Quantitative laws describing market dynamics before and after interest-rate change and other financial shocks

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- **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).
- **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).
- Inside Science media coverage: http://www.insidescience.org/current_affairs/http_www_insidescience_org_current_affairs_1_1596

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

Outline

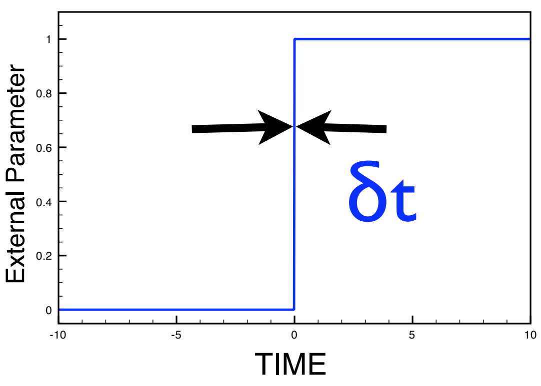
1. What kind of perturbations occur in the stock market?
2. Case study: Federal Interest Rate change announcements
3. Response dynamics *before* in addition to after market shocks
4. Can we relate the response dynamics to the magnitude of the financial shock?

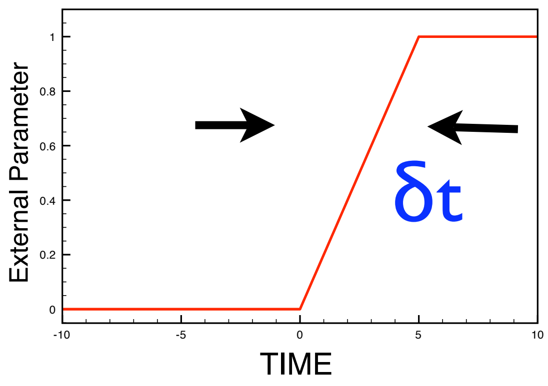
Part 1:

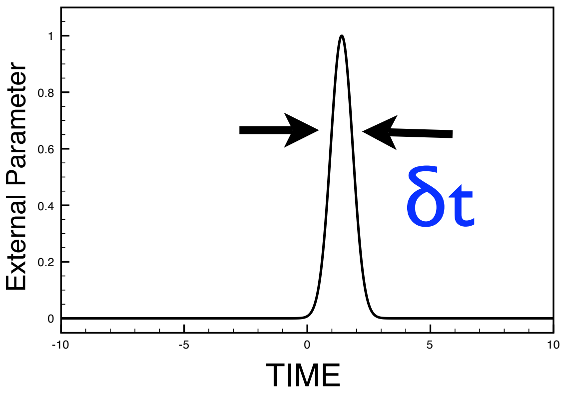
Perturbations that can cause financial shocks

1) Perturbations

- A change in an external control parameter that takes the system out of "equilibrium"
- The change takes place over time-interval δt
- The response time Δt (return-to-equilibrium time) can characterize the system as:
    - a simple combination of system elements
    - a complex combination of system elements







1) 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)

1) Qualitative example of cascading price formation... $60 *Nook* price cut→ $70 *Kindle* price cut

Forbes.com

U.S. EUROPE ASIA

Today In Tech

The Economics Of Kindle

Lee Gomes, 06.24.10, 07:43 PM EDT

SAN FRANCISCO -- When Amazon cut the price of its Kindle e-reader this week from $259 to $189, it marked the latest move in the transformation of a 21st-century industry--technology--to one resembling a 19th-century one--safety razors.

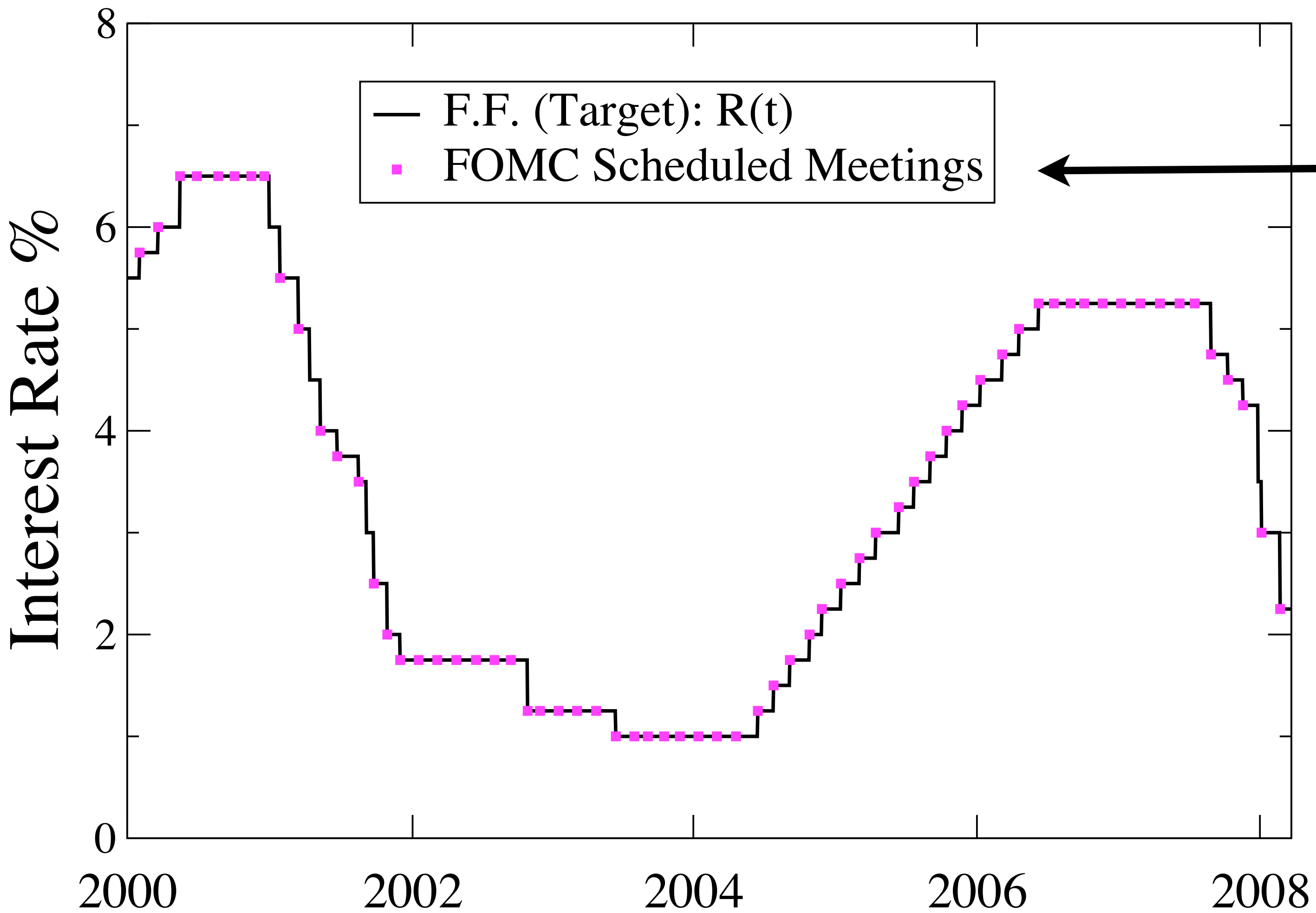
Amazon's price cut came a day after **Barnes & Noble** (BKS - news - people) cut $60 from the price of its Nook e-reader, which now can be had for $139. Analysts said both moves were a response to the apparent popularity of **Apple**'s (AAPL - news - people) new iPad, which has its own book reading software built in.

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.

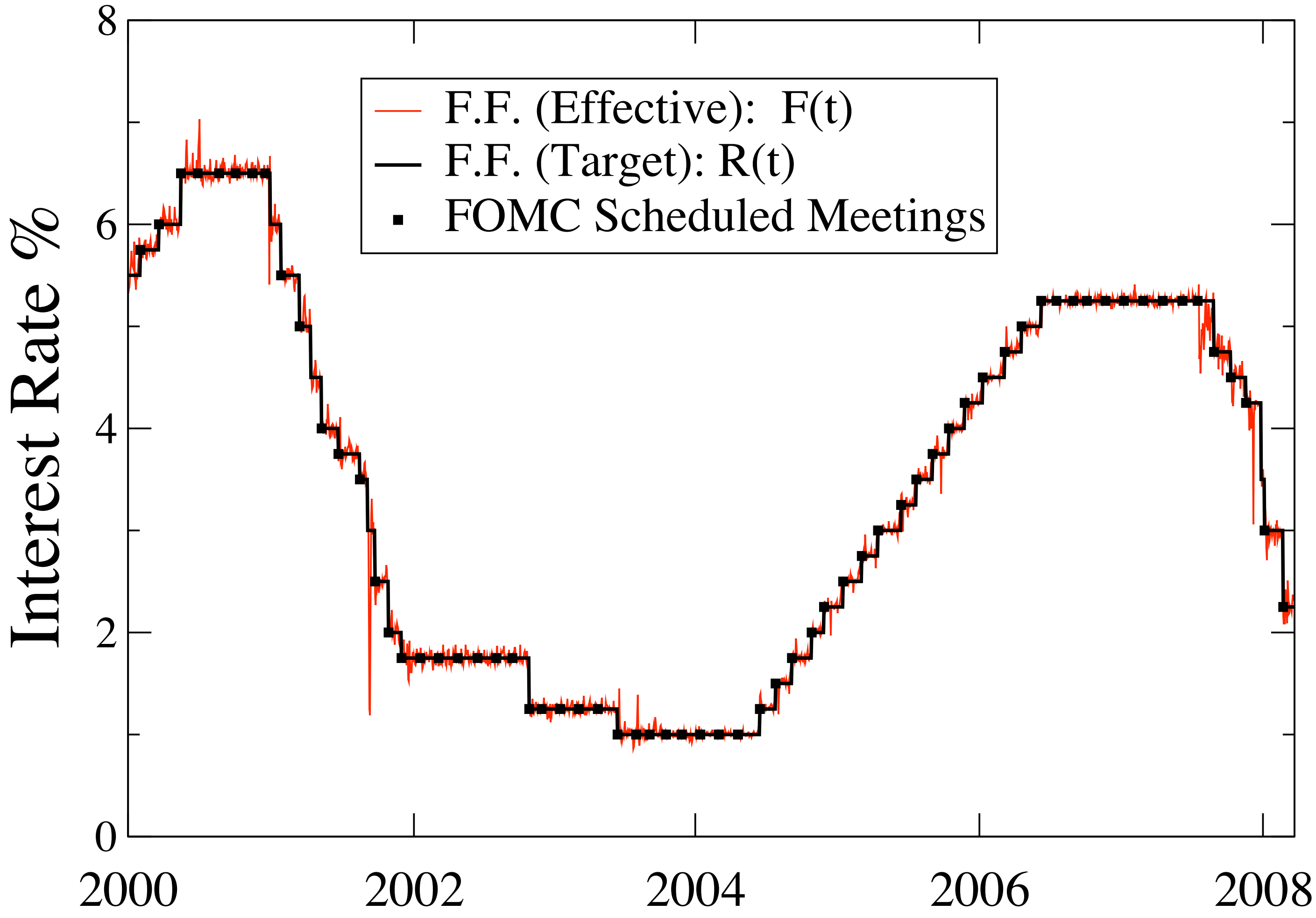


66 FOMC meetings!

Interest rates change by "step function" @ FOMC meetings

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 ■).
- 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

2) Federal Interest Rates (set benchmarks for banks)

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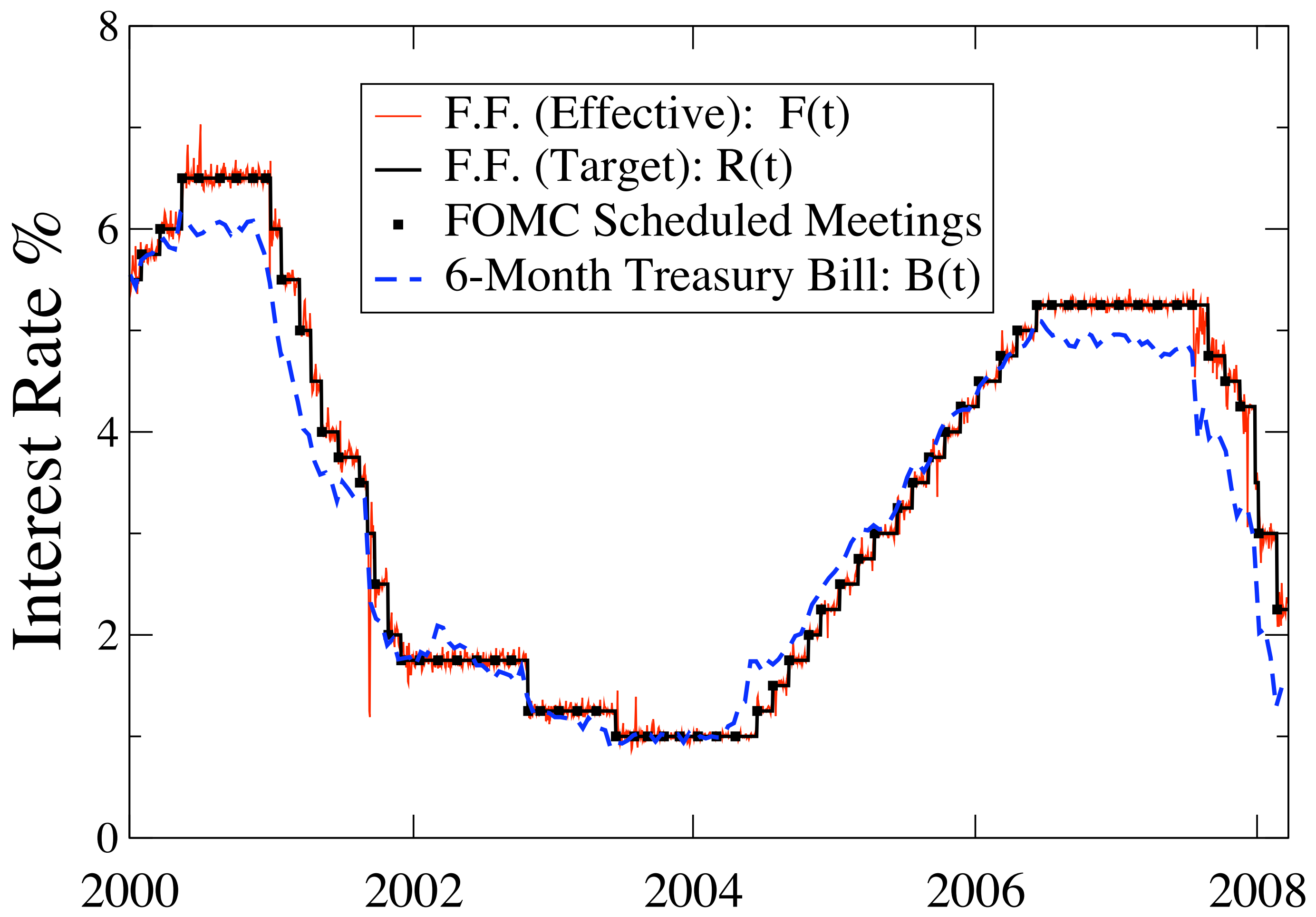
- The **Federal Interest Effective rate F(t)**, ("overnight rate") is an open market realization of the Target rate.
- **U.S. Treasury Bills B(t)**, are a "riskless" security issued by the U.S. Treasury.



The T-Bill anticipates movement in the Target rate

2) Federal Interest Rates (set benchmarks for banks)

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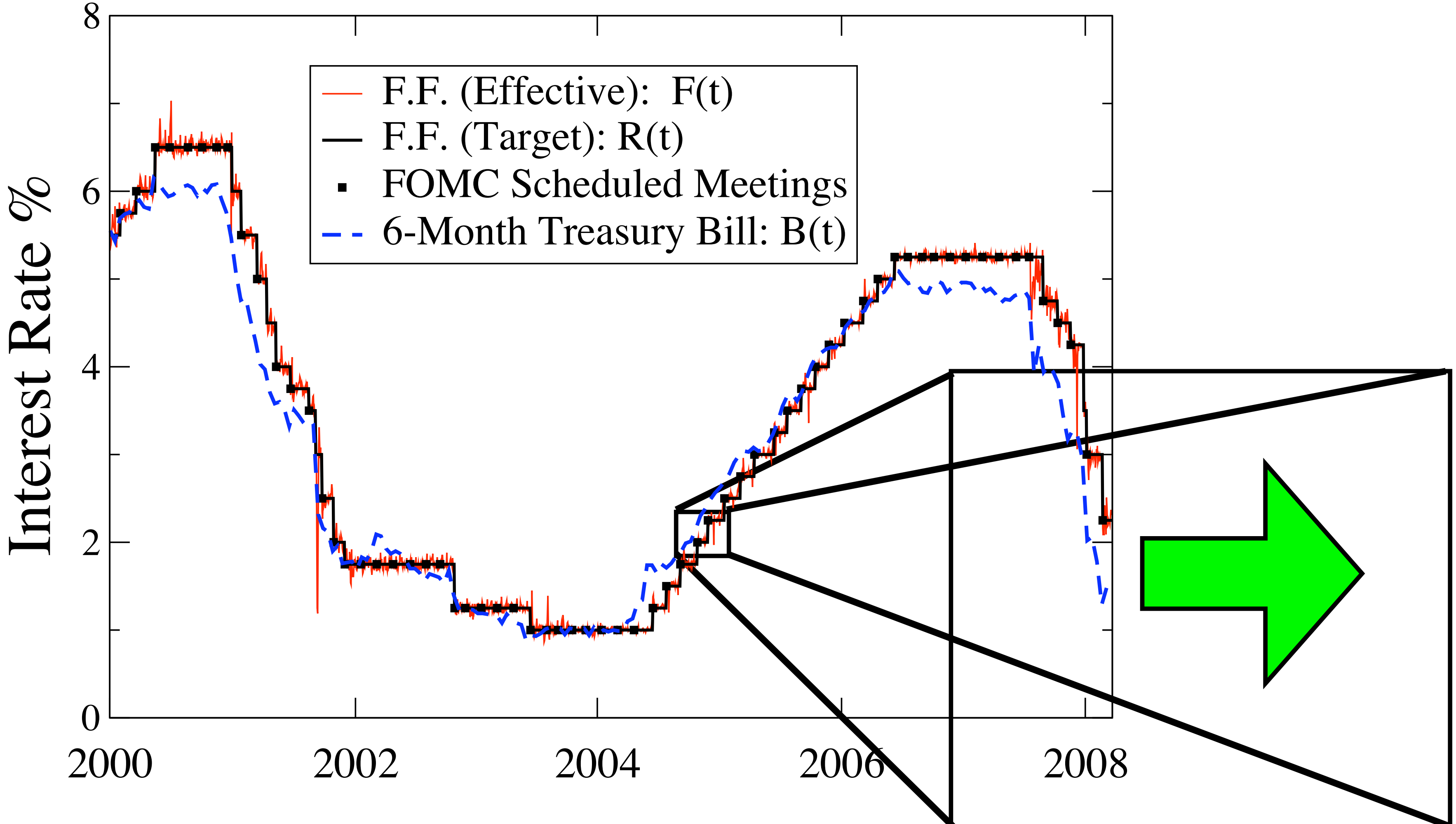
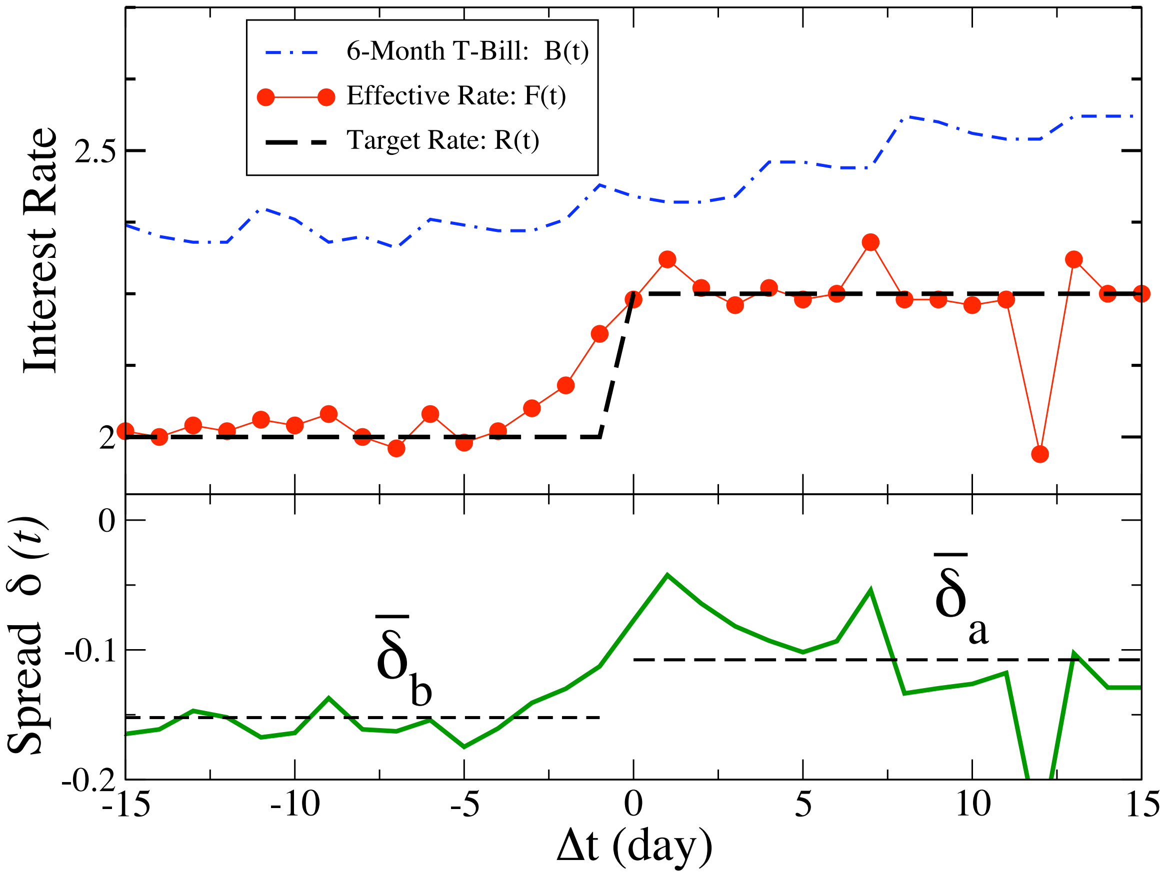


A large set of frequent events to study!

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.



12/14/2004

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

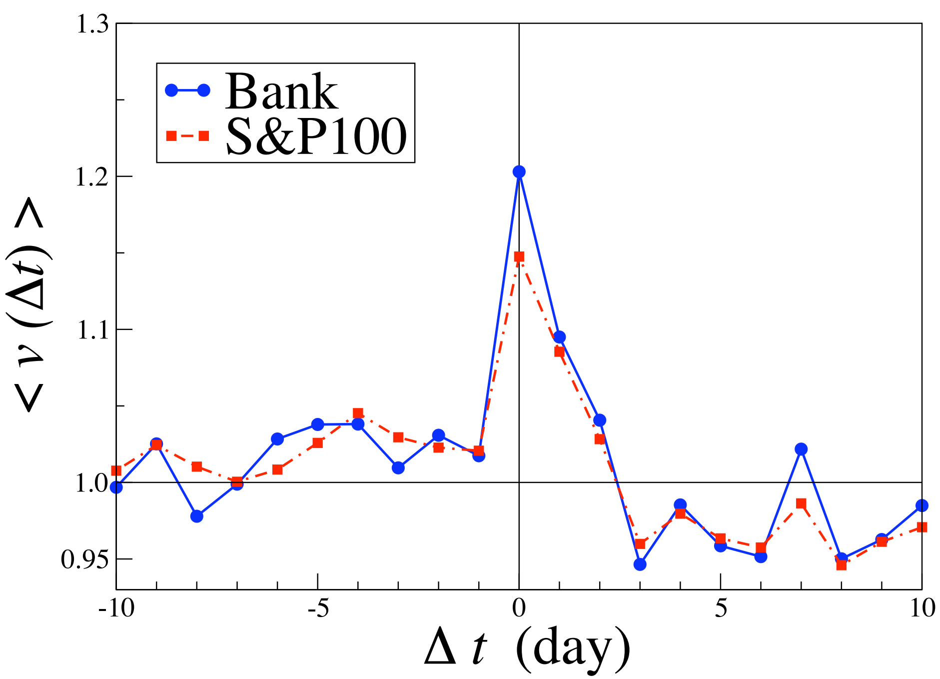
Part 3(a):

- 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 $V_i \equiv v_i(\Delta t = 0)$

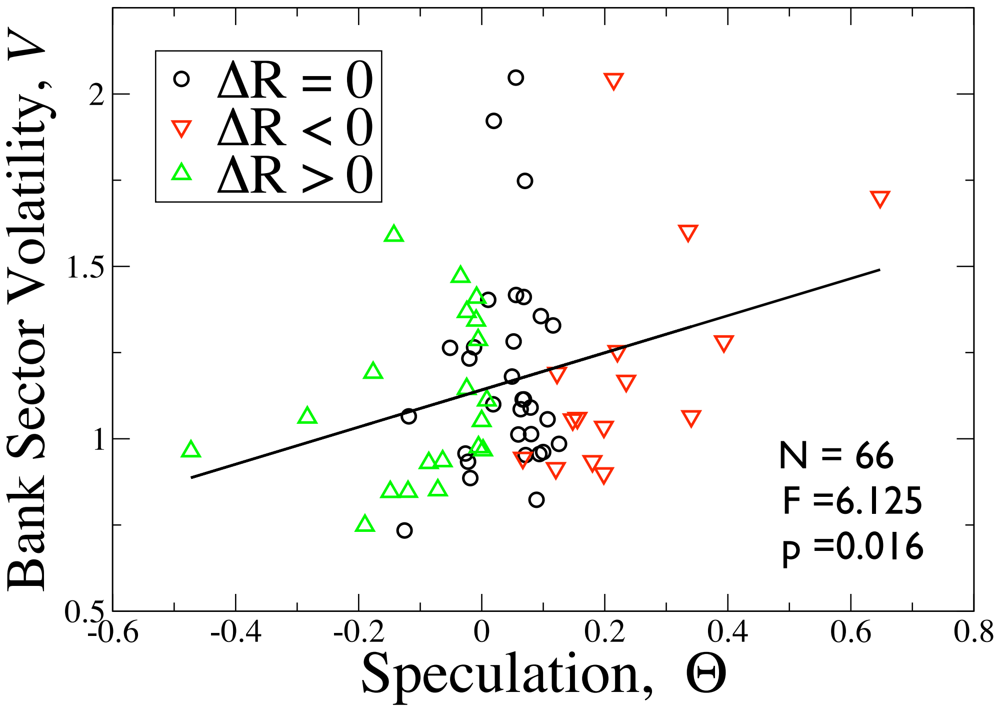


~ 20 % increase in market volatility!

Significant increase in market volatility on FOMC announcement days

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 ($\Delta R < 0$), 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" $\delta(t)$:

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

"Speculation" :

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

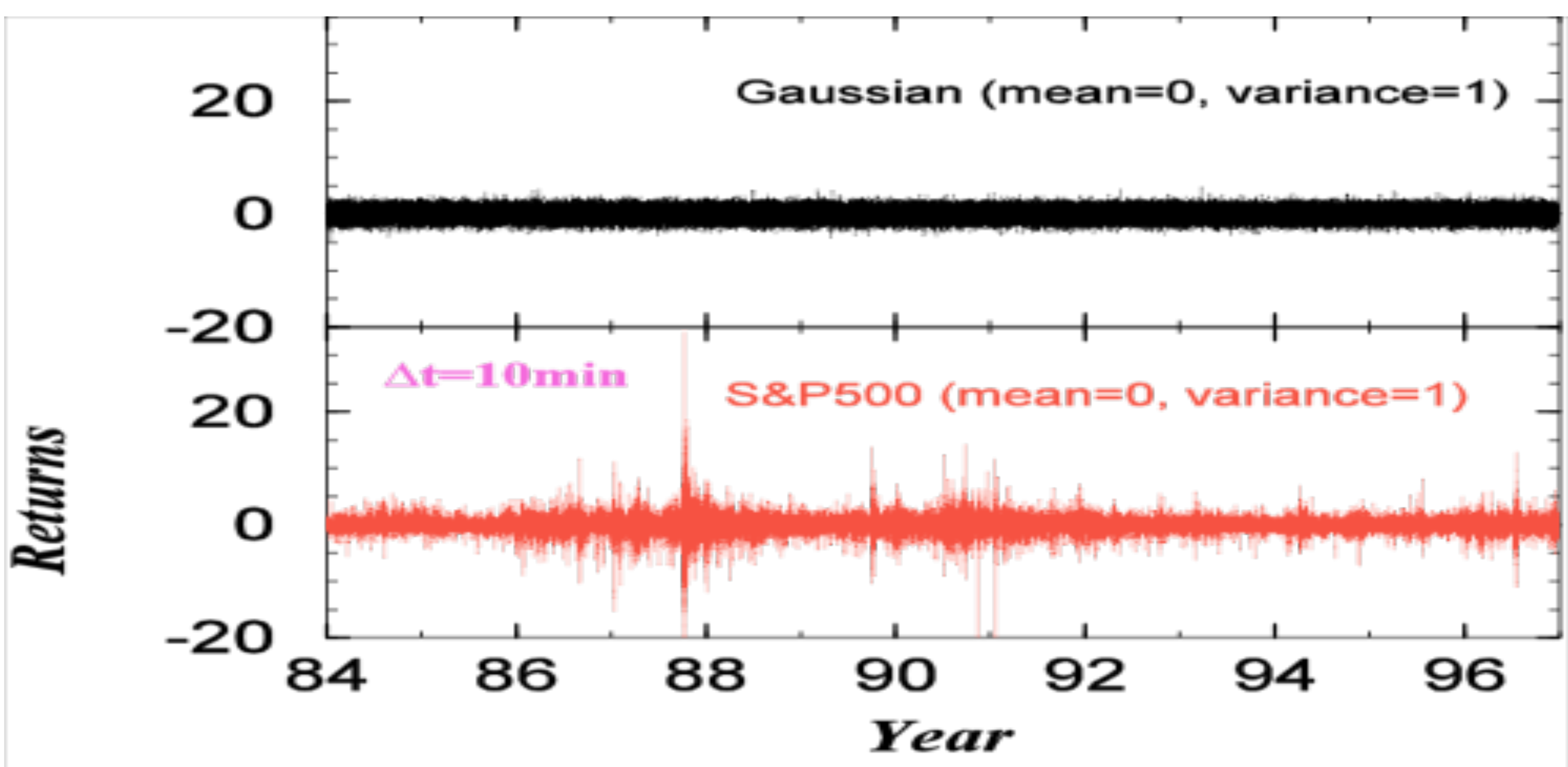
Markets are more volatile when anticipating rate decrease ($\Delta R < 0$)

Part 3(b):

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

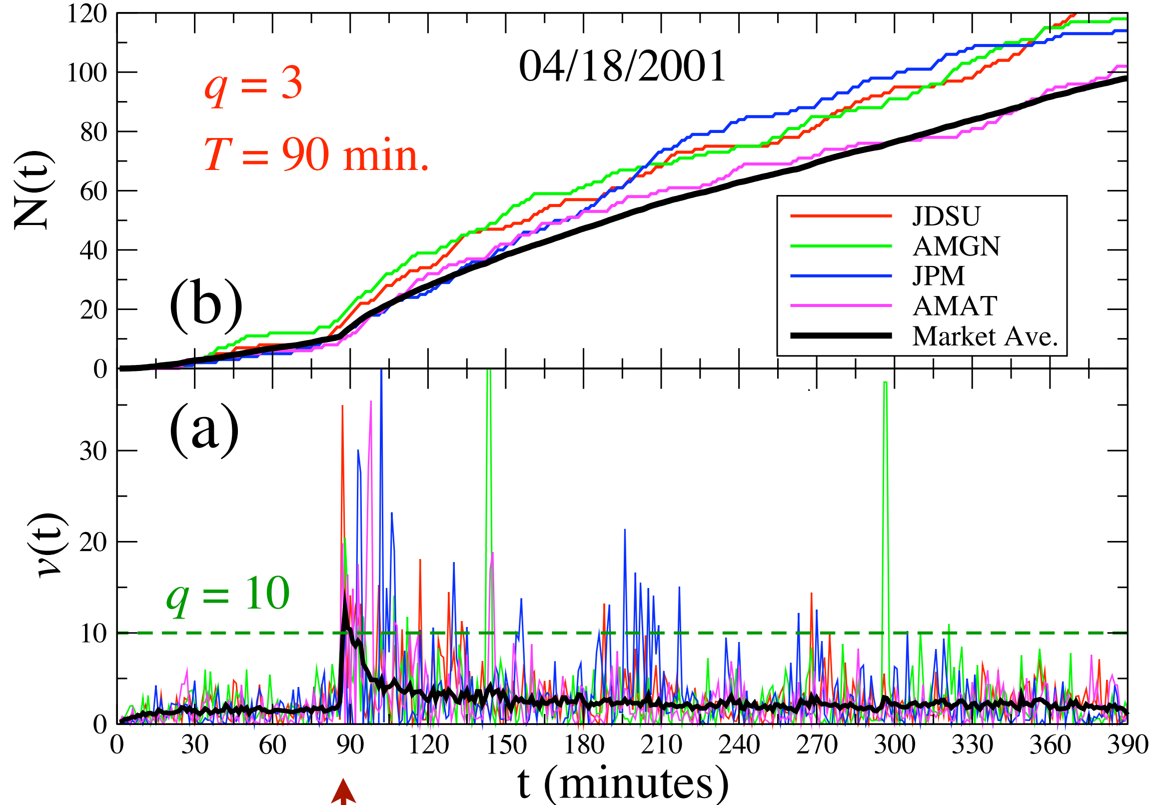
3) Stylized facts for Market volatility at the intraday time scale

- "**Fat tails**": Inverse-cubic power law quantifies frequency of price returns (fluctuations), which are far from Gaussian! (Mantegna, Gopikrishnan, Plerou, Gabaix, Stanley)
- **Long-term memory**: significant volatility autocorrelation for ~ several months (Liu, Gopikrishnan, Wang, Stanley)
- **Significant cross-correlations** between stocks: (Mantegna, Plerou, Bouchaud, Stanley)



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 $q \equiv 3$ evolves with time, before and after the announcement of the interest-rate change occurring at time T



T_{FOMC}

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

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

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

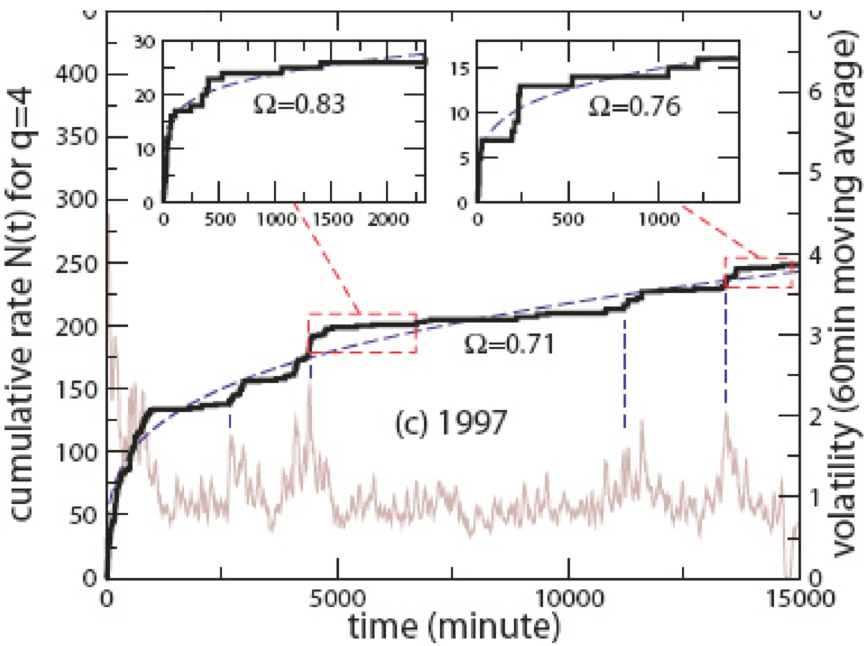
Cascading aftershocks immediately after T_{FOMC}

3) Omori aftershock law

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

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



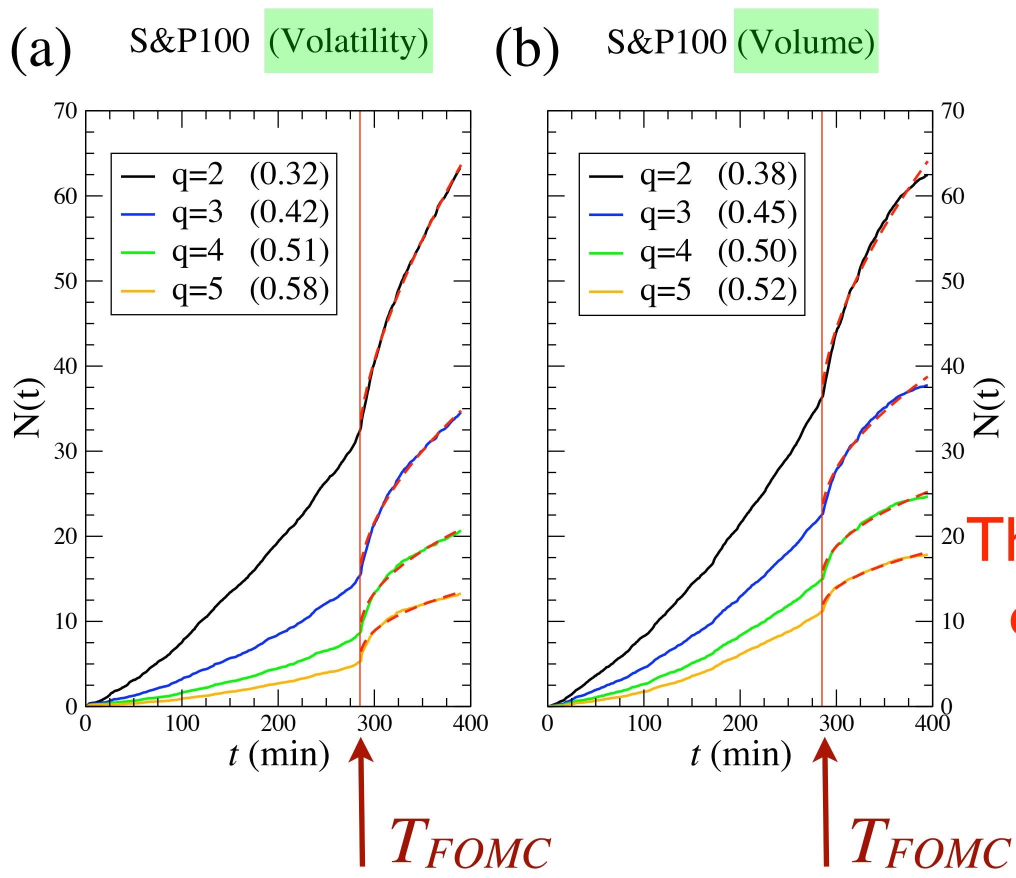
Omori-law aftershocks occur on all scales

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.

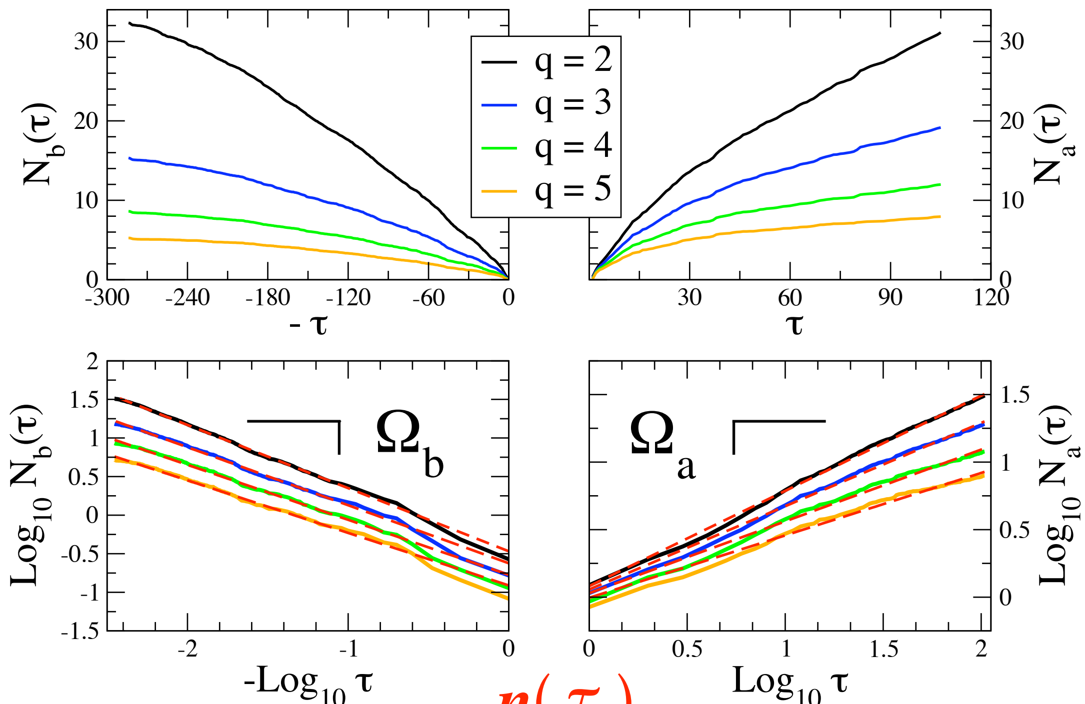


T is typically 2:15 pm ET for scheduled meetings!

The regularity in the FOMC meeting conditions allows for comparison

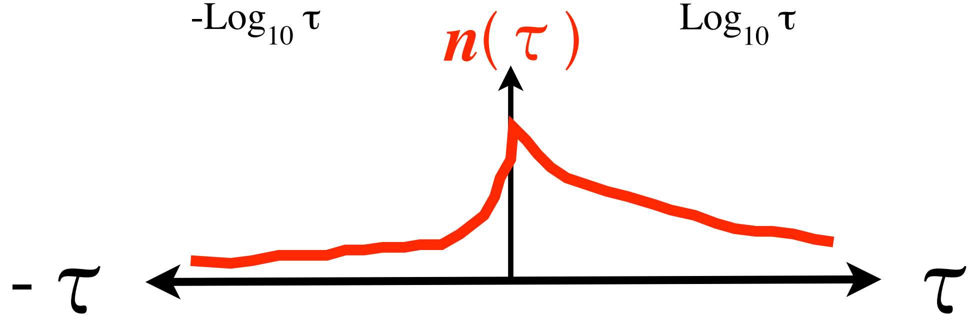
3) 19 FOMC events

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



285 min. before T

105 min. after T

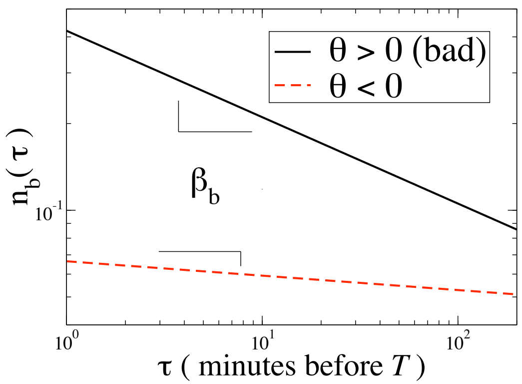


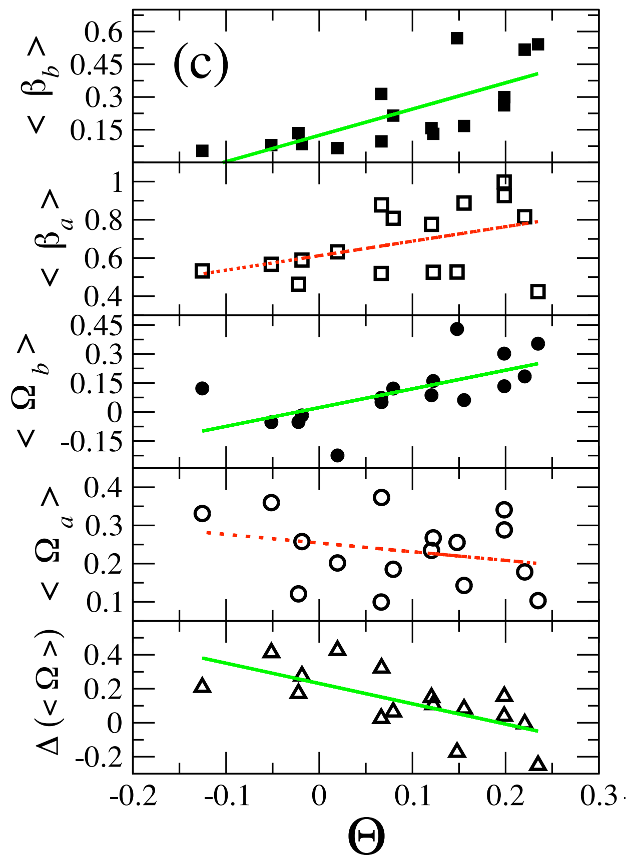
We identify significant precursors that are also described by an "inverse" Omori-law

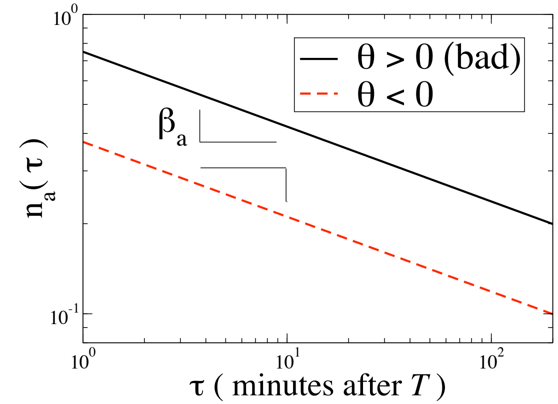
3) Omori response parameters Ω and β

- The Speculation ***Θ*** quantifies the market sentiment before the announcement
- In the case of ***Θ > 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

Part 4:

Can we relate the response dynamics to the "magnitude" M of the financial shock?

4) Market dynamics immediately before and after more common financial shocks...

- Fed announcements are just one type of market perturbation
- For many news events, it is difficult to know the exact time T_c of the news, so we develop method which uses a statistical criteria to find financial shocks of large magnitude $M \equiv log_{10} V(T_c)$ and analyze 219 financial shocks of varying size in :

  A. M. Petersen, F. Wang, S. Havlin, and H. E. Stanley, PRE **82**, 036114 (2010)

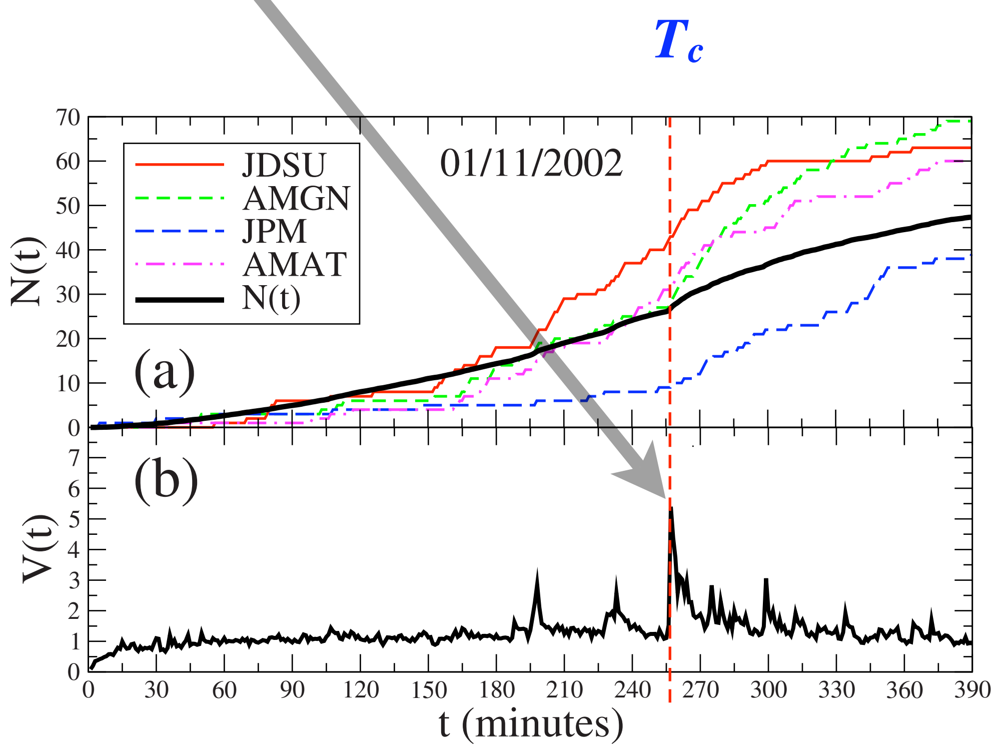
3 Questions:

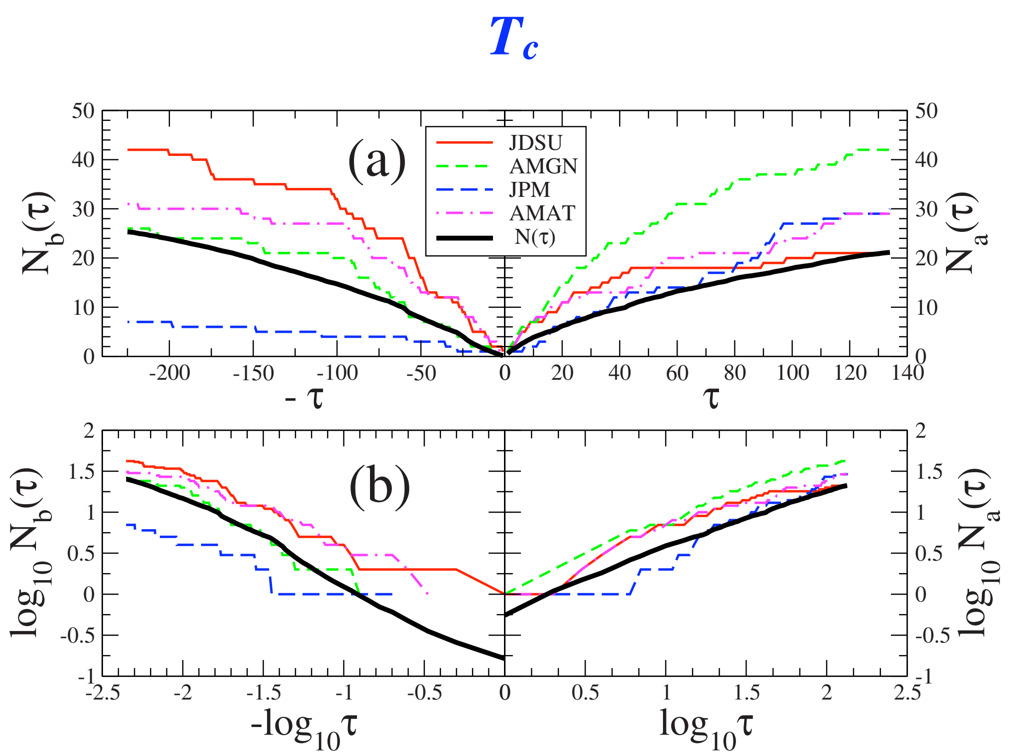
- **Omori law**: how does the rate $n(t)$ of volatility aftershocks (preshocks) decay with time? How do the amplitude β and exponent Ω depend on the main shock magnitude M?
- **Bath law**: what is the relation between the value of the main shock volatility $V(T_c)$ and the value of the second largest aftershock $V_{2,a}$ (or preshock $V_{2,b}$)?
- **Productivity law**: How many aftershocks (or preshocks) above a given threshold can be expected after a main shock of magnitude M?

4) Quantifying the regularities in financial shock cascades

- Another instance of a financial shock, corresponding to a public speech made by Fed chairman Alan Greenspan about the course of post-9/11 economic recovery and the " 'significant risk' that an economic recovery would fail to take hold" - NY Times 01/12/2002

- ***V(T)*** is the average 1-minute volatility calculated for the most-active 531 stocks
- ***M*** $\boldsymbol{\equiv \log_{10} V(T_c)}$ is the magnitude associated with the largest volatility spike of the largest volatility cascade



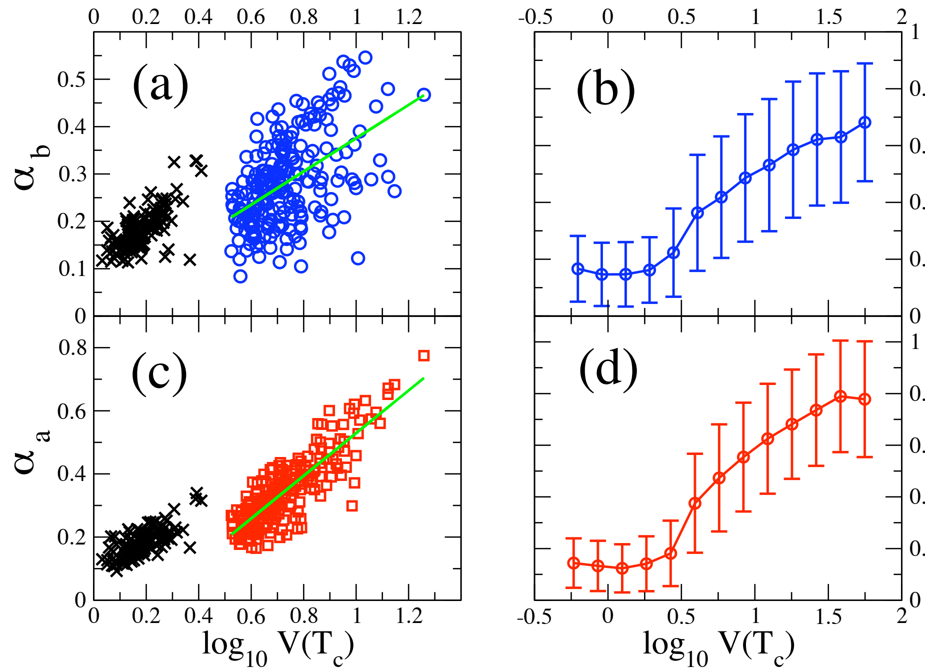


4) Omori law: response dynamics

- How do the aftershocks (preshocks) decay with time around ***T***

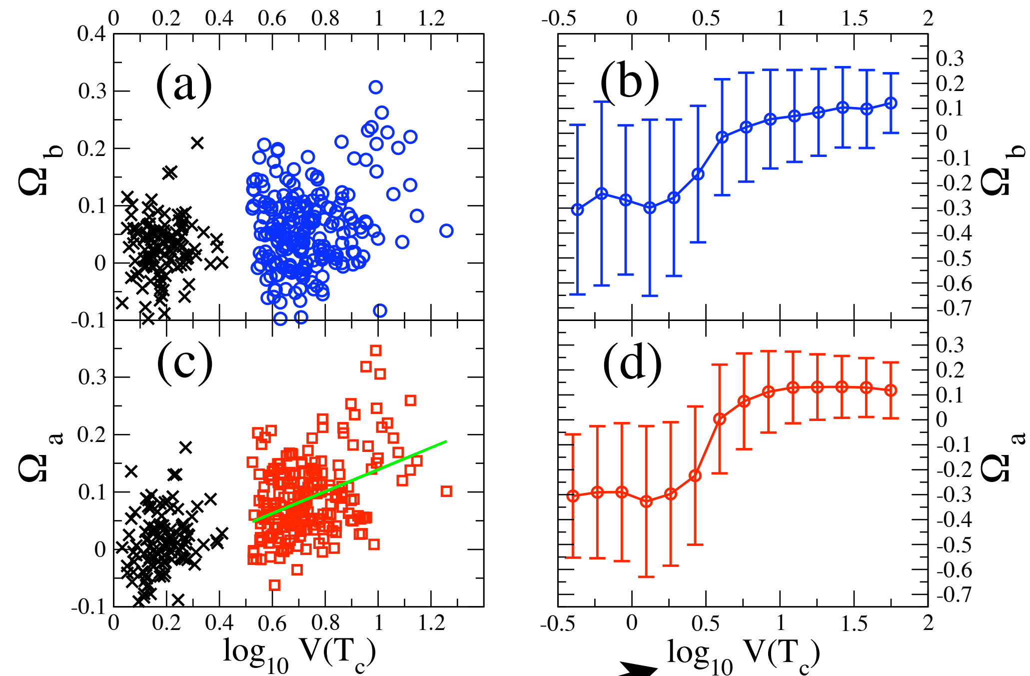
Omori amplitude α

Stocks Index Indiv. Stocks



Omori exponent Ω

Stocks Index Indiv. Stocks



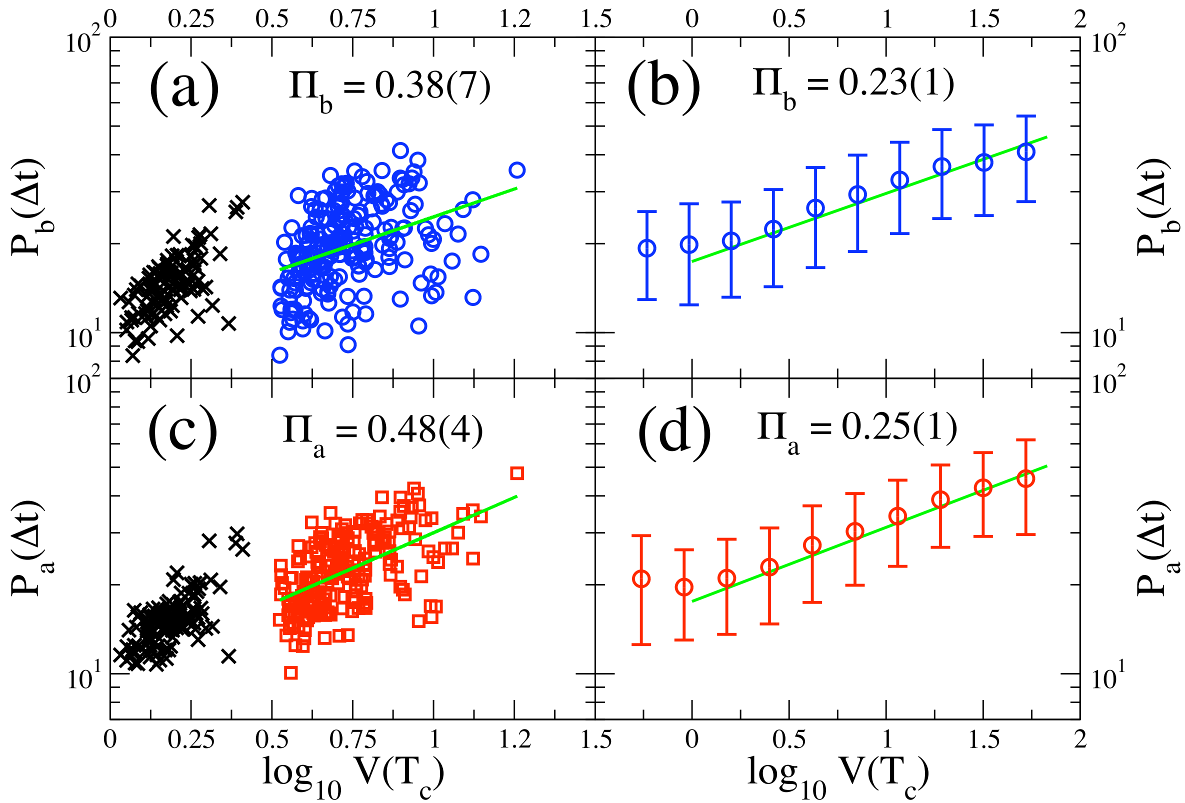
Crossover magnitude $M_x \equiv log_{10}\, V(T_c) \cong 0.5$

4) Productivity law (model free)

- Given a time window $\Delta t \equiv 90$ minutes from the main shock, we quantify the relation between the number of aftershocks $P_a(\Delta t)$ (or preshocks $P_b(\Delta t)$) above a given threshold $q=3\sigma$.

$$P_{a,b}(\Delta t) \equiv N_{a,b}(\Delta t) \sim V(T_c)^{\Pi_{a,b}}$$

Stocks Index Indiv. Stocks

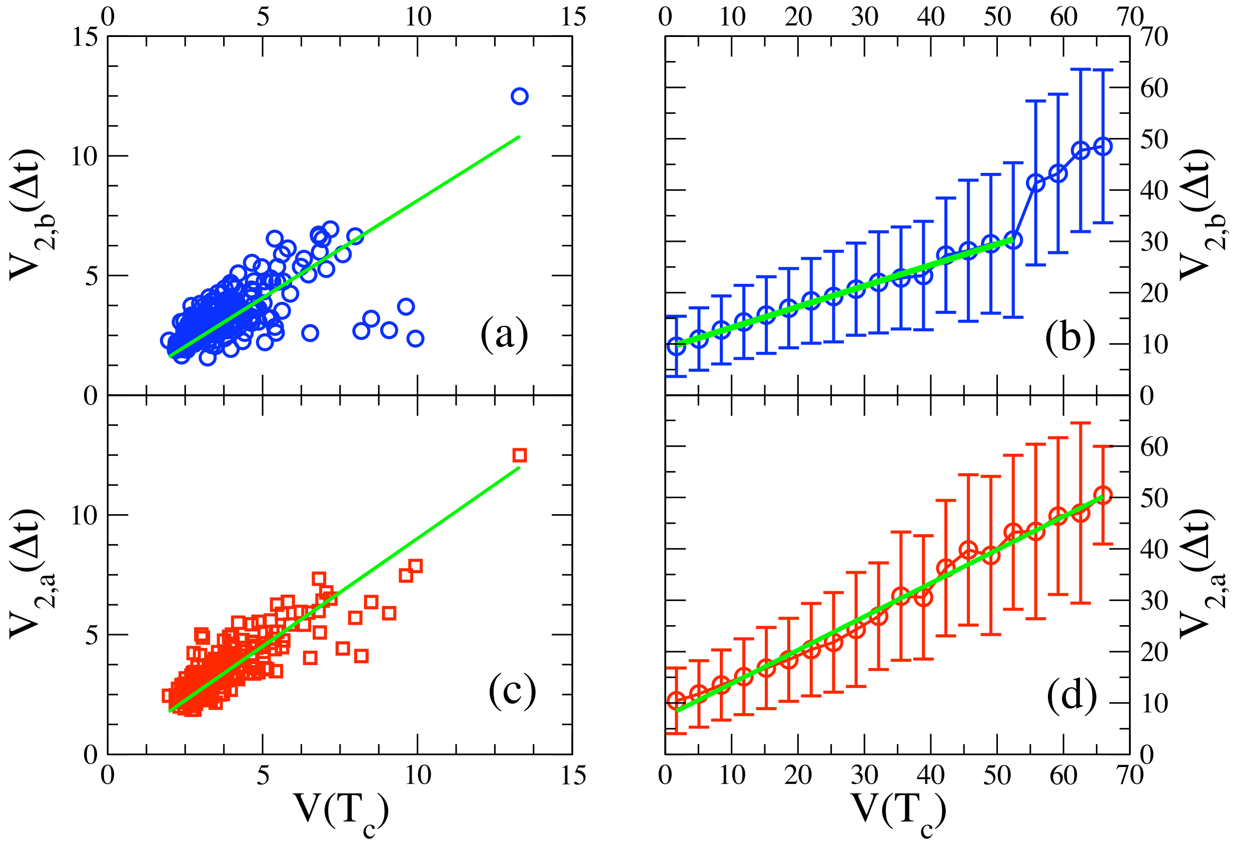


The productivity exponent Π can be used to estimate the the expected total "size" of a financial cascade

4) Bath's law (model free)

- How big is the biggest aftershock $V_{2,a}(\Delta t)$ or preshock $V_{2,b}(\Delta t)$ given a main-shock volatility $V(T_c)$?

$$B \equiv M_1 - M_2 = \log_{10} V(T_c) - \log_{10} V_2 \approx 0.092$$



Due to a complex financial cascading mechanism (herding) which has strong memory properties, the aftershocks can be just as detrimental as the main-shock.

Summary & Take Home Message

- Omori law (power-law) describes the decay of aftershocks in financial markets following FOMC news (global perturbation) $\rightarrow$ non-trivial market correlations

- Possibility that there is a universal underlying mechanism (e.g. non-linear shot noise) which governs the cascading dynamics in complex systems

- 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.

- In the case of FOMC news, the Omori exponent $\langle \Omega_a \rangle$ is related to the amount of market "surprise": Bigger surprise $\rightarrow$ longer time to adjust

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

Thank You!

Title: *Quantitative laws describing market dynamics before and after interest-rate change and other financial shocks*

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. I will follow up the analysis of FOMC market shocks with analysis of other market shocks of varying magnitude $M = \log V(T_c)$, where $V(T_c)$ is the volatility of the market at the minute T_c of the main shock. We show that cascading of volatility before and after financial shocks exhibit statistical regularities by using conceptual methods from earthquake physics to address three questions related to Omori's law, Bath's law, and the Productivity law. Our results could be useful in the development and implementation of emergency response measures for times of financial crisis.

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.