Why do asset prices move?

Impact and Second Generation models

J.P. Bouchaud, Capital Fund Management

Why ask?

- Crucial question in theoretical Economics and Finance: what is the information reflected by prices & what are markets good for?

- Crucial question for investment strategies: is there any way to predict how prices will move?

- Crucial question for risk control/regulation: understanding why and how prices move allows one to devise efficient risk models and useful regulation (?)

The Sacred Lore of Theoretical Economics

- Efficient market theory: Agents are rational and Markets are in equilibrium

- Prices reflect faithfully the Fundamental Value of assets and only move because of exogeneous unpredictable news.

- Platonian markets which merely reveal fundamental values without influencing them – or is it a mere tautology??

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

By the way...

- Agents (us humans) do make errors and have regrets, (cognitive or sensorial biases, imperfect or superabundant information, urgency, negligence, etc.)

- Problems can be algorithmically so complex that we have to make suboptimal decisions

- Agents are deeply influenced by the behaviour of others – who might have more information (??)

- $\longrightarrow$ Even silly trades do impact prices and may create positive feedback loops

First generation models of markets

- Rooted in the idea that dynamics is exogenous and markets are efficient, Financial Engineering:

- (1) postulate any process that

  - is tractable

  - looks vaguely similar to real data

- (2) brute force calibrate, on “liquid” markets (supposed to be efficient) and price options or more exotic derivatives

- Examples: Brownian motion (Black-Scholes), GARCH, Heston, Local vol., Lévy, Multifractal, etc. , etc., etc.

BUT

- NONE of these models are justified by "first principles", or agent based models, such that parameters can be (at least in principle) *computed*

- Inspiration from physics: macroscopic (or hydrodynamic) laws from microscopic elements

  – Navier-Stokes from molecular collisions

  – Magnetic properties from individual spins

  – Phase diagram of bodies from individual atoms, etc. etc.

BUT

- Uncontrolled brute force calibration are often based on absurd models (e.g. local volatility models) and can be extremely dangerous:
  - Even liquid markets are in fact not liquid and not efficient – e.g. plain vanilla equity option markets
  - Errors and biases are amplified in a non-linear way – e.g. using plain vanillas to price exotic options using local vol.
  - Self fulfilling prophecies and feedback loops – e.g. portfolio insurance and the 87 Black-Scholes induced crash, etc.

BUT

- To calibrate does not mean to understand
- A perfect fit is not a theory – often a red-herring
- Let's try to undestand what's going on at the micro level

Some empirical facts

- Financial markets offer Terabytes of information (weekly) to try to investigate why and how prices move

- A) Are news really the main determinant of volatility?

  Exogenous vs. endogenous dynamics

- B) Are price really such that supply instantaneously equals demands? How fast information is included in prices?

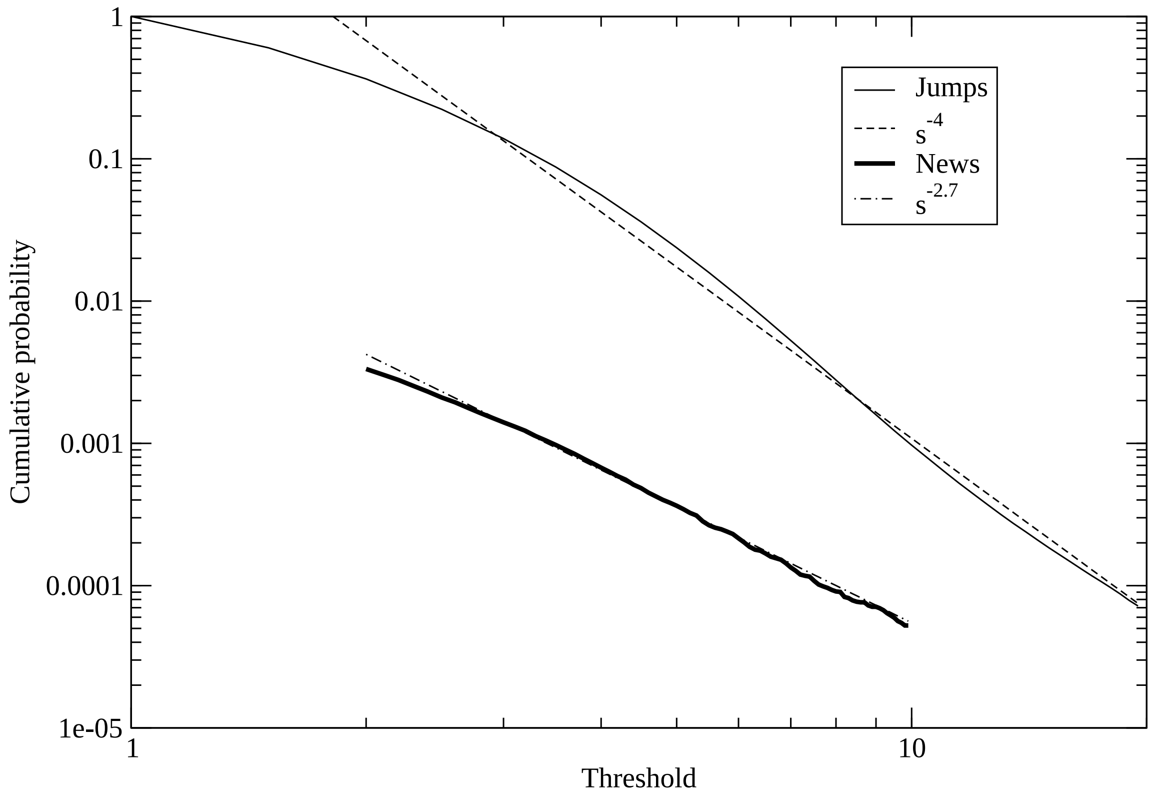
A) Exogenous or endogenous dynamics?

- 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 endogeneous

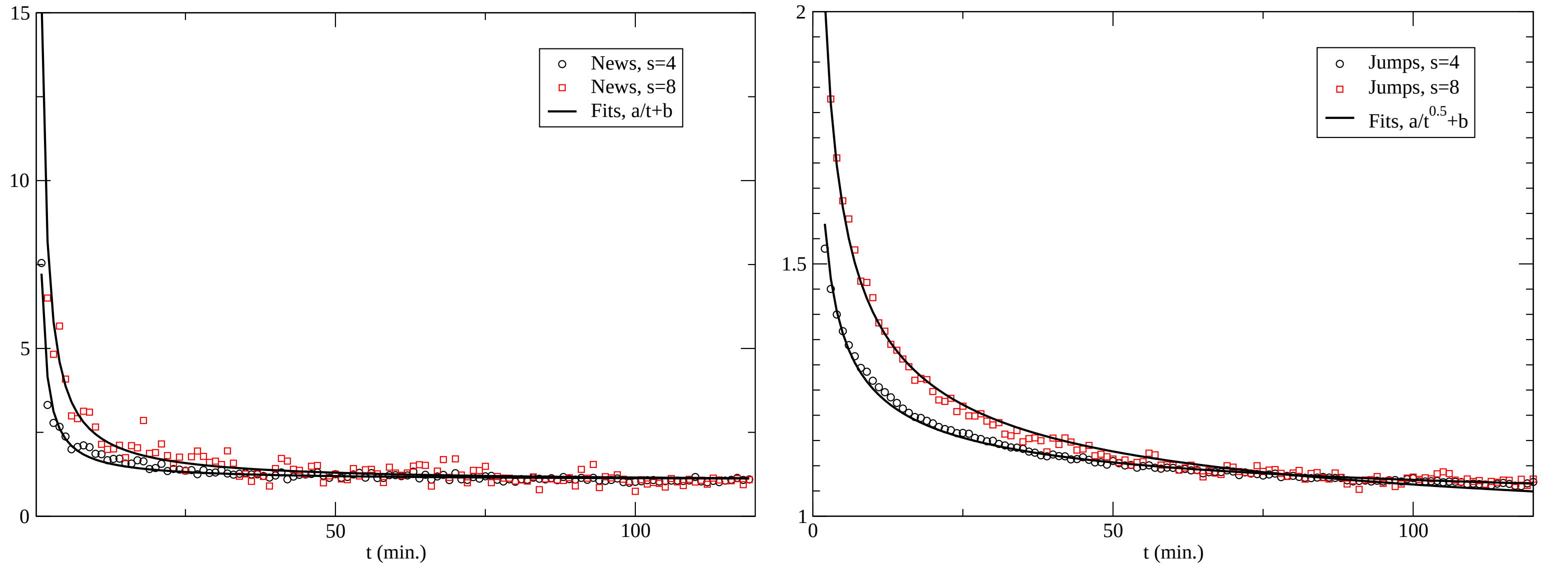
- Different statistics: return distributions and 'aftershocks' (volatility relaxation)

Jumps



Power-law distribution of news jumps and no-news jumps. With A. Joulin, D. Grunberg, A. Lefevre

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

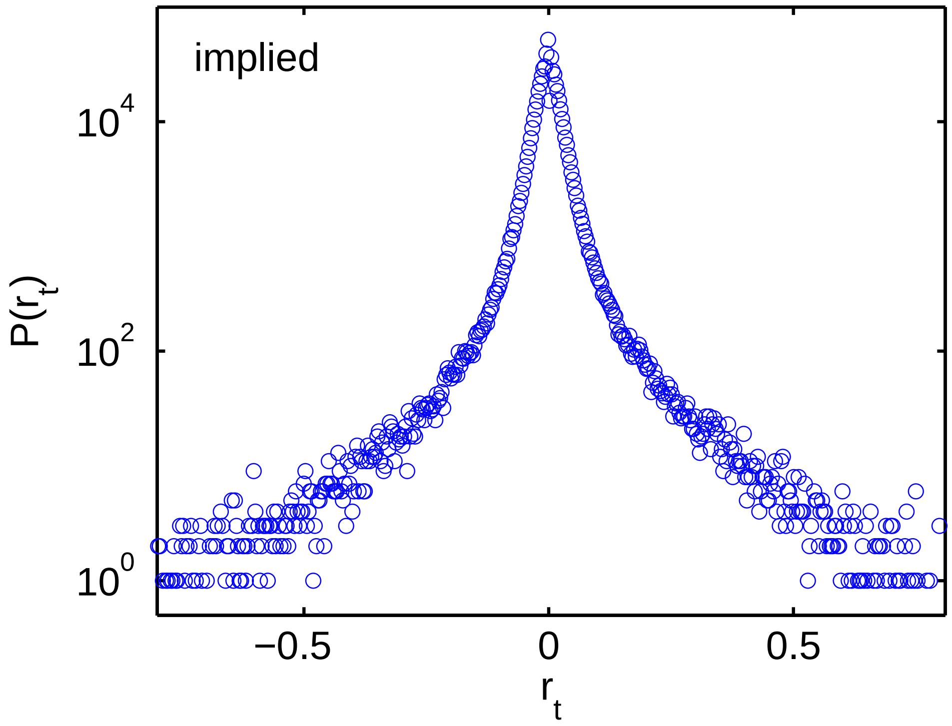
A) Exogenous or endogenous dynamics?

- Power-law distribution of price changes for anything that is traded

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

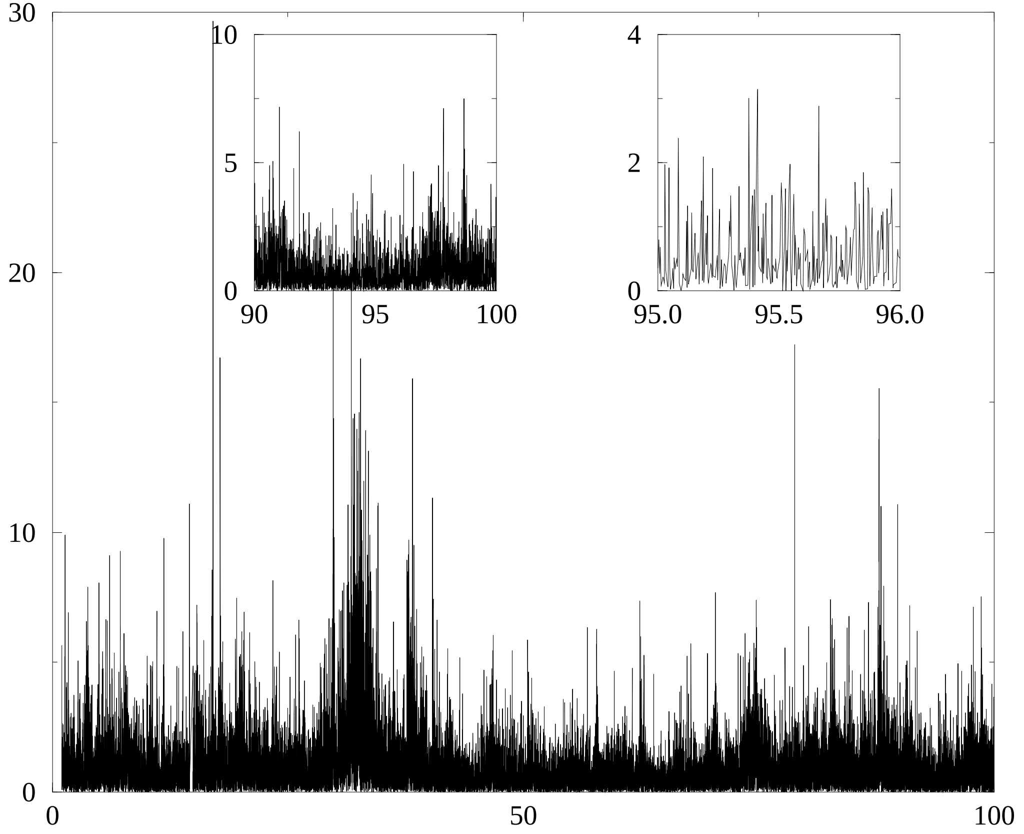
- Universal observations !!

Power-law tails



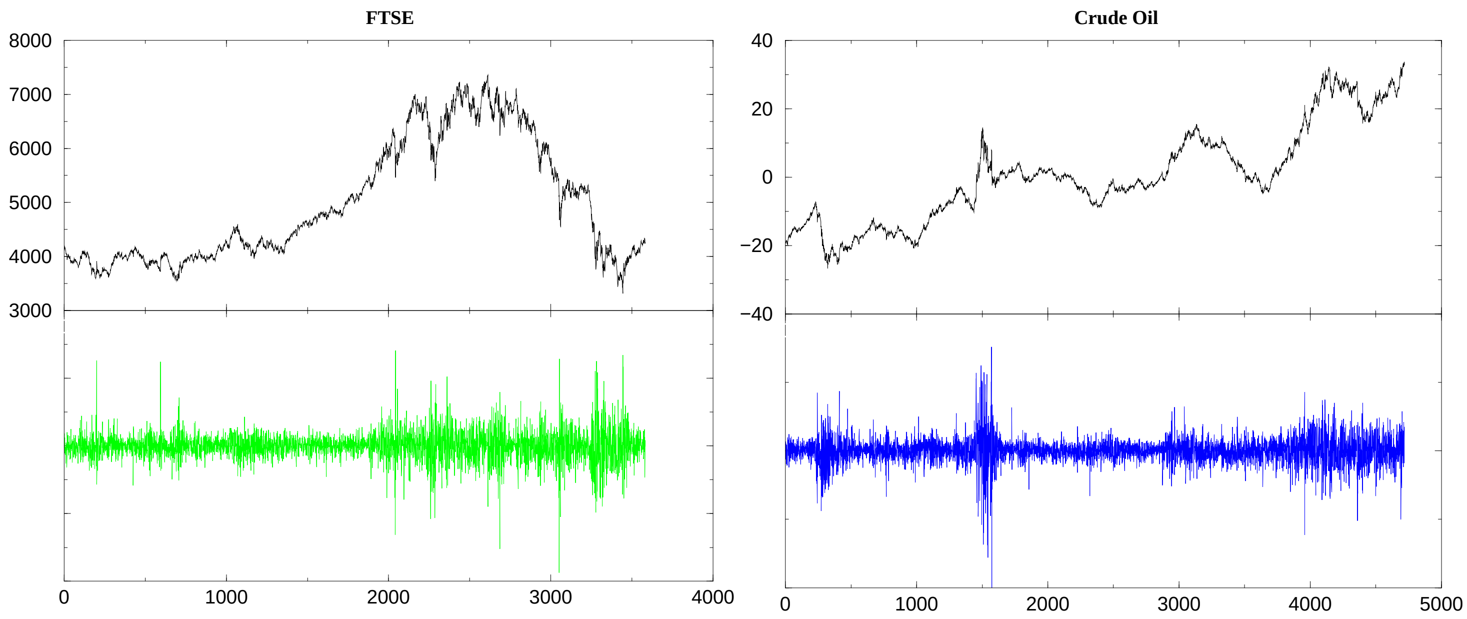
Distribution of daily volatility moves on option markets or *any other traded stuff*: inverse cubic law

Multiscale intermittency



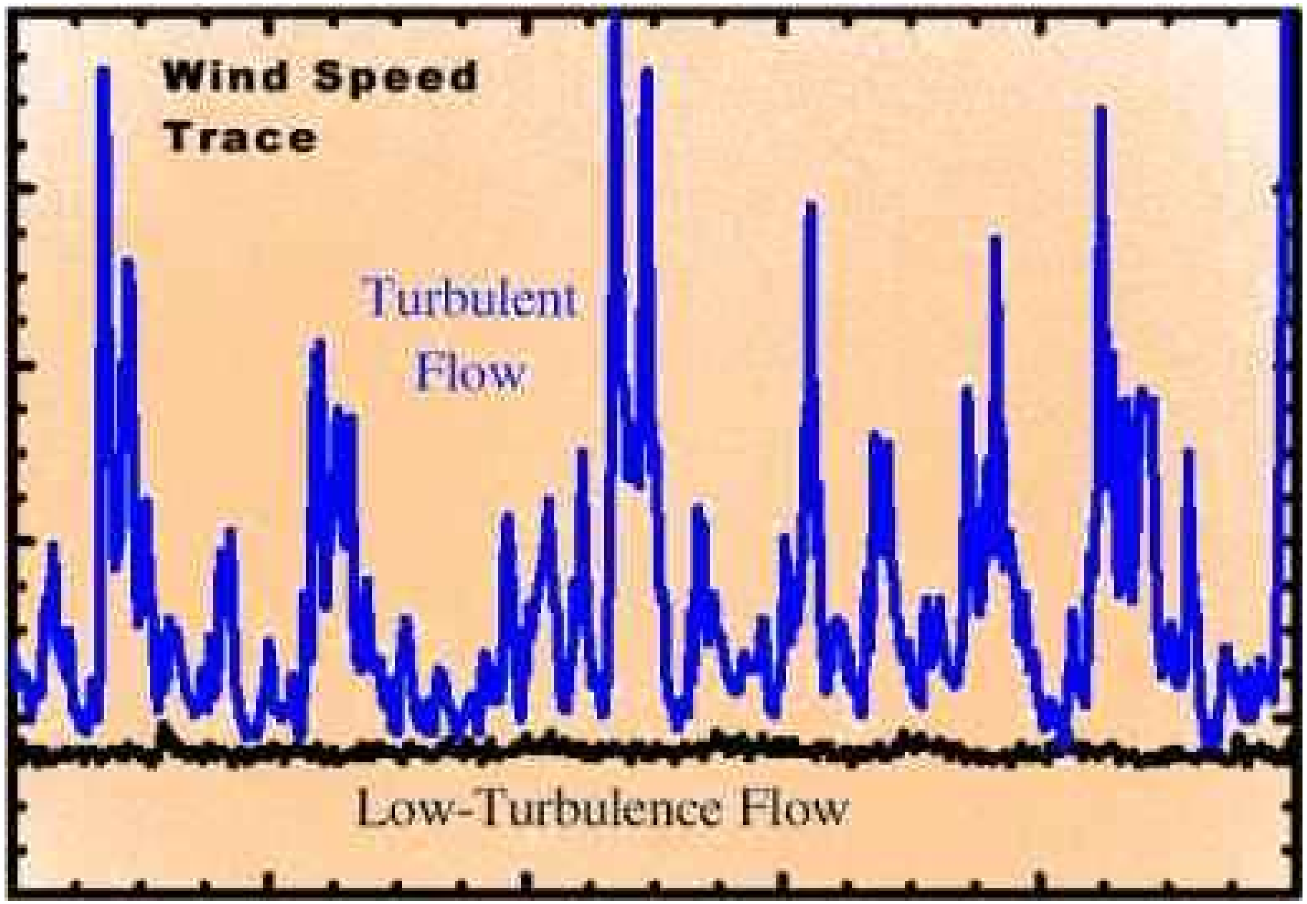
Excess volatility, with long range memory – a "multifractal" process, see Mandelbrot-Calvet-Fisher and Bacry-Muzy

Multiscale intermittency



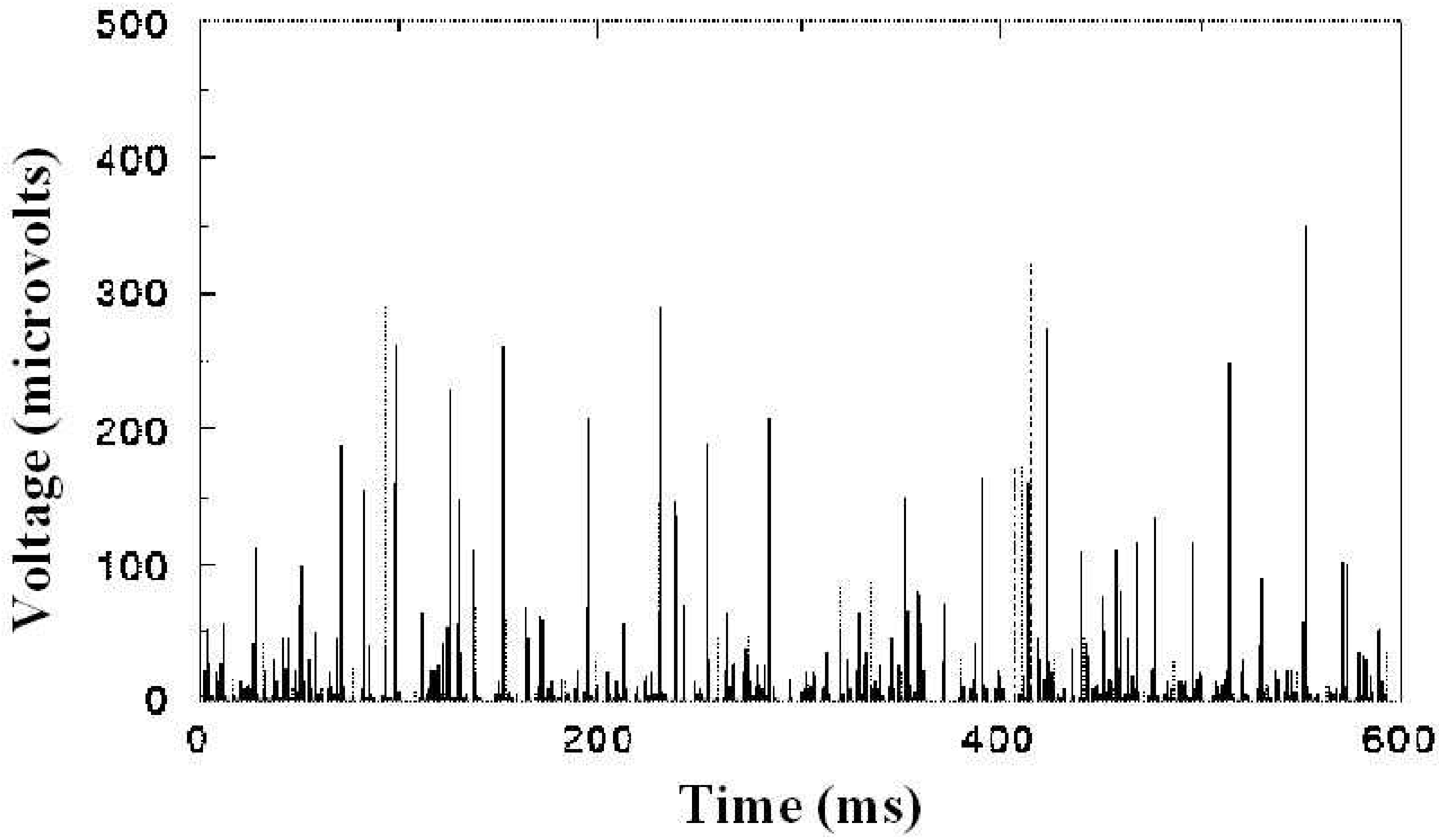
Excess volatility, with long range memory– looks a lot like endogeneous noise in complex systems

Turbulence: intermittency



Slow, regular and featureless exogeneous drive but intermittent endogeneous dynamics

Barkhausen noise



Slow, regular and featureless exogeneous drive but intermittent endogeneous dynamics

B) Are markets in "equilibrium?"

- UHF data allows one to understand the microscopics of order flow and price formation

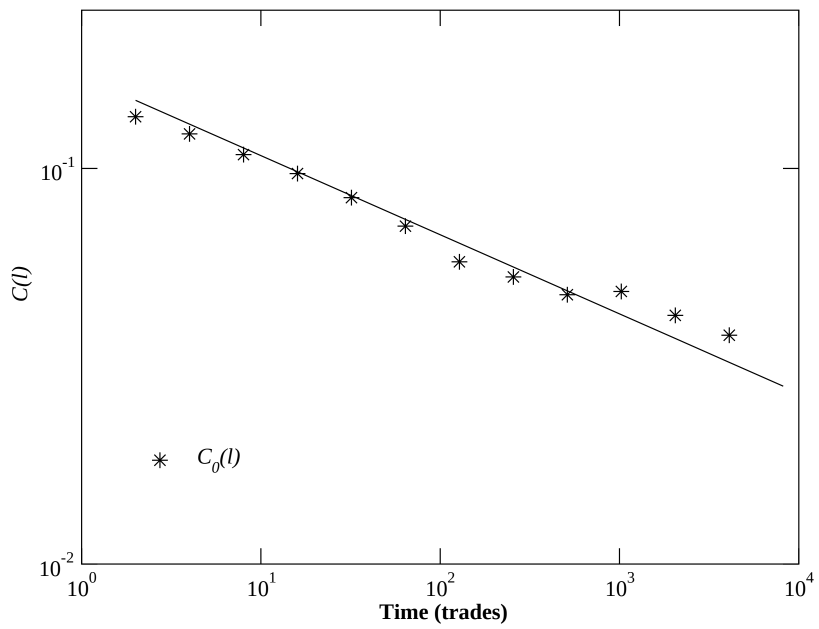
- One can distinguish buy orders from sell orders

- Surprise: the autocorrelation of the sign of trades is very long-range correlated over several days or weeks (see also Lillo-Farmer)

$$\mathcal{C}(\ell) \propto \ell^{-\gamma} \qquad \gamma < 1$$

- A beautiful paradox: Sign of order flow very predictable and orders impact the price – but no predictability in the sign of price changes ?? – see below

Trade correlations



Correlations extend to several days! $- p_s(10000) = 53\%$

B) Are markets in "equilibrium?"

- Even "liquid" markets offer a *very small immediate liquidity* (10^{-5} for stocks) – buyers/sellers have to fragment their trades over days, weeks or even months

- "Information" can only be *slowly incorportated into prices*, latent demand does not match latent supply

- Markets are hide and seek games between "icebergs" of buyers and sellers and are *not* in instantaneously in equilibrium

Some empirical facts

- A) Are news really the main determinant of volatility?
  - No, endogenous dynamics more likely, markets are complex systems that generate rich endogenous dynamics
- B) Are price really such that supply instantaneously equals demands?
  - No, "information" can only be very slowly incorportated into prices

What is impact?

- 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 have no price impact – prices stick to "Fondamental Values"

- A more plausible story: since there is no easy way to distinguish informed from non informed traders, all trades statistically impact prices since other agents believe that some of these trades might contain useful information – a mechanism leading to feedback loops and avalanches

Impact

- On anonymous markets, the origin of trades ("informed" vs. "non-informed") cannot be decided

  Anyway, the information contained in each trade is very small – cf below

- Trading, even uninformed and with relatively small volumes in usual market conditions, strongly influences prices and leads to measurable effects – even "liquid" markets are not that liquid

  (1% of the daily volume moves the price by 5% of the daily volatility!!)

- Impact of trades is crucial to understand why prices move: the price process is not God given and we merely observe it tracking the "true" value

Impact & volatility

- Using high frequency data, one can measure impact accurately:

$$\mathcal{I}_+ = E[p_{n+1} - p_n | \epsilon_n = +1], \qquad \mathcal{I}_- = -E[p_{n+1} - p_n | \epsilon_n = -1]$$

- Empirical finding (1): impact is proportional to spread

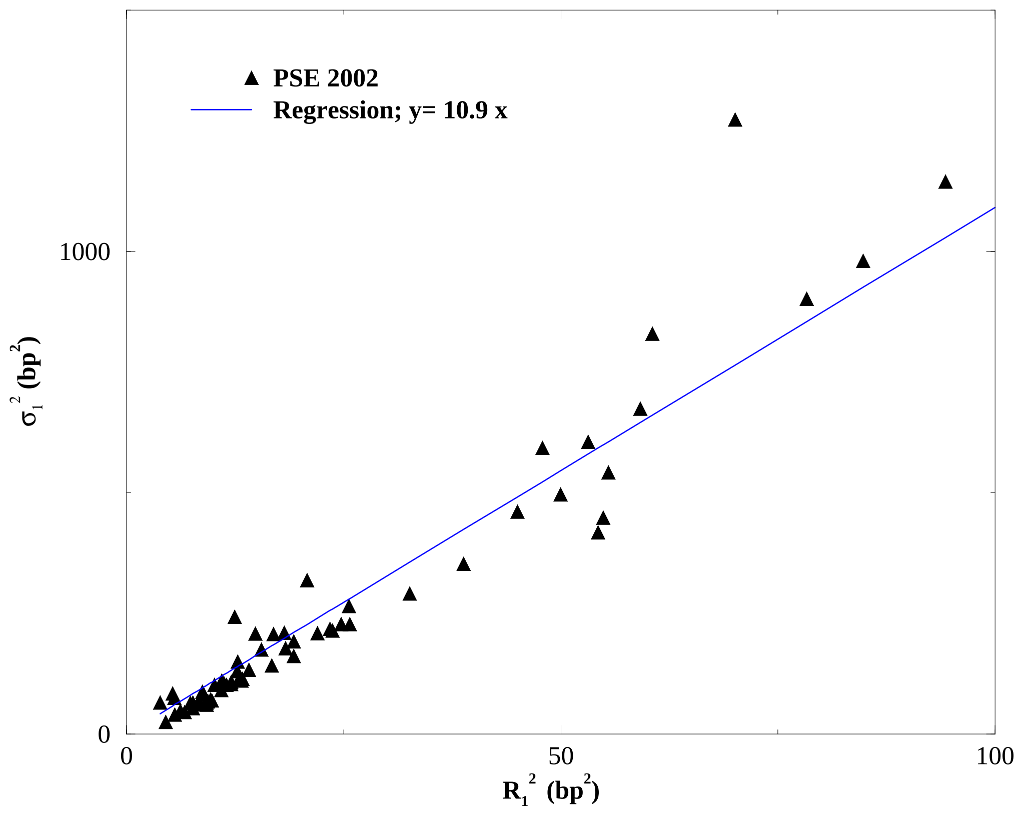
$$\mathcal{I}_+ = \mathcal{I}_- \approx 0.3\, S$$

- Empirical finding (2): volatility per trade is proportional to impact

$$\sigma_1^2 = A\mathcal{I}^2 + BJ^2, \qquad B \approx 0$$

- Volatility is indeed mostly due to impact of trades – very little to quote jumps J without trades (“news”)

Volatility: impact + news?



Very little contribution from quote jumps J without trades ("news")

– with J. Kockelkoren, M. Potters, M. Wyart

Impact: non linear and transient

- Impact is highly non trivial to model (both non-linear and non local in time)

$$p_t = p_{-\infty} + \lambda \sum_{\ell=1}^{\infty} G(\ell) \left(\epsilon S V^{\psi}\right)\Big|_{t-\ell},$$

- $\psi \approx 0.2$: very concave impact

- The impact function $G(\ell)$ decays as $\ell^{-\beta}$ as to exactly offset the correlation of trades and remove predictability of returns!

$$\beta = \frac{1-\gamma}{2}, \qquad 0 \le \gamma \le 1$$

Impact: non linear and transient

- Bachelier's legacy: the random walk nature of prices results from a subtle balance between trending order flow and mean-reverting impact

- $G(\infty)$ is Hasbrouck's definition of the information content of a single trade, and it is very small ($G(\infty) \ll G(1)$).

Transient impact: more technicalities

- Mid-point fluctuations in trade time: diffusion

$$\mathcal{D}(\ell) = \left\langle \left(p_{n+\ell} - p_n\right)^2 \right\rangle \approx \sigma_1^2 \ell$$

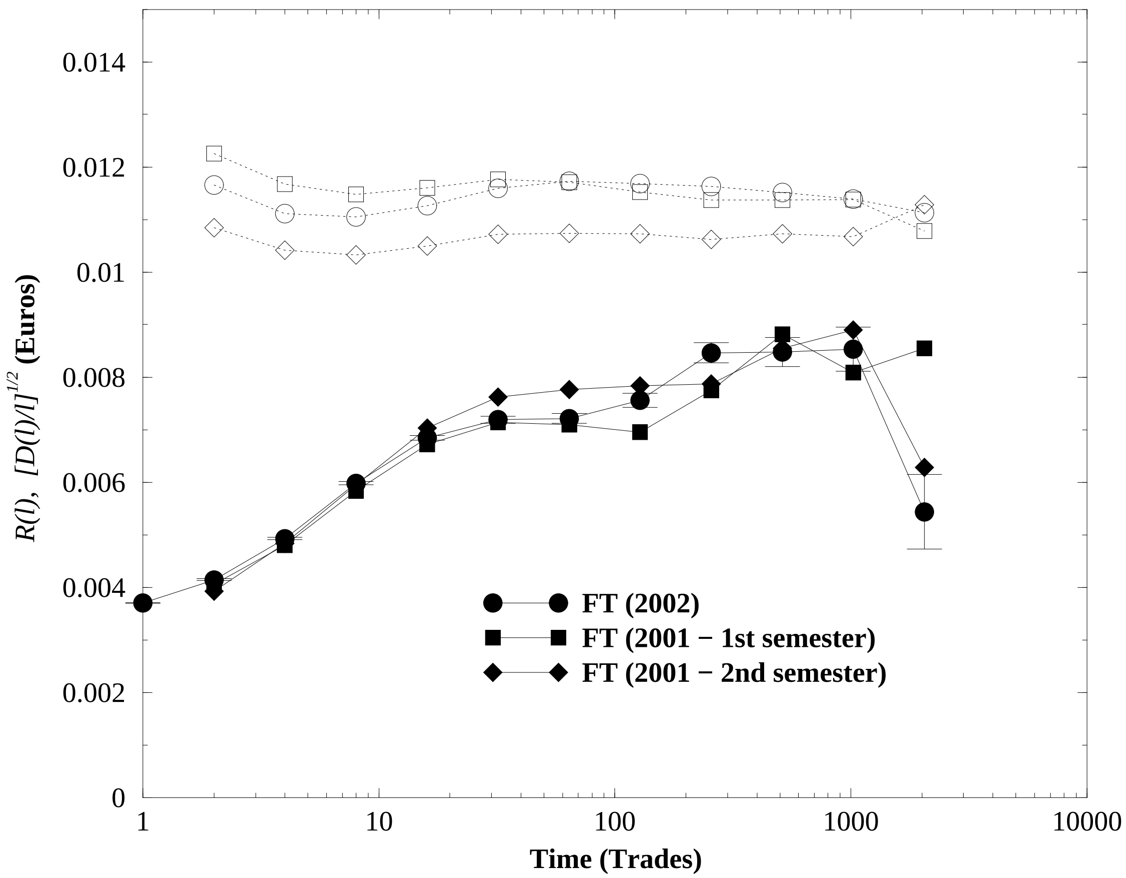
- Average response function:

$$\mathcal{I}(\ell) = \left\langle \left(p_{n+\ell} - p_n\right) \cdot \varepsilon_n \right\rangle$$

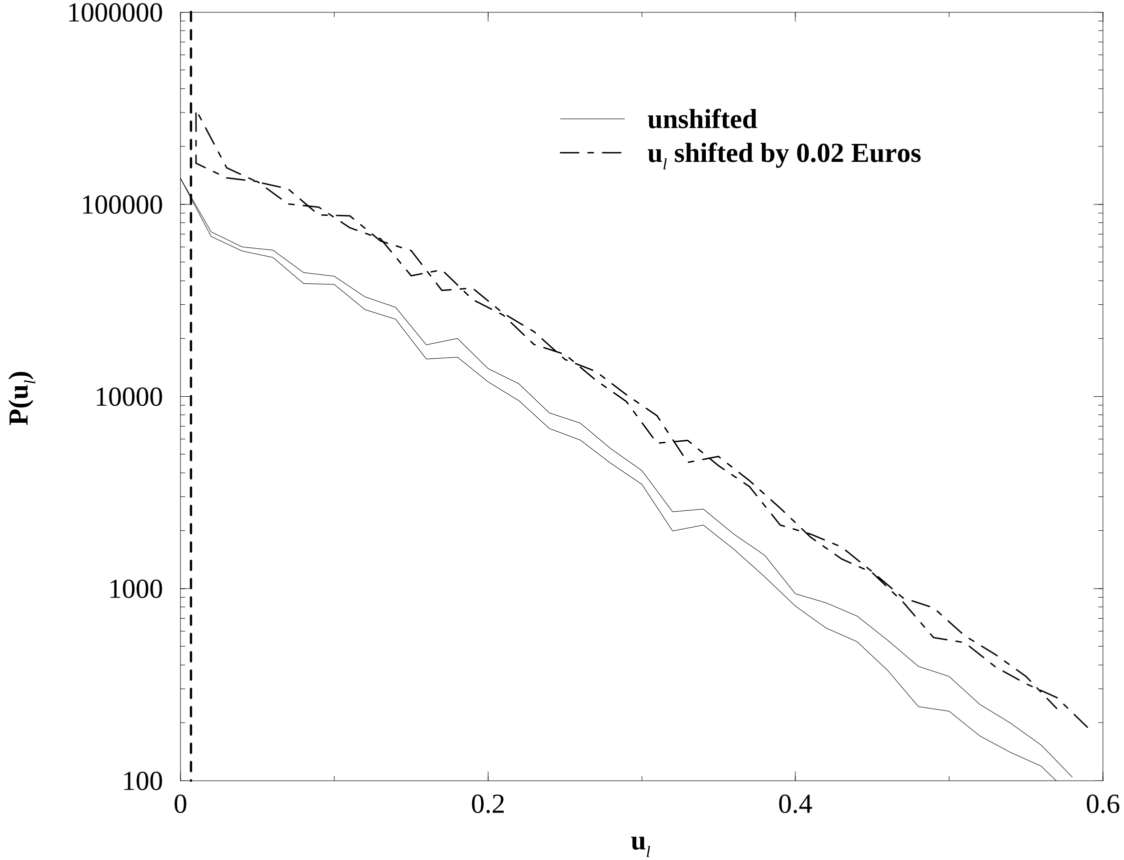
- The full distribution of $u_\ell = (p_{n+\ell} - p_n).\varepsilon_n$ is nearly symmetrical around its mean $\mathcal{I}(\ell) = \langle u_\ell \rangle \ll \sqrt{\mathcal{D}(\ell)}$:

  $\longrightarrow$ Very few trades can be qualified as 'informed' on the short run

Average response



Impact distribution



$\ell = 128$: where are the 'informed' trades??

Transient impact: more technicalities

- An exact relation that allows to measure $G(\ell)$:

$$\mathcal{I}(\ell) = K \left[G(\ell) + \sum_{0<n<\ell} G(\ell - n)\mathcal{C}(n) + \sum_{n>0} \left[G(\ell + n) - G(n) \right] \mathcal{C}(n) \right]$$

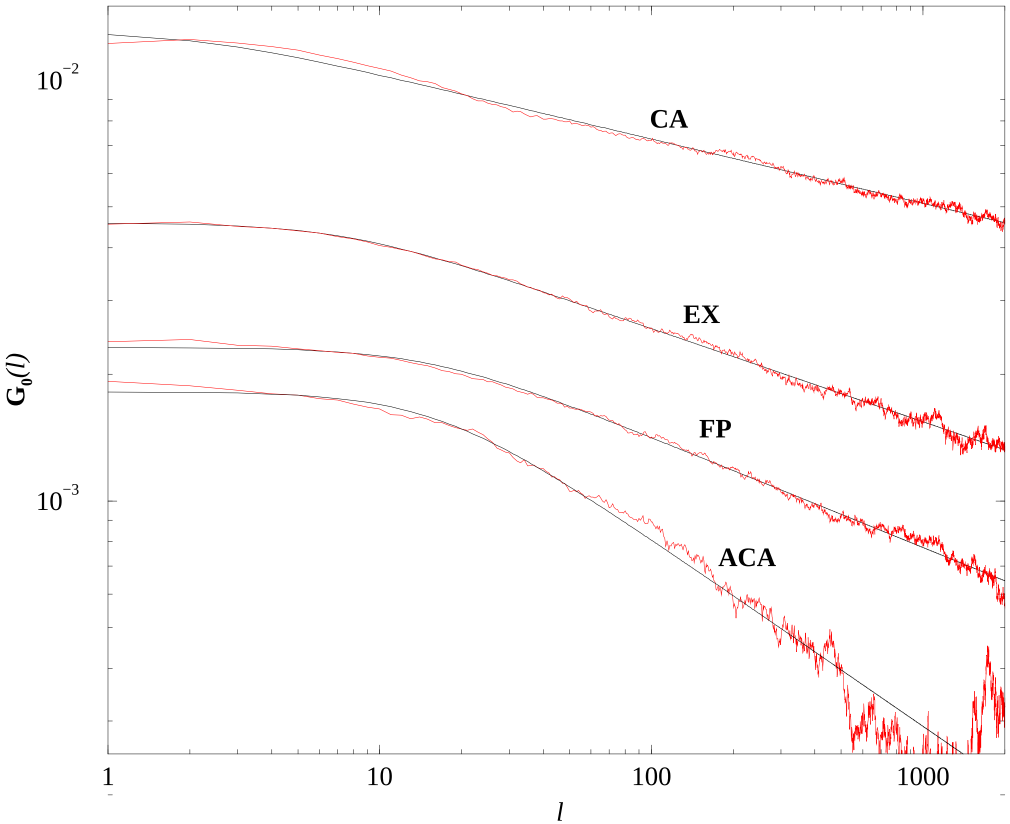
(and a more complicated equation for $\mathcal{D}(\ell)$).

- If $C(\ell) \sim \ell^{-\gamma}$ and $G(\ell) \sim \ell^{-\beta}$ then:

$$\mathcal{D}(\ell) \sim \ell^{2-2\beta-\gamma}$$

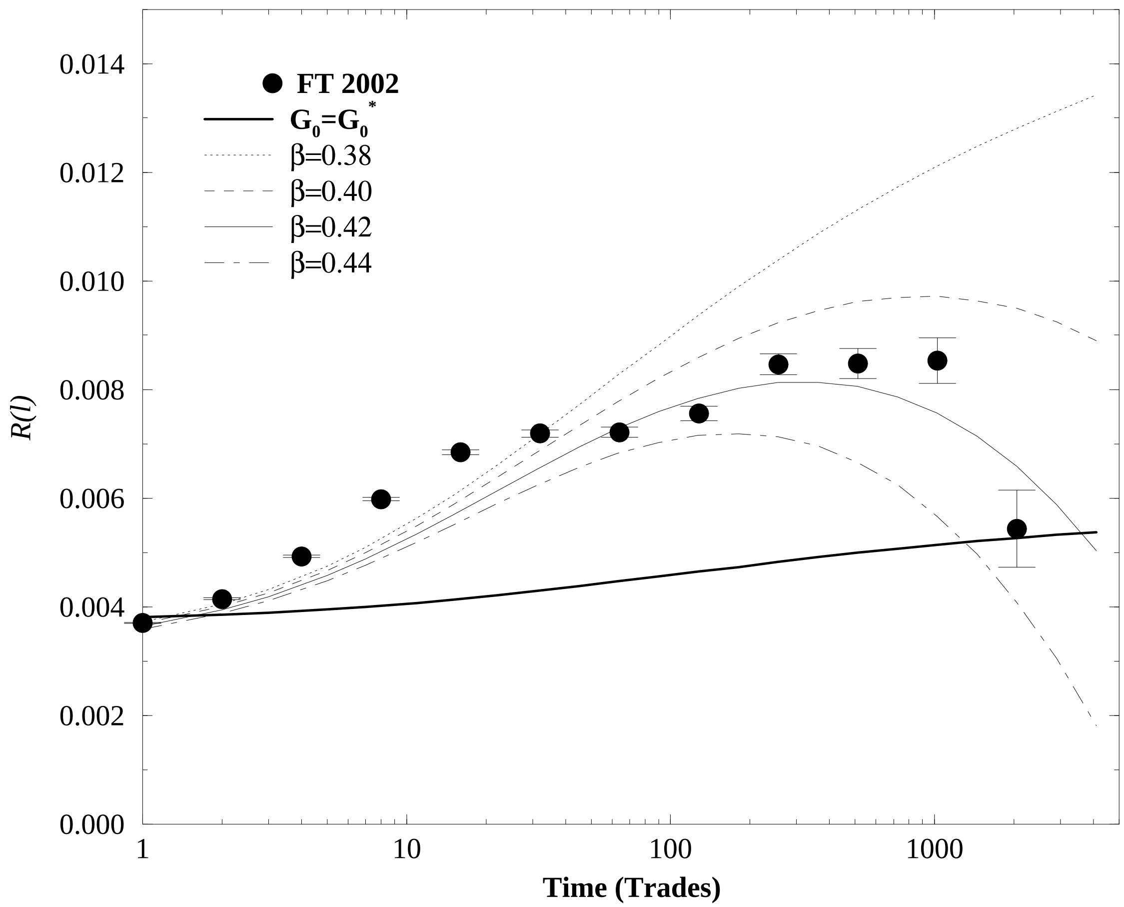
- For diffusion to be normal: $\beta = (1 - \gamma)/2$

Critically resilient markets



Decay of $G(\ell)$ for different stocks: impact is transient – with J. Kockelkoren, M. Potters

Theoretical and empirical response function



Second generation models

- Markets are complex systems (i.e. made of *heterogeneous, interacting elements*) $\longrightarrow$ rich endogenous dynamics

- "Second generation" models should start from:
  - agent based models (what do traders do?),
  - high frequency microstructure data,
  - a proper theory of *impact* (non-linear, transient,...)
  - identify interactions, feedback loops and contagion mechanisms

Second generation models

- Coarse-graining *should* lead to the emergence of some universality, power-laws and intermittency (but how, precisely?)

- Should allow to predict (at least qualitatively) the value and dynamics of the parameters (volatility, correlations, etc.)

- Help identify systemic instabilities

  (e.g. spread $\rightarrow$ vol. $\rightarrow$ spread and May 6th "flash crash")

- Think about rules and regulations that endogenize stabilisation mechanisms

  (e.g. mark-to-market with liquidity discount, dynamic make/take fees, etc.)