards criticality (Minority games, stick balancing task, etc.) – see F. Patzelt, K. Pawelski

References

- This talk is based on the following papers:

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▷ R. Chicheportiche, J.-P. Bouchaud, *The fine structure of volatility feedback*, arXiv:1206.2153

▷ 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: simple models and challenges*, J. Stat. Phys. 151, 567 (2013)