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

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A. M. Petersen, E. Wang, S. Havlin, and H. E. Stanley, Market dynamics immediately before and after

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A. M. Petersen, F. Wang, S. Havlin, and H. E. Stanley, Market dynamics immediately before and after interest-rate change and other financial shocks before and after Quantitative laws describing market dynamics

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

Outline

Motivation: A better understanding of financial crises can help prepare emergency plans for response dynamics in financial markets.
Part 1: Perturbations that can cause financial shocks
1) Perturbations

- Perturbations

A change in an external control parameter that takes the system out of equilibrium.

The change takes place over time interval $\Delta t$.

The response time $\Delta t$ (return-to-equilibrium time).

The system as:

- A complex combination of system elements
- A simple combination of system elements
- A complex combination of system elements

Can characterize the system as:

- $\Delta t$
T
ypical perturbations in the Stock Market

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

Fundamentally change expectations of future earnings; impacting market value

"The Announcement Effect": Both news and the anticipation of news can

These new e-paper devices now can be had for $139. Analysts said both moves were in response to the apparent popularity of Apple’s iPad. News - people (cut $60 from the price of its book reader, Barnes & Noble (BKS -)

$60 Nook price cut → $70 Kindle price cut

The Economics Of Kindle
Part 2: Probing market response dynamics using common Fed interest-rate changes
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" at FOMC meetings.

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- The Federal Interest Effective rate \( F(t) \) is an open market realization of the Target rate.

The Effective rate fluctuates around the Target rate.

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- 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**

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A large set of frequent events to study!
Using F(t) and B(t) we can quantity market speculation.

\[ q^t_i(t_0)^q_i(t) \equiv \Theta \]

Speculation:

\[ (1)^t_i \ln B(t) - (1)^t_i \ln F(t) \equiv (1)^t_i \]

Relative Spread \( q(t) \):

\[ \delta(t) \equiv \ln F(t) - \ln B(t) \]

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

Prior to the scheduled meeting announcements, market speculation, concerned with whether or not the rate will be changed and by how much, causes anticipation (stress) in the markets.

- Target rate \( R(t) \) and effective rate \( F(t) \).
- The value of the T-Bill \( B(t) \) is closely linked to the value of the Federal Reserve.

2) Relative Spread between F(t) and B(t)
Part 3(a): How important are Fed announcements?

- How important are Fed announcements?

- Can we quantify the speculation related to the financial shock?

- How important are Fed announcements?
Daily market volatility $v(t)$ is the high-low price range within one trading day calculated using daily price data for the top 100 companies in the S&P500.

- The average market volatility before and after a FOMC announcement (66 meetings analyzed over an 8-year period 2000-2008) is defined as $\Delta v(t) \equiv \langle v(t) \rangle$.

- Market volatility around FOMC meetings: daily time scale.
Markets are more volatile when anticipating rate decrease ($\forall R > 0$).

\[ q_i(t) \equiv \Theta_i, \quad \Theta_i = \text{Speculation} \]

\[ g_i(t) \equiv \ln B_i(t) - \ln R_i(t) \]

Relative "Spread" $g_i(t)$:

\[ (\Theta = \text{Volatility}) \equiv \forall V_i \quad \text{speculation} \]

FOMC meeting volatility $\Theta_i$ quantifies the "speculation" over a rate change in the week before the FOMC meeting.

- Liquidity typically corresponds to bad news.
- Rate decreases ($\forall R > 0$), which encourage borrowing and increase money news, "bad news" $\forall R > 0$.

Sign Effect: market volatility is larger in response to "bad news" as compared to "good news".
Part 3(b):
Fed announcement the time of the after and before response dynamics both.
3) stylized facts for market volatility at the intraday time scale

- Fat tails: Inverse-cubic power law quantifies frequency of price returns (fluctuations).
- Significant cross-correlations between stocks: (Mantegna, Plerou, Bouchaud, Stanley)
- Long-term memory: significant volatility autocorrelation for ~ several months (which are far from Gaussian) (Mantegna, Gopikrishnan, Plerou, Gabaix, Stanley)
- Stylized facts for market volatility at the intraday time scale: (Mantegna, Gopikrishnan, Plerou, Gabaix, Stanley)
3) Market Volatility: Intraday Time Scale

Data analyzed: TAD (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 of the given company, allowing for cross-comparison.

We next study how the rate of events above a volatility threshold evolves with time. Before and after the announcement of the interest-rate change occurring at time $T_{FOMC}$, we calculate the intraday market volatility $v(t)$ in units of the standard deviation of the given company, allowing for cross-comparison.

Parameter values: $\varepsilon = b$, $T = 90$ min. (b)
The Omori law quantifies the rate $n(t)$ of earthquake aftershocks. Econophysicists use the Omori law to quantify the decay of volatility after market crashes (Lillo & Mantegna, 2003; Weber et al., 2007; Petersen et al., 2010).

The Omori law quantifies the rate $n(t)$ of earthquake aftershocks.

$$n(t) \sim \frac{Z_t}{t} \sim \alpha \frac{|t - T|}{\beta}$$

Aftershocks occur on all scales.

\[ 0 = L \]
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.

\[ N(t) \]

\[ q=2 \] (0.32)
\[ q=3 \] (0.42)
\[ q=4 \] (0.51)
\[ q=5 \] (0.58)

S&P100 (Volatility)

The regularity in the FOMC meeting is typically 2:15 pm ET. The regularity in the FOMC meeting conditions allows for comparison of scheduled meetings.

- Market response is the same for both financial news and financial crises, reminiscent of scale-free behavior found in many complex systems.


We find that the Omori law describes the decay of aftershocks in financial markets in the following FOMC news on the 1-min time resolution for 19 FOMC meetings in the 2-year period 2001-2002.
We identify significant precursors that are also described by an “inverse” Omori-law.

$|J - t| = 2$ 105 min. after $J$

$285$ min. before $J$

We analyze both before and after the FOMC meeting using the displaced time $|J - t|$.

The Omori amplitude and the Omori decay exponent $\nu$ for each FOMC meeting we quantify the market response calculating.

$(3)$ 19 FOMC events
Omori response parameters and the Speculation 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. A smaller decay exponent \( \beta \) represents a longer aftershock. The Speculation quantifies the market sentiment before the announcement. In the case of \( \theta < \Theta \), corresponding to bad market sentiment and a possible rate decrease, the dynamics before and after the announcement have large amplitude. A smaller decay exponent \( \beta \) represents a longer aftershock. A smaller decay exponent \( \beta \) represents a longer aftershock. Bank sector: 18 financial companies.

\[ T \] response-time

\( \Theta \) Omori Response Parameters \( \Theta \) and \( \beta \)
Can we relate the response dynamics to the "magnitude" of the financial shock? 

Part 4:
There is a threshold after a main shock of magnitude $M$.

Productivity law: How many aftershocks (or preshocks) above a given $M$?

Bath law: What is the relation between the value of the second largest aftershock $\gamma^2$ (or preshock $\gamma^2$) and the value of the main shock volatility $\gamma^2$?

Omori law: How does the rate $n(t)$ of volatility aftershocks (preshocks) decay with time? How do the amplitude and exponent $g$ depend on the main shock magnitude $M$?

Questions:

- For many news events, it is difficult to know the exact time $T^e$ of the news, so we developed a method which uses a statistical criteria to find financial shocks of large magnitude $M$. For more common financial shocks...

Market dynamics immediately before and after...
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.

Quantifying the regularities in financial shock cascades...
\( \text{Crossover magnitude} \quad M_0 \equiv (\sigma T)^\lambda \log 10 \equiv \tau \theta \)

\[ \begin{align*}
\text{Omori amplitude} & \quad \alpha \\
\text{Omori exponent} & \quad \gamma \\
\text{Indiv. Stocks} & \quad \text{Stocks Index} \\
(p) & \quad (c) & \quad (p) & \quad (c)
\end{align*} \]

How do the aftershocks (preshocks) decay with time around \( T_{\text{Indiv. Stocks Index}} \)?

4) Omori Law: Response dynamics
The productivity exponent $\beta$ can be used to estimate the expected total "size" of a financial cascade above a given threshold $\Theta = b$. Given a time window of 90 minutes from the main shock, we quantify the relationship between the number of aftershocks or preshocks $(1\nabla)^q d$ or $(1\nabla)^p d$.

$$q^{-\beta} (1\nabla)^q N \sim (1\nabla)^q \Lambda$$

$(1\nabla)^q d$ (or preshocks) $(1\nabla)^p d$ (or aftershocks)
4) Bath's law (model free)

\[ V(T_c) \approx V_{2,a} - V_{2,b} \approx 0.092 \]

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

\[ B \equiv M_1 - M_2 = \log_{10} V(T_c) - \log_{10} V_{2,a} \approx 0.092 \]

\( (\partial L) \Lambda \) shock volatility given a main- or preshock (\( \Lambda \)) \( ^q, r \) whereas \( (\Lambda \Lambda q, r) \) or \( (\Lambda \Lambda q, r) \) \( ^q, r \) How big is the biggest aftershock
In the case of FOMC news, the Omori exponent $\tau > 0$ 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.

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.

- Omori law (power-law) describes the decay of aftershocks in financial markets following FOMC news (global perturbation).
- Non-trivial market correlations.
- Non-linear shot noise which governs the cascading dynamics in complex systems.
- Possibility that there is a universal underlying mechanism (e.g., non-linear shot noise) which governs the cascading dynamics in complex systems.

Take Home Message:

- A better understanding of response dynamics in financial markets can help prepare emergency plans for financial crises.
Thank You!
Abstract:

Information flows through various technological avenues, keeping the ever-changing world up-to-date. As a first case study, I will present the market response to U.S. Federal Reserve rate changes. We show that the announcement of a Federal Reserve rate change causes a financial shock, where the dynamics after the announcement are described by an analogue of Omori's 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 magnitudes. We 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 are described by an analogue of Omori's 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 magnitudes.

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 are described by an analogue of Omori's 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 magnitudes.
Federal Interest Rates

- The U.S. Treasury Bill ($T_B$), is a type of security issued by the U.S. Treasury.
  - These securities are very risk free, as they are backed by the U.S. government.
  - The internal maturity length (here we consider only the 6-month $T_B$). These Treasury Issues the "T-Bill" comes in several versions, distinguished by their maturity lengths.

- Federal Target interest-rate ($R(1)$), 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 ($F(1)$), ("overnight rate") is an open market realization of the Target rate. $F(1)$ is a weighted average over all lending transactions each day, and oscillates around the $R(1)$.

Federal Interest Rates

- Benchmark and a barometer for the U.S. and global economies.
- Borrowing and lending activities. The Fed rates serve as both a benchmark for banks in their day-to-day operations and a benchmark for the rest of the world. The rates are set by the Fed at Federal Reserve meetings.