Quantitative law describing market dynamics

(Can we better understand market crashes by studying market dynamics...)

before and after interest-rate change

Alexander M. Petersen

http://physics.bu.edu/~amp17/

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Collaborators:

Prof. Shlomo Havlin	Bar-Ilan Univ., Israel
Dr. Fengzhong Wang	Boston Univ., U.S.A.
Prof. H. Eugene Stanley	Boston Univ., U.S.A.

- **A. M. Petersen,** F. Wang, S. Havlin, and H. E. Stanley, Quantitative law describing market dynamics before and after interest-rate change. Phys. Rev. E 82, 036114 (2010).
- **A. M. Petersen,** F. Wang, S. Havlin, and H. E. Stanley, Market dynamics immediately before and after financial shocks: quantifying the Omori, productivity, and bath laws. Phys. Rev. E 81, 066121 (2010).

Motivation: A better understanding of response dynamics in financial markets can help prepare emergency plans for financial crises

Outline

1. What kind of perturbations occur in the stock market?
2. Case study: Federal Interest Rate change announcements
3. Response dynamics *before* in addition to after market shocks

Part1)
Typical perturbations in the Stock Market

Company specific or global :

- Earnings forecast & report (quarterly)
- Upgrades, Downgrades
- Stock split announcement, Dividends announcement
- Generic News: unemployment reports, consumer confidence reports.....
- Political events, national catastrophe

"The Announcement Effect": Both news and the *anticipation* of news can fundamentally change expectations of future earnings, impacting market value

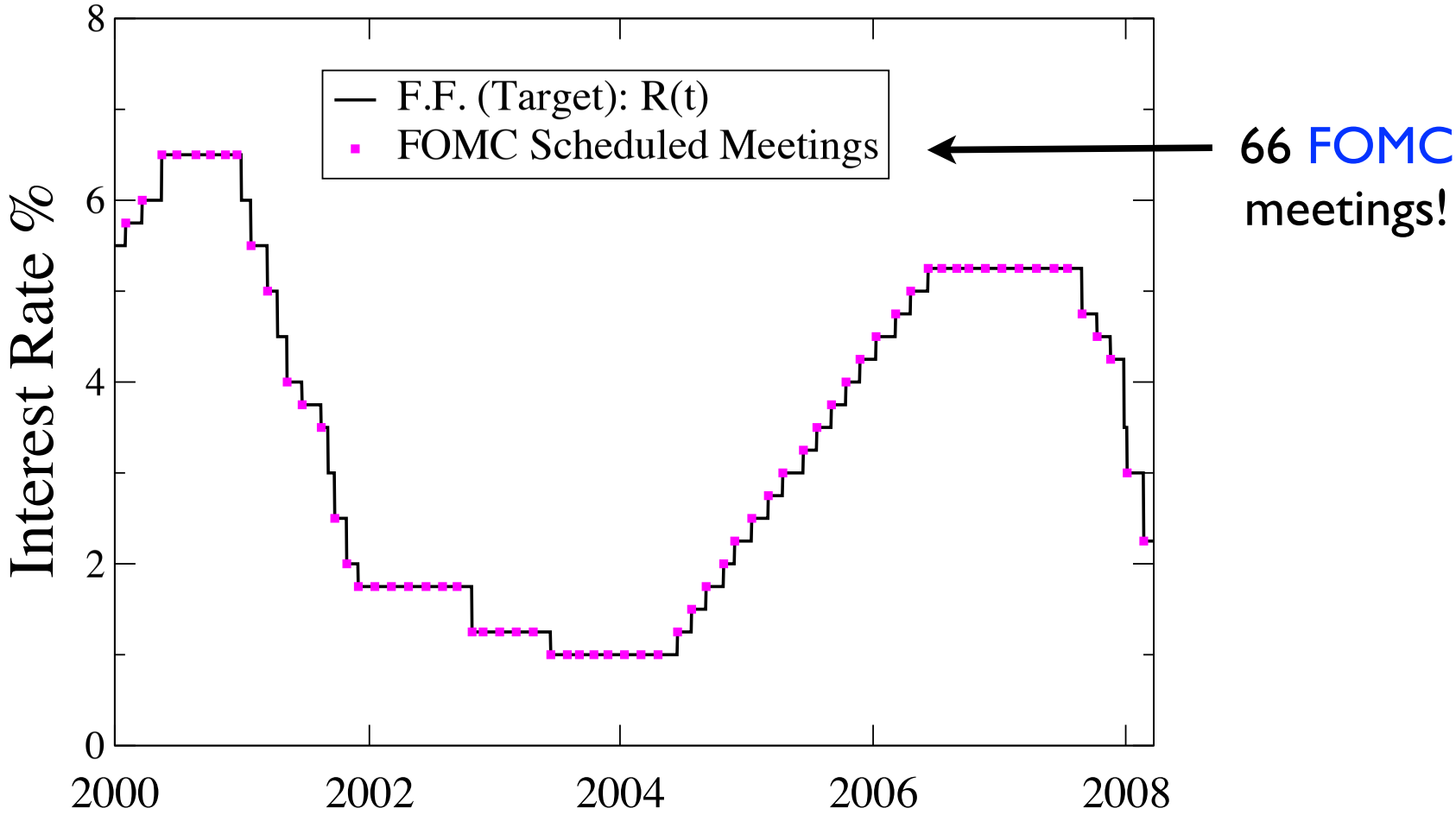
(Demiralp & Jorda, Econ. Policy Rev., 2002)

Part 2:

Probing
market response dynamics
using common Fed
interest-rate changes

2) Federal Interest Rates (set benchmarks for banks)

- The **Federal Interest Target rate R(t)**, is set by the U.S. Federal Reserve (Fed) at Federal Open Market Committee (FOMC) meetings (denoted by ■). These meetings are scheduled in advance and announced publicly. Typically, there are 8 scheduled FOMC meetings per year.



Interest rates change by "step function" @ FOMC meetings

2) Federal Interest Rates (set benchmarks for banks)

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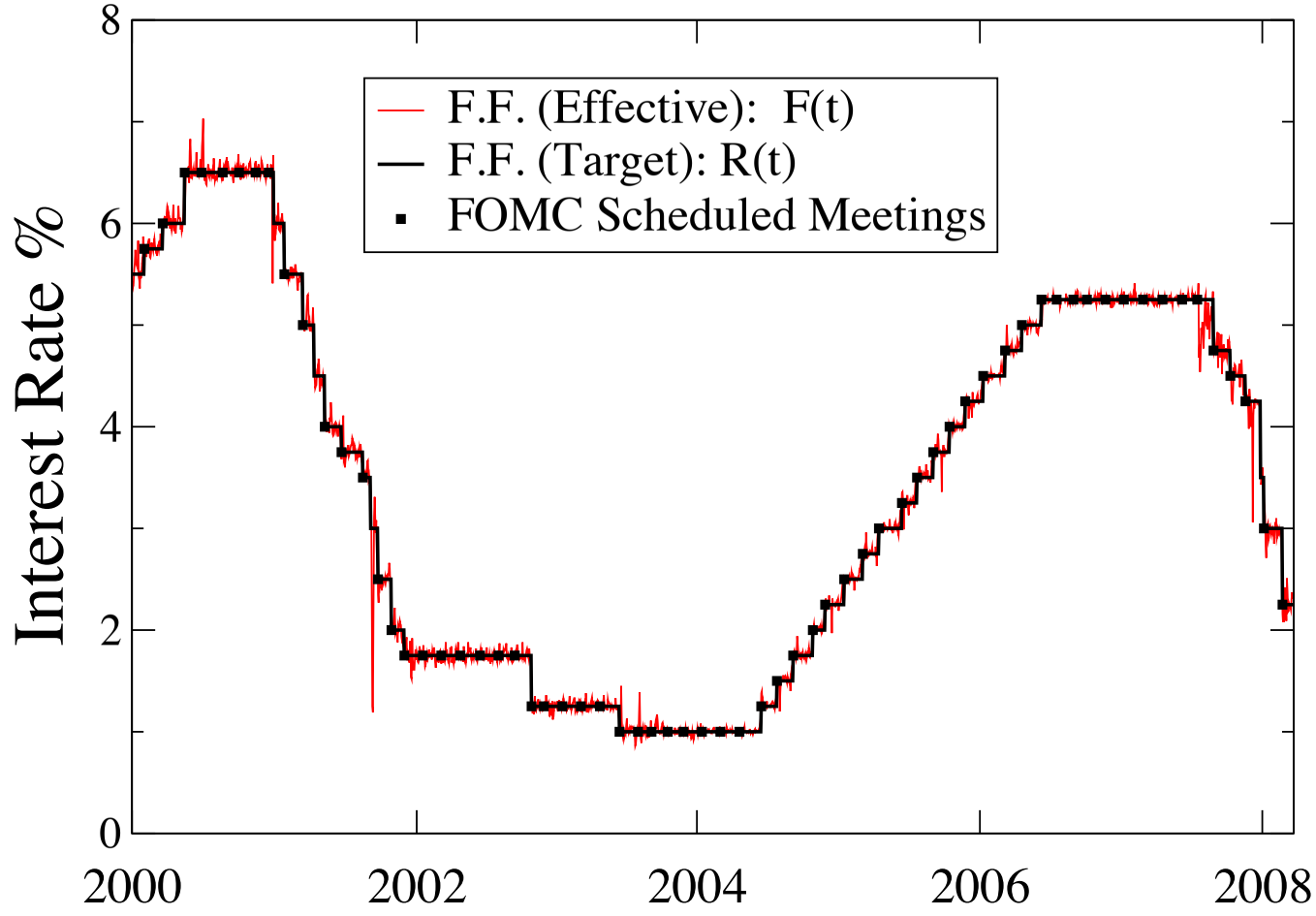
- The **Federal Interest Effective rate F(t)**, ("overnight rate") is an open market realization of the Target rate.



The Effective rate fluctuates around the Target rate

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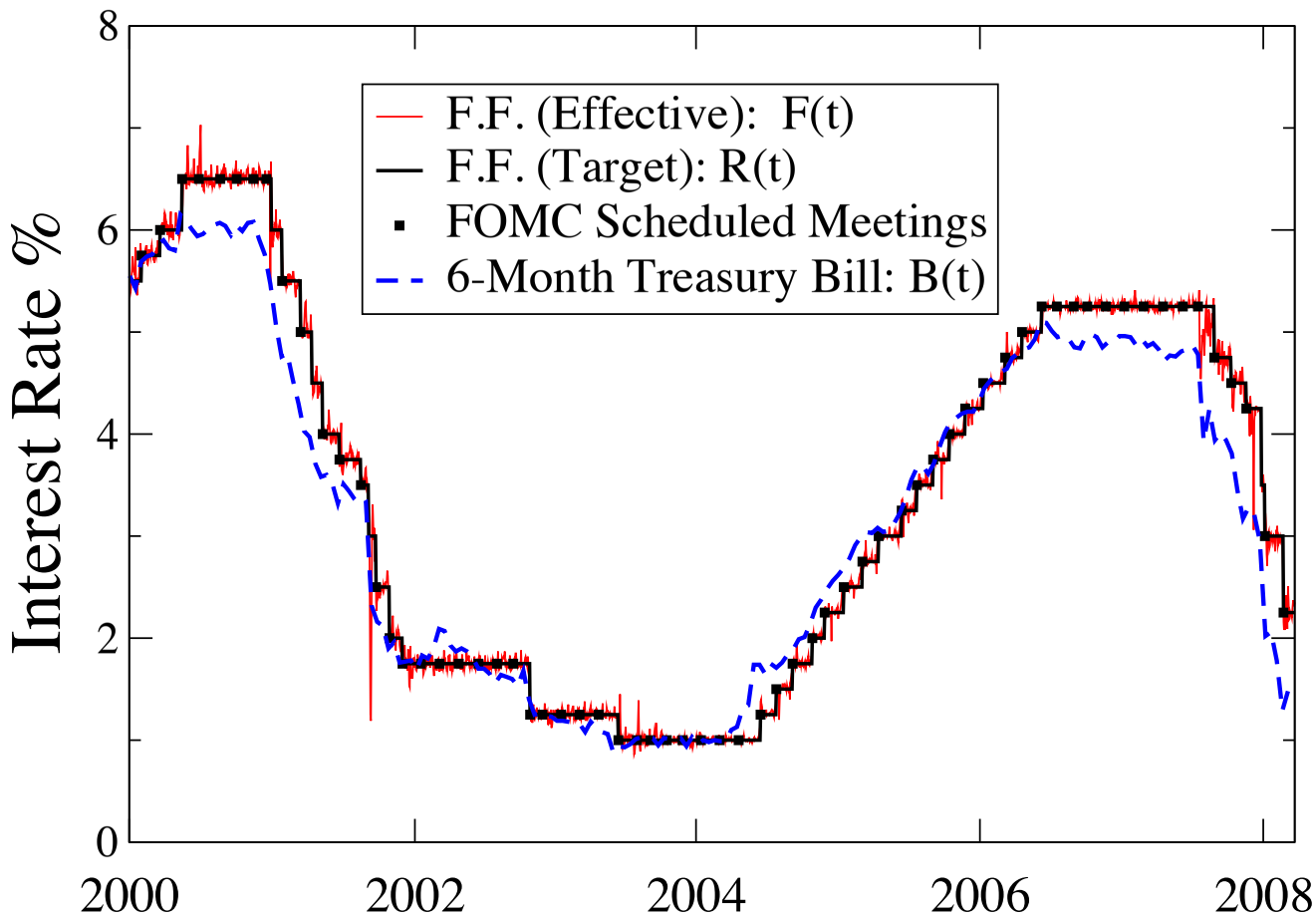
- **U.S. Treasury Bills B(t)**, are a "riskless" security issued by the U.S. Treasury.



The T-Bill anticipates movement in the Target rate

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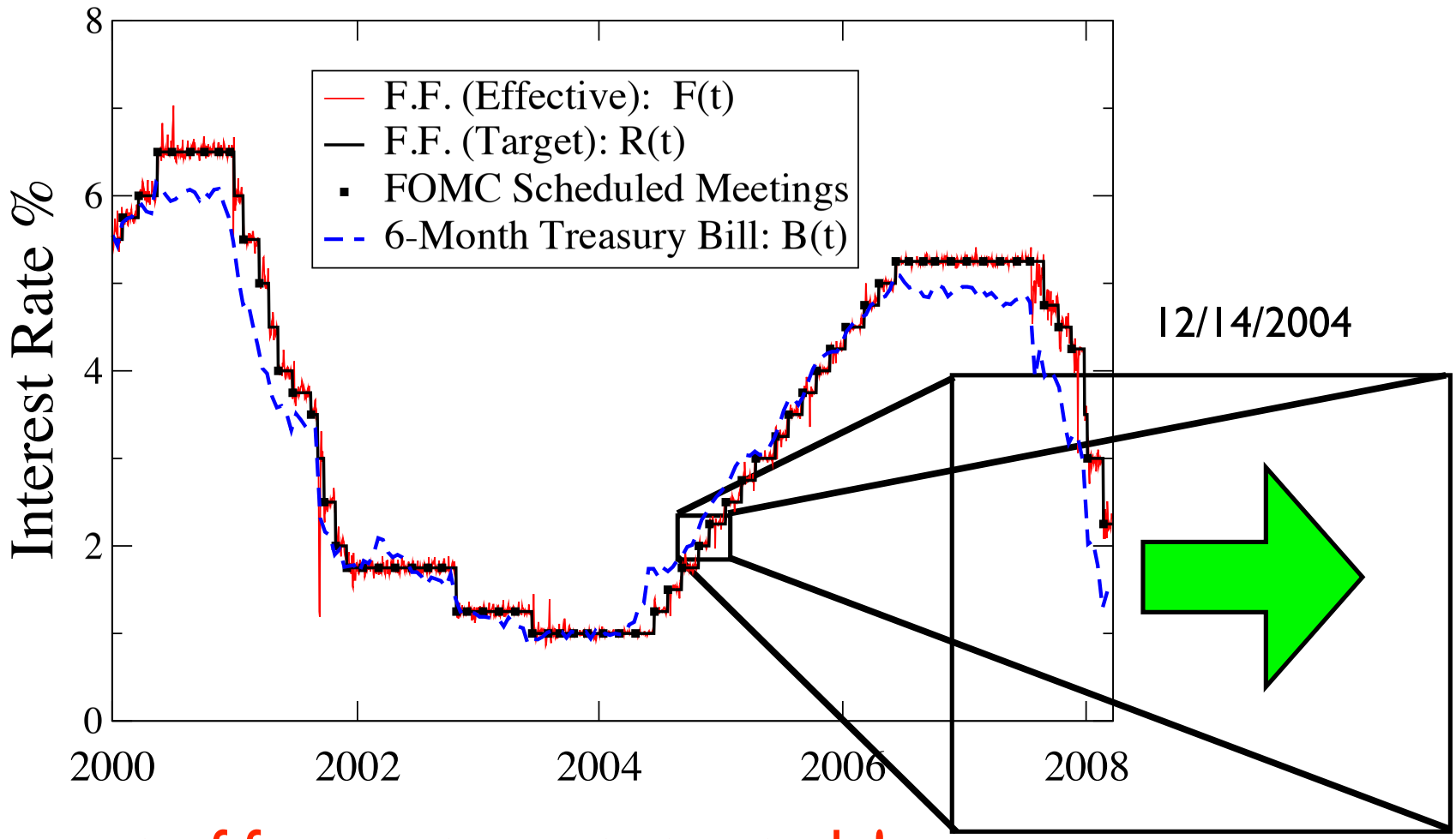
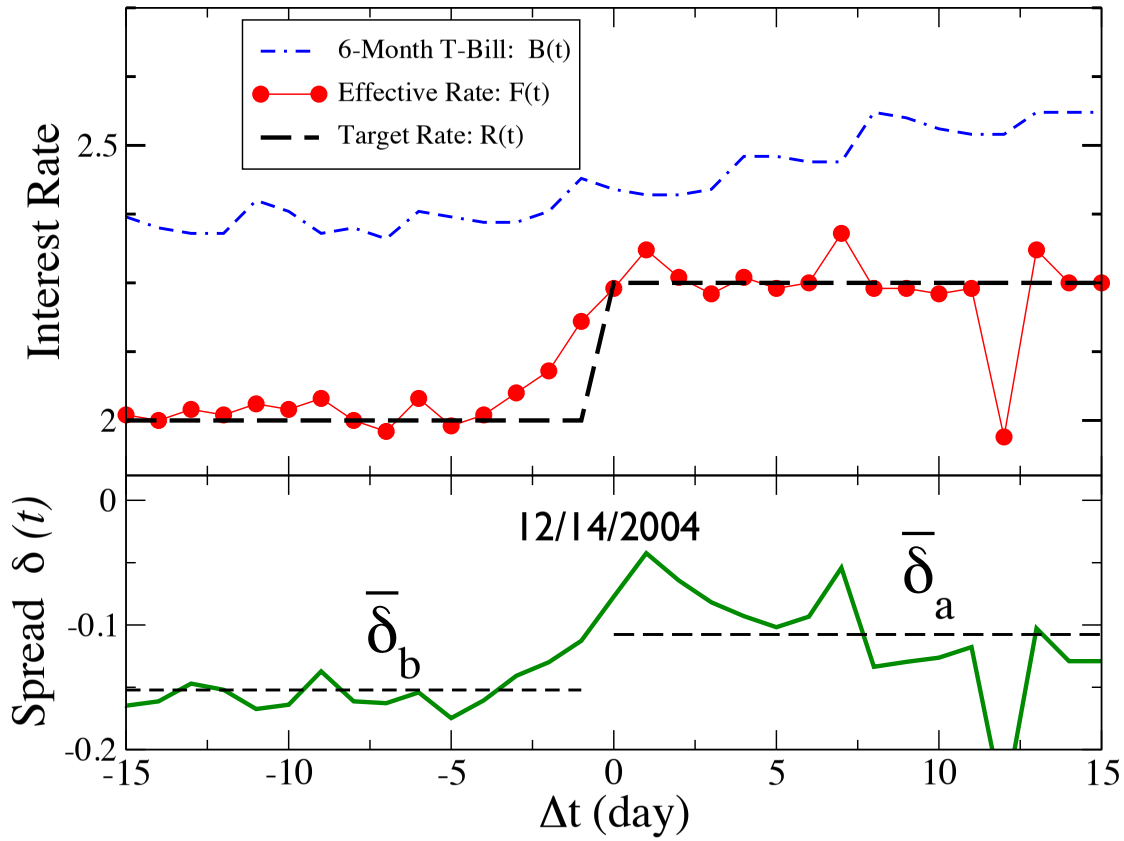


A large set of frequent events to study!

2) Relative Spread between F(t) and B(t)

- The value of the T-Bill **B(t)** is closely linked to the value of the Federal Target rate **R(t)** and Effective rate **F(t)**.
- Market speculation, concerned with whether or not the rate will be changed and by how much, causes anticipation (stress) in the markets prior to the scheduled meeting announcements.



Relative "Spread" δ(t):

$$\delta(t) \equiv \ln F(t) - \ln B(t)$$

"Speculation" :

$$\Theta_i \equiv \overline{\delta(t)}_{i,b}$$

Using F(t) and B(t) we can quantify market speculation

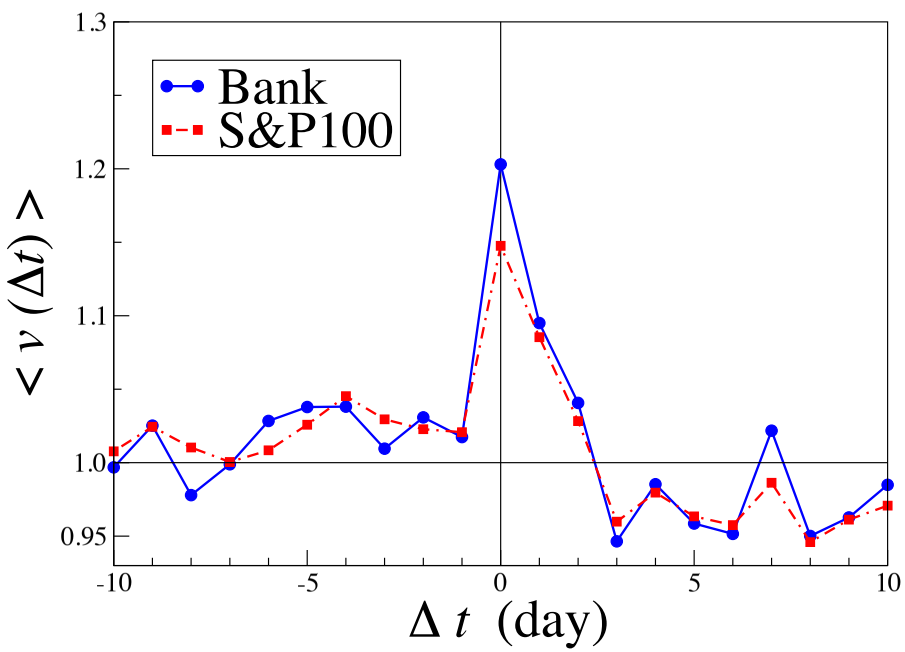
Part 3(a):

- How important
are Fed announcements?

- Can we quantify the speculation
(stress) related to the financial shock?

3) Market volatility around FOMC meetings: daily time scale

- Daily market volatility $v(t) \equiv ln[p_{hi}(t)/p_{low}(t)]$ is the high-low price range within one trading day calculated using daily price data for the top 100 companies in the S&P500
- $\langle v(\Delta t)\rangle = \frac{1}{66}\sum_{i=1}^{66} v_i(\Delta t)$ the average market volatility Δt days before and after a FOMC announcement (66 meetings i analyzed over 8-year period 2000-2008).
- We define FOMC meeting volatility $V_i \equiv v_i(\Delta t = 0)$



~ 15-20 % increase in market volatility!

Significant increase in market volatility on FOMC announcement days

Part 3(b):

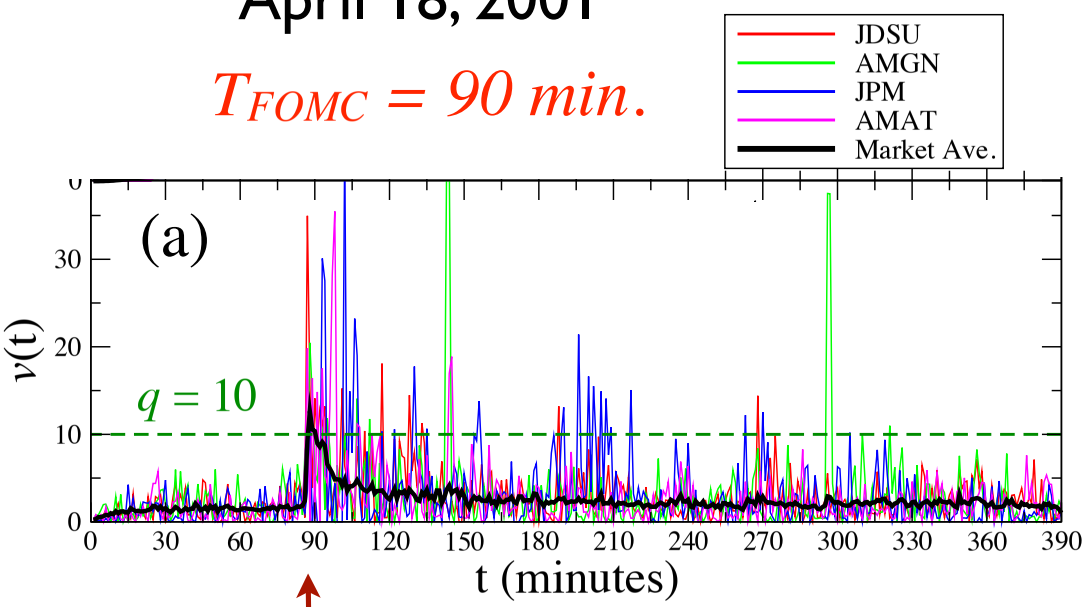
- Response dynamics both after and *before* the time of the Fed announcement

3) Market volatility: intraday time scale

- Data analyzed: TAQ (trades and quotes) for the top 100 companies in the S&P500. We refined data for each transaction into 1-minute time resolution time series for each company, together comprising ~ 20 x 10^6 data values.
- For each company, we calculate the intraday market volatility $v(t)$ in units of the standard deviation σ of the given company, allowing for cross-comparison
- We next study how the rate of events above a volatility threshold $q = 3$ evolves with time, before and after the announcement of the interest-rate change occurring at time T

April 18, 2001

$T_{FOMC} = 90\ min.$



T_{FOMC}

$$v(t|dt) = \left|\ln p(t) - \ln p(t-dt)\right|$$

$$n_q(t|dt) = \frac{1}{dt} \times \begin{cases} 0 & v(t) < q \\ 1 & v(t) \geq q \end{cases}$$

Cascading aftershocks immediately after T_{FOMC}

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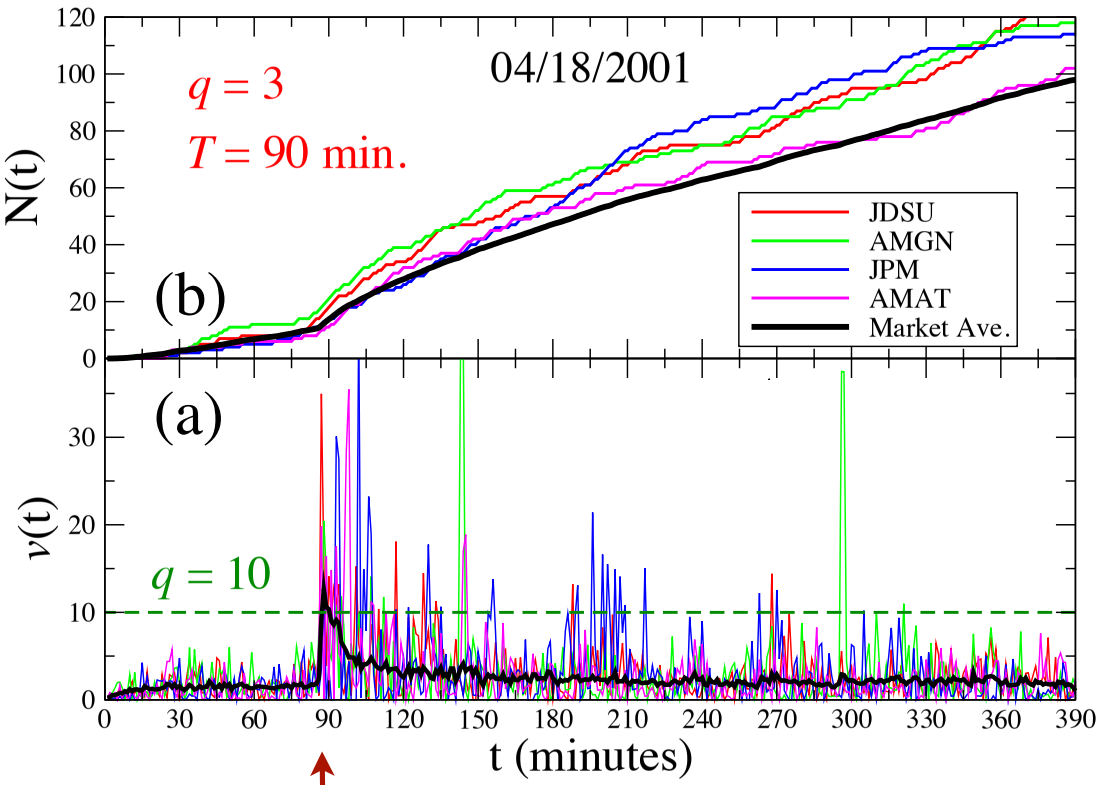


$$N(t) = \int_0^t n(t')dt'$$

T_{FOMC}

Cascading aftershocks immediately after T_{FOMC}

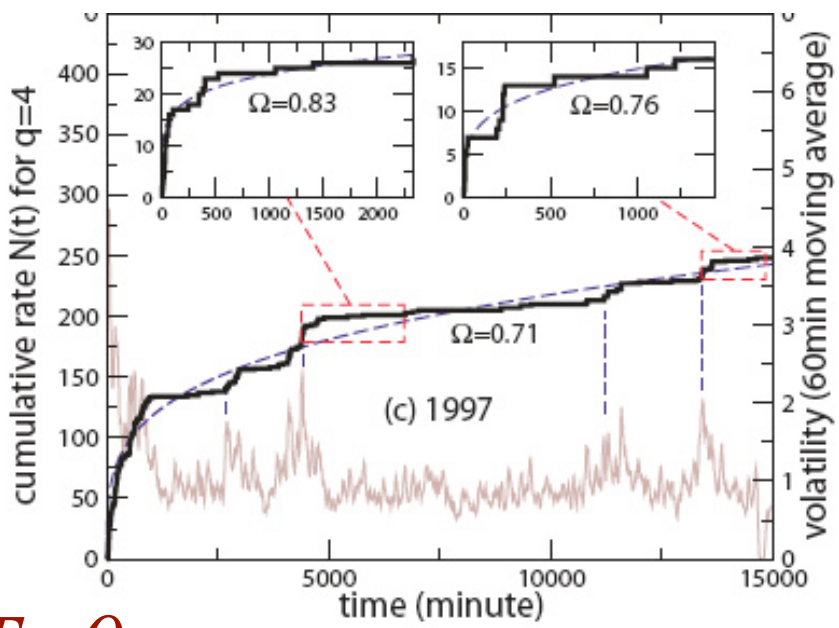
3) The Omori aftershock law predicts the volatility decay pattern after a market crash

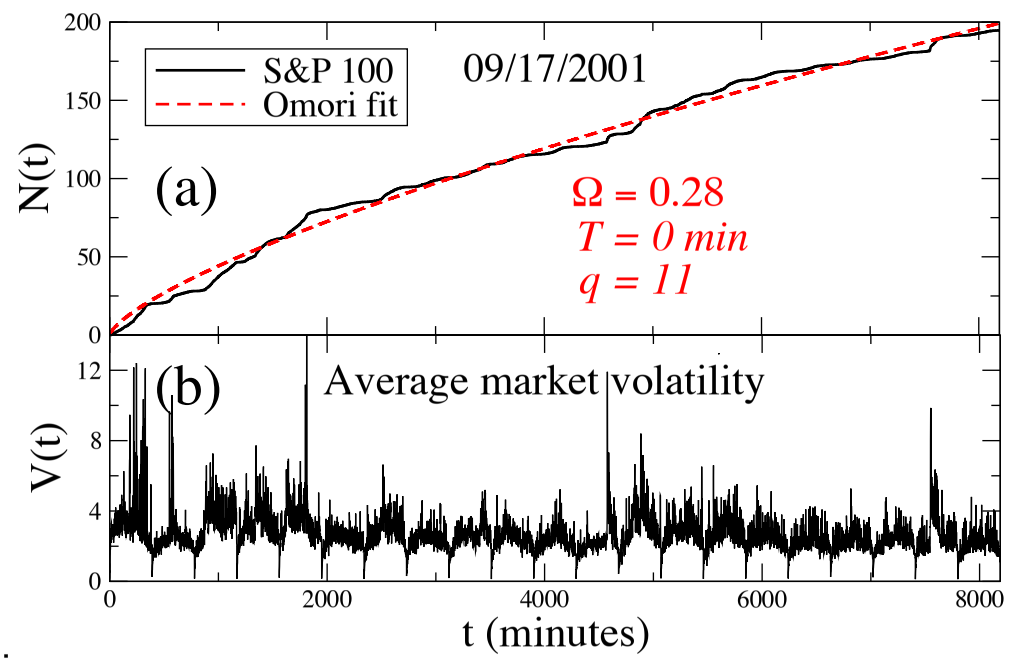
- The Omori law quantifies the rate ***n(t)*** of earthquake aftershocks
- Econophysicists use the Omori law to quantify the decay of volatility aftershocks after market crashes (Lillo & Mantegna, 2003; Weber et al., 2007; Petersen et al., 2010).

Omori Law $$n(|t-T|) \sim \alpha |t-T|^{-\Omega}$$

$$N(|t-T|) = \int_T^t n(|t'-T|)dt' \sim \beta(|t-T|)^{1-\Omega}$$

Omori-law aftershocks occur on all scales

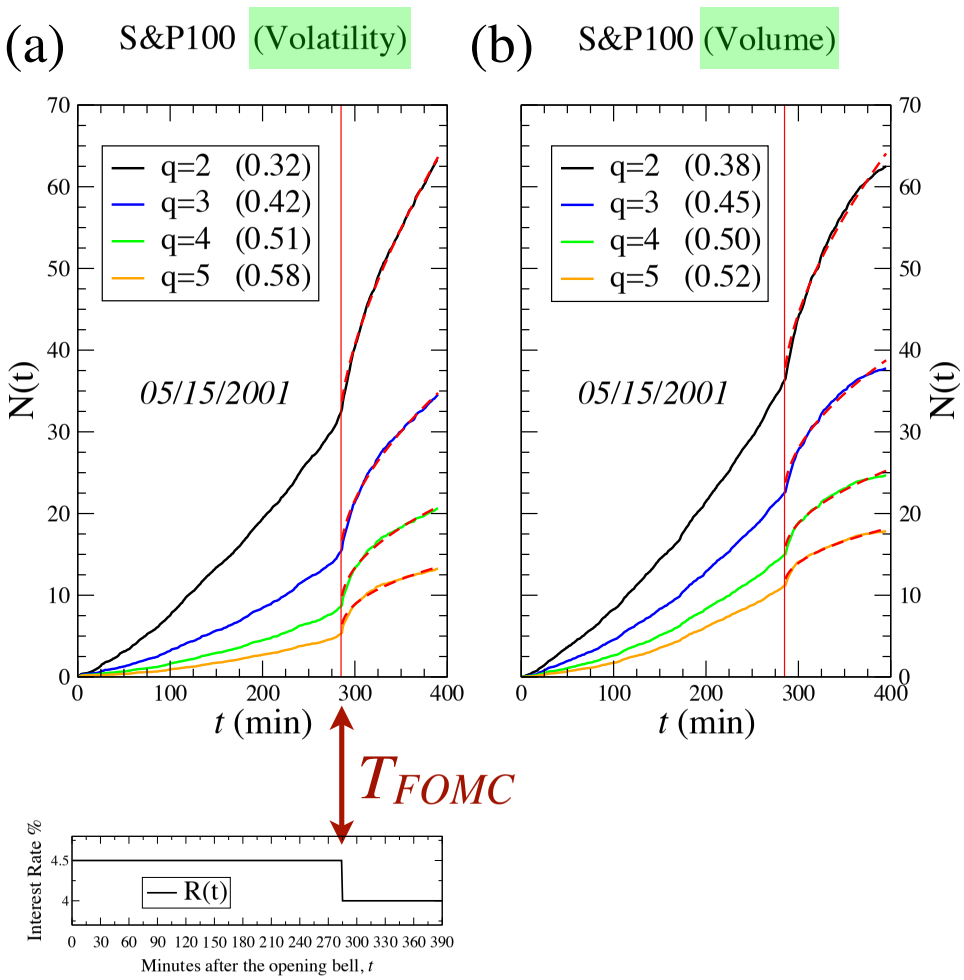




$T=0$ Weber, et al. Phys. Rev. E **76**, 016109 (2007).

3) Omori response to FOMC news

- We find that the Omori law describes the decay of aftershocks in financial markets following FOMC news on the 1-min time resolution for 19 FOMC meetings in the 2-year period 2001-2002.
- Market response is the same for both financial news and financial crises, reminiscent of scale-free behavior found in many complex systems.



T is typically 2:15 pm ET for scheduled meetings! (285 minutes)

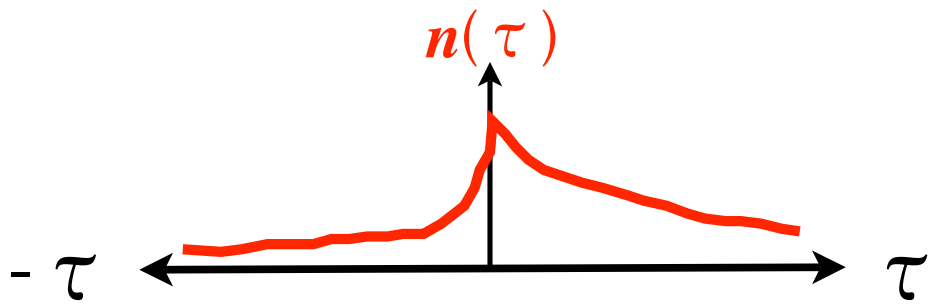
The regularity in the *FOMC* meeting conditions allows us to aggregate and analyze many T_{FOMC} events

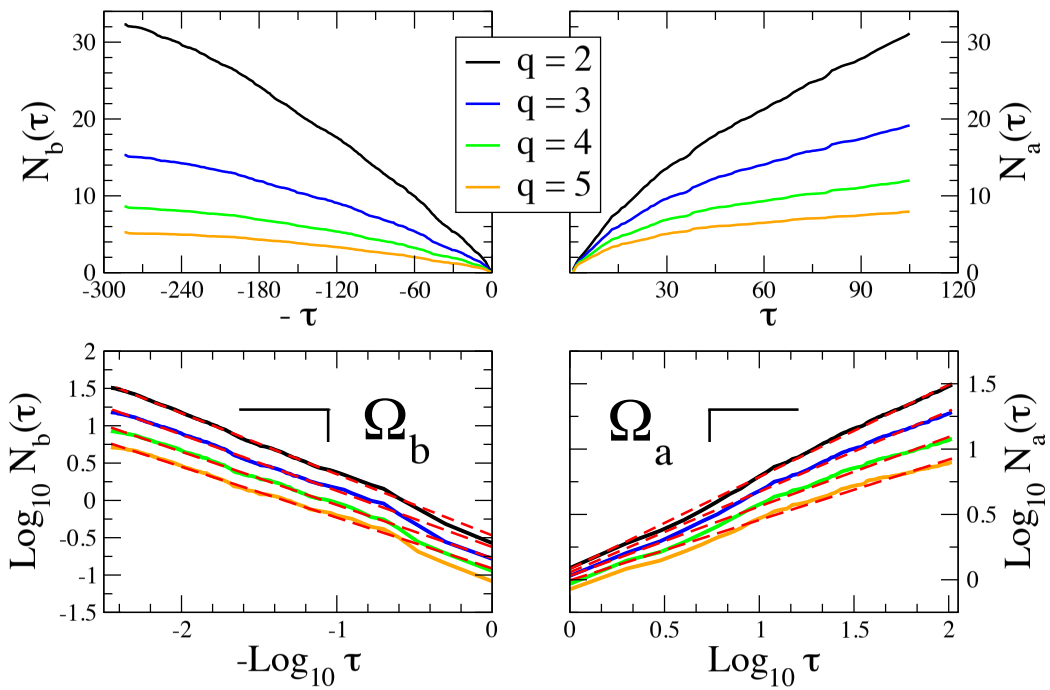
3) 19 FOMC events

- For each FOMC meeting we quantify the market response calculating the Omori amplitude β and the Omori decay exponent Ω
- We analyze both before and after T_{FOMC} using the displaced time $\tau = |t - T|$

285 min. before T

105 min. after T

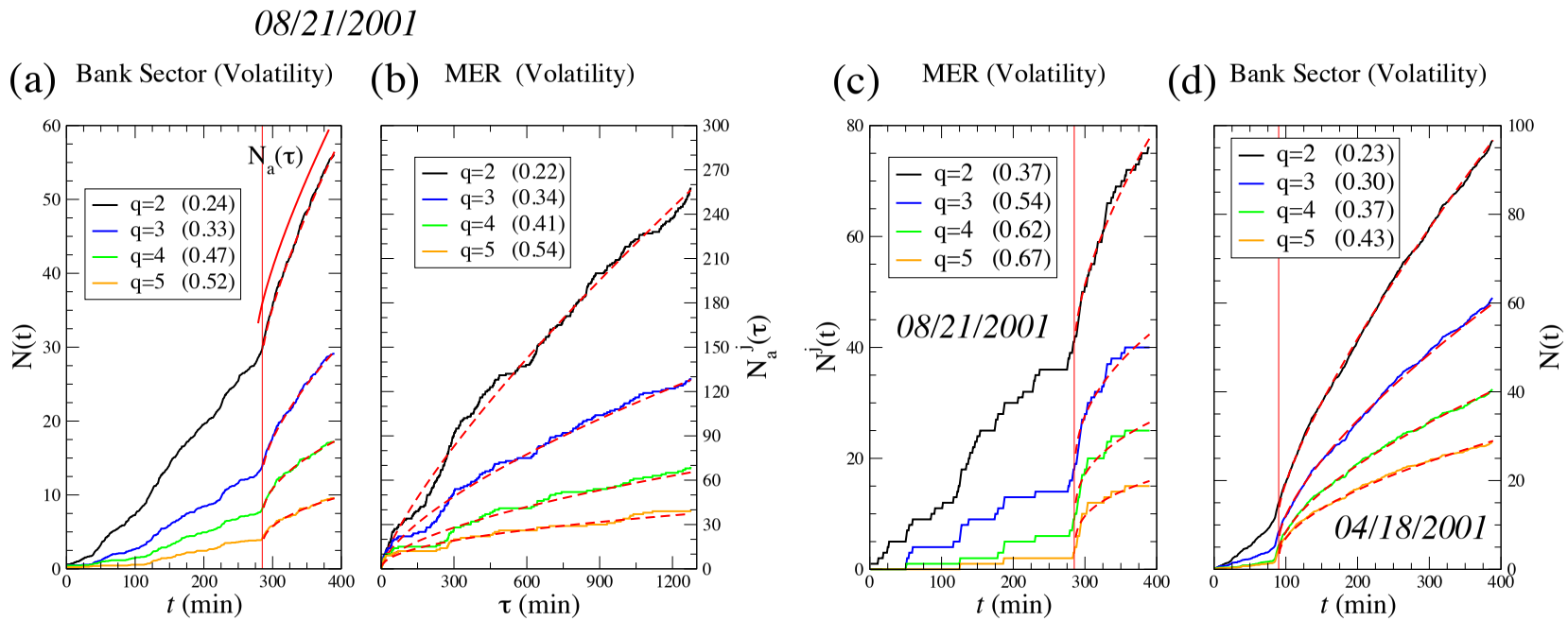




We identify significant precursors that are also described by an "inverse" Omori-law

3) Other examples

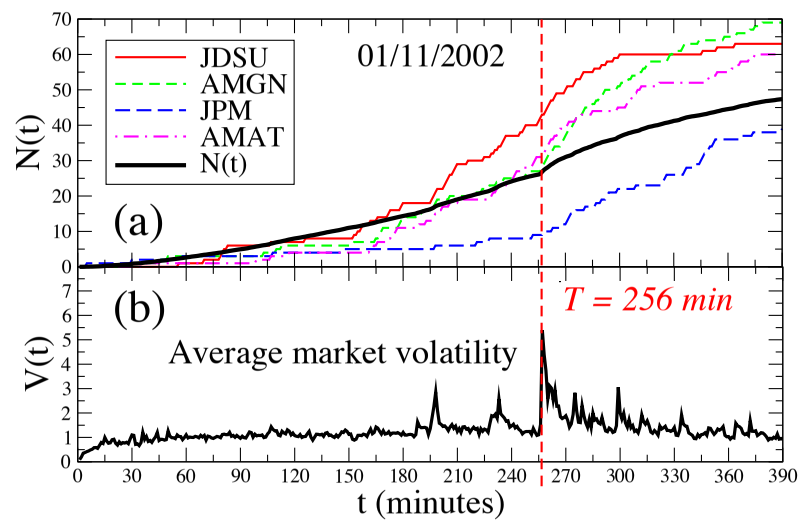
FOMC



Omori-law can extend for several days

Non-FOMC market shock:

Public statement by Fed. Chairman Greenspan about recovery of US economy also triggers cascade!

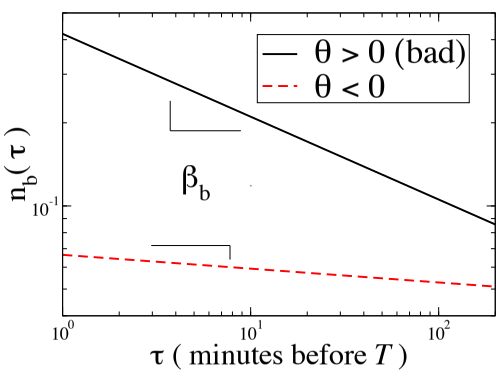


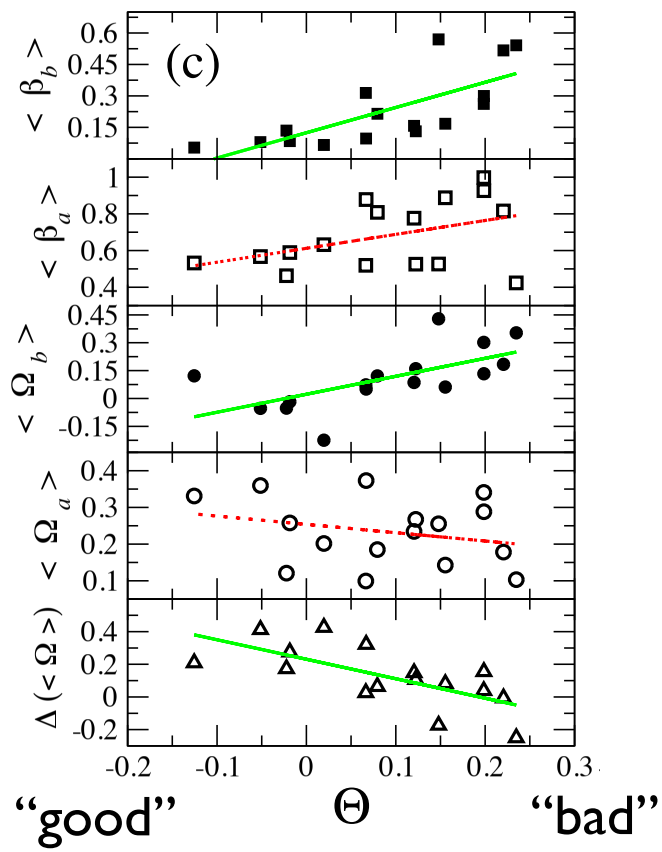
● **A. M. Petersen,** F. Wang, S. Havlin, and H. E. Stanley, Market dynamics immediately before and after financial shocks: quantifying the Omori, productivity, and bath laws. Phys. Rev. E 81, 066121 (2010).

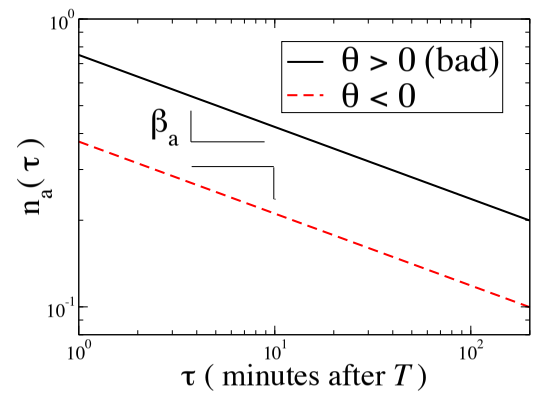
3) Omori response parameters Ω and β

- The Speculation Θ quantifies the market sentiment before the announcement
- In the case of $\Theta > 0$, corresponding to bad market sentiment and a possible rate decrease, the dynamics before and after the announcement have large amplitude β. A smaller decay exponent Ω represents a longer aftershock response-time Δt

Bank Sector: 18 financial companies







Omori parameter values are also consistent with the Sign Effect

Summary & Take Home Message

- Omori law (power-law) describes the decay of aftershocks in financial markets following FOMC news (global perturbation) → market cascades that can last for up to 3 days after T for banking companies
- Possibility that there is a universal underlying mechanism (e.g. non-linear shot noise) which governs cascading dynamics in financial markets for a large range of market shock size **A. M. Petersen,** F. Wang, S. Havlin, and H. E. Stanley, Market dynamics immediately before and after financial shocks: quantifying the Omori, productivity, and bath laws. Phys. Rev. E 81, 066121 (2010).
- The response of the stock market is the same for both financial news and financial crises, reminiscent of scale-free behavior found in many complex systems.
- The Omori exponent $\langle \Omega_a \rangle$ is related to the amount of market "surprise": Bigger surprise → longer time for market to adjust
- A better understanding of response dynamics in financial markets can help prepare emergency plans for financial crises

Thank You!

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Title: *Quantitative law describing market dynamics before and after interest-rate change*

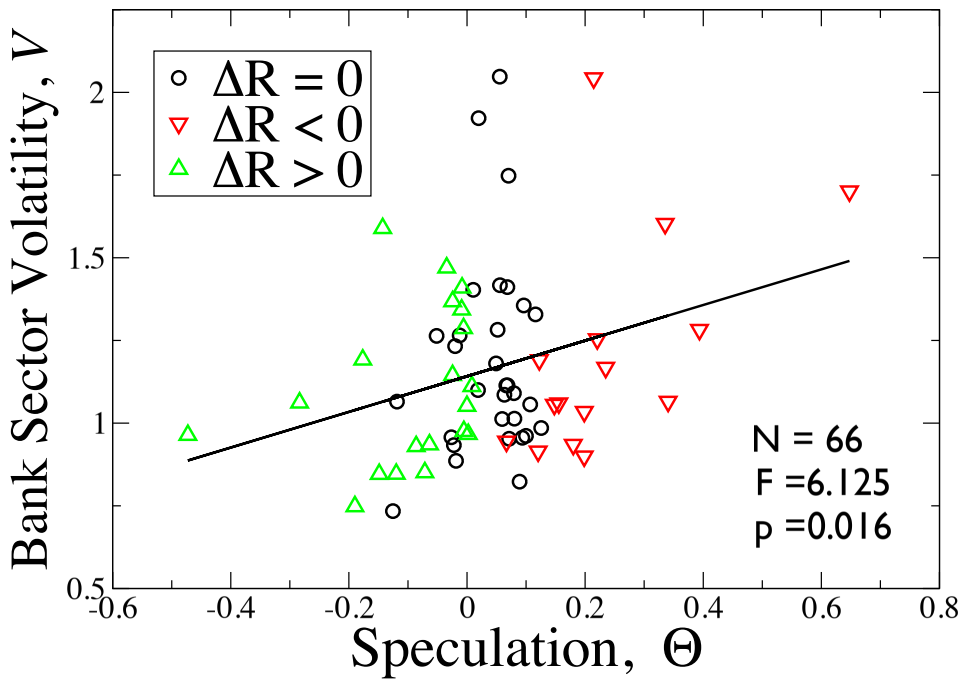
Abstract:

Information flows through various technological avenues, keeping the ever-changing world up-to-date. All news carries some degree of surprise, where the perceived magnitude of the news certainly depends on the recipient. In financial markets, where speculation on investment returns results annually in billions of dollars in transactions, news plays a significant role in perturbing the complex financial system both on large and small scales.

In this talk I will discuss the behavior of U.S. markets both before and after a large number of financial shocks. As a first case study, I will present the market response to U.S. Federal Open Market Committee (FOMC) meetings, and show that the announcement of a U.S. Federal Reserve rate change causes a financial shock, where the dynamics after the announcement is described by an analogue of the Omori earthquake law. This is the first study to quantitatively relate the size of the market response to the news which caused the shock and to uncover the presence of quantifiable preshocks. We demonstrate that the news associated with interest rate change is responsible for causing both the anticipation before the announcement and the surprise after the announcement. We estimate the magnitude of financial news using the relative difference between the U. S. Treasury Bill and the Federal Funds Effective rate. Our results are consistent with the "sign effect," in which "bad news" has a larger impact than "good news." Furthermore, we observe significant volatility aftershocks, confirming a "market underreaction" that lasts at least 1 trading day.

3) the Sign Effect: Asymmetric response to "bad" and "good" news

- **Sign Effect** = market volatility is larger in response to "bad news" as compared to "good news." Rate decreases (ΔR < 0), which encourage borrowing and increase money liquidity, typically correspond to bad news.
- Θ : quantifies the "speculation" over a rate change in the week before the FOMC meeting
- FOMC meeting volatility $V_i \equiv v_i(\Delta t = 0)$



Relative "Spread" δ(t):

$$\delta(t) \equiv \ln F(t) - \ln B(t)$$

"Speculation" :

$$\Theta_i \equiv \overline{\delta(t)}_{i,b}$$

Markets are more volatile when anticipating rate decrease (ΔR < 0)

2) Federal Interest Rates

- Federal Interest rates set a benchmark for banks in their day-to-day borrowing and lending activities. The Fed rates serve as both a benchmark and a barometer for the U.S. and global economies.

- The **Federal Target interest-rate R(t)**, is set by the U.S. Federal Reserve (Fed) at Federal Open Market Committee (FOMC) meetings. These meetings are scheduled in advance and announced publicly. Historically, there have been around 8 scheduled FOMC meetings per year.

- The **Federal Effective interest-rate F(t)**, ("overnight rate") is an open market realization of the Target rate. **F(t)** is a weighted average over all lending transactions each day, and oscillates around the **R(t)**.

- The **U.S. Treasury Bill B(t)**, is a type of security issued by the U.S. Treasury. The ``T-Bill" comes in several versions, distinguished by their maturity length (here we consider only the 6-Month T-Bill). These securities are very risk free, as they are backed by the U.S. government.