Early Signs of Financial Crises

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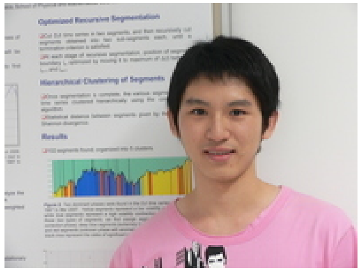
Acknowledgements



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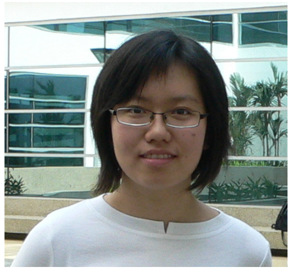

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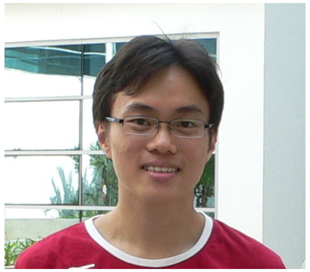

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Motivation

- A financial crisis is a "diseased state" of the market.
- In medicine, early intervention is more effective, and less costly than a late cure.
  - For current crisis, trillions of dollars in relief and stimulus, just starting to see little positive results.
- Early economic and financial intervention requires:
  - sensitive detection of structural changes in market; and
  - robust classification of structural changes as onset of financial crisis.
- Identify structural changepoints enroute to economic recovery:
  - learn which relief and stimulus measures are effective; and
  - presumably, same measures should be effective as interventions.

Data & Models

- Dow Jones Industrial Average (DJI): representative spectrum of industries.
- Time series between 1 Jan 1997 to 31 Aug 2008: M segments from P phases.
- Half-hourly frequency: statistically detect segments as short as 1 day.
- Normal index movement (NIM) model:
  - index movements within segment m normally distributed with mean μ_m and variance σ_m^2;
  - actual changes in index.
- Log-normal index movement (LIM) model:
  - log-index movements within segment m normally distributed with mean μ'_m and variance ${\sigma'_m}^2$;
  - percentage changes in index;
  - popular in finance literature.
- Maximum likelihood estimates $\hat{\mu}_m$, $\hat{\sigma}_m$, $\hat{\mu}'_m$, and $\hat{\sigma}'_m$.

Jensen-Shannon Divergence

- Recursive entropic segmentation scheme to determine M. [Bernaola-Galván *et al*, Phys. Rev. E **53**, 5181 (1996); Román-Roldán *et al*, Phys. Rev. Lett. **80**, 1344 (1998)];

- If $\mathbf{x} = (x_1, \ldots, x_i, x_{i+1}, \ldots, x_N)$ single segment with mean μ and variance σ^2, likelihood

$$L_1 = P(\mathbf{x}|\mu, \sigma^2) = \prod_{j=1}^{N} \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left[-\frac{(x_j - \mu)^2}{2\sigma^2}\right].$$

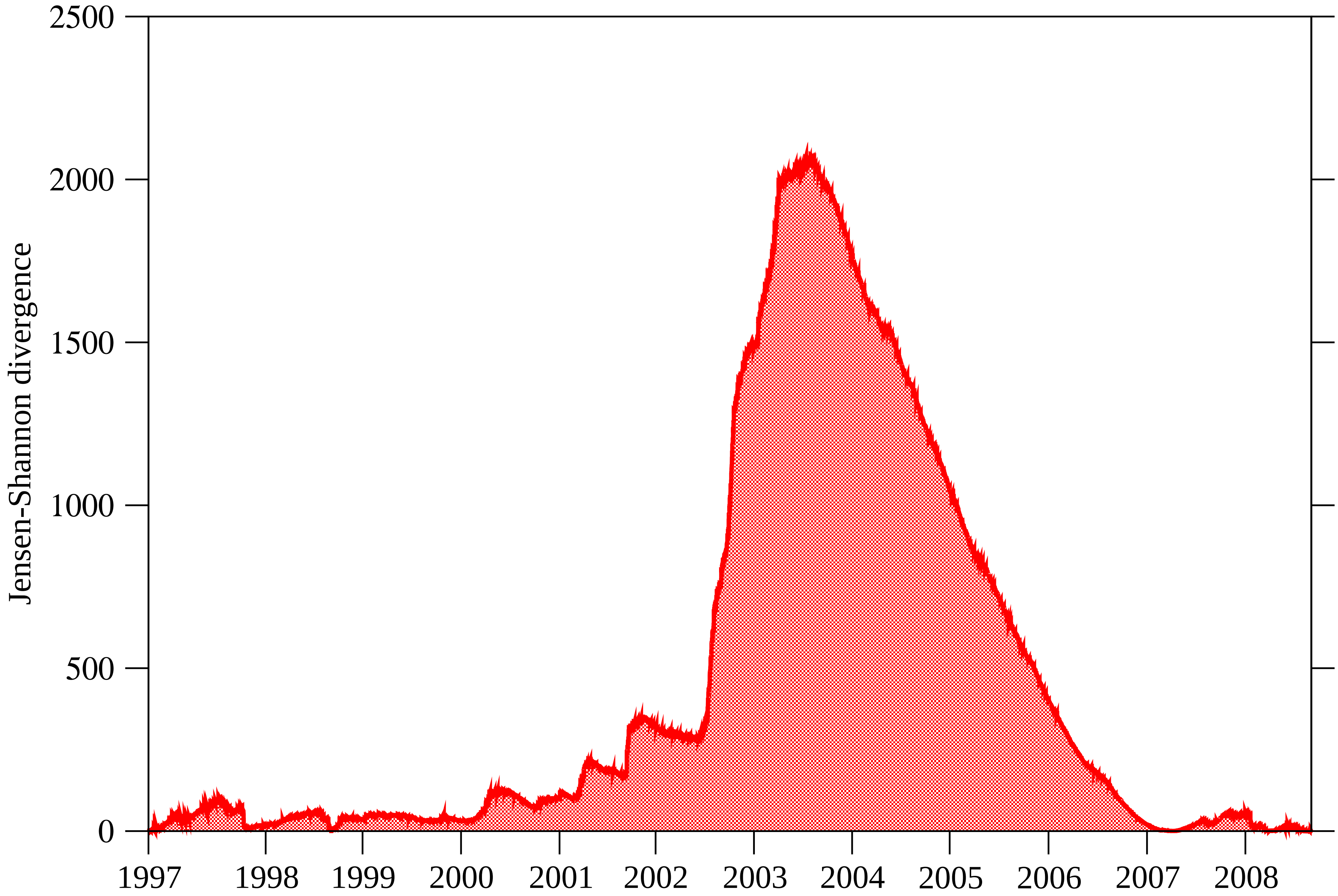
- If $\mathbf{x}$ two segments, $\mathbf{x}_L = (x_1, \ldots, x_i)$ with mean μ_L and variance σ_L^2, and $\mathbf{x}_R = (x_{i+1}, \ldots, x_N)$ with mean μ_R and variance σ_R^2, likelihood

$$\begin{aligned} L_2(i) &= P(\mathbf{x}_L|\mu_L, \sigma_L^2) P(\mathbf{x}_R|\mu_R, \sigma_R^2) \\ &= \prod_{j=1}^{i} \frac{1}{\sqrt{2\pi\sigma_L^2}} \exp\left[-\frac{(x_j - \mu_L)^2}{2\sigma_L^2}\right] \prod_{j=i+1}^{N} \frac{1}{\sqrt{2\pi\sigma_R^2}} \exp\left[-\frac{(x_j - \mu_R)^2}{2\sigma_R^2}\right]. \end{aligned}$$

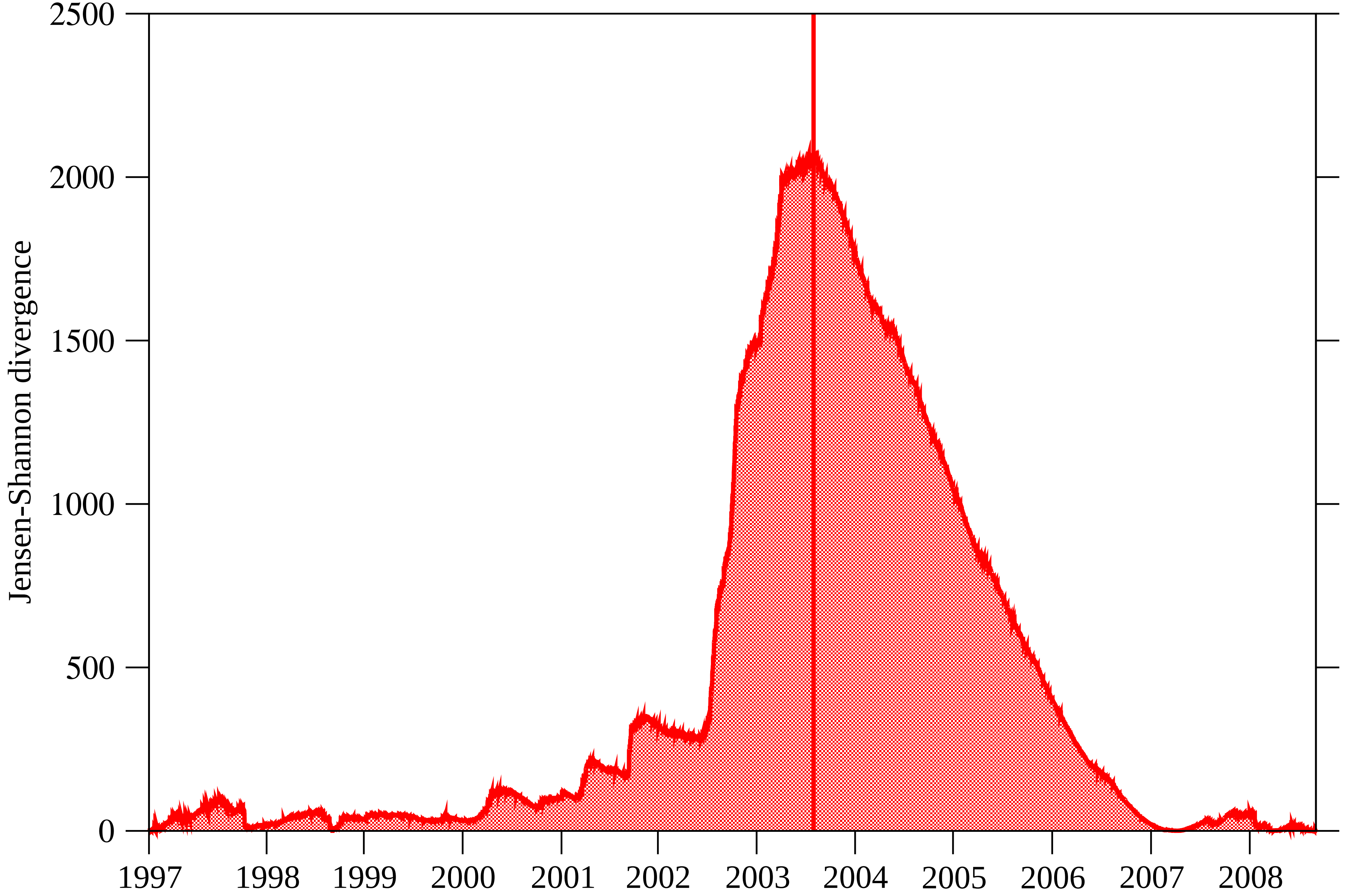
- Define Jensen-Shannon divergence to be

$$\Delta(i) = \log \frac{L_2(i)}{L_1} \geq 0. \qquad (1)$$

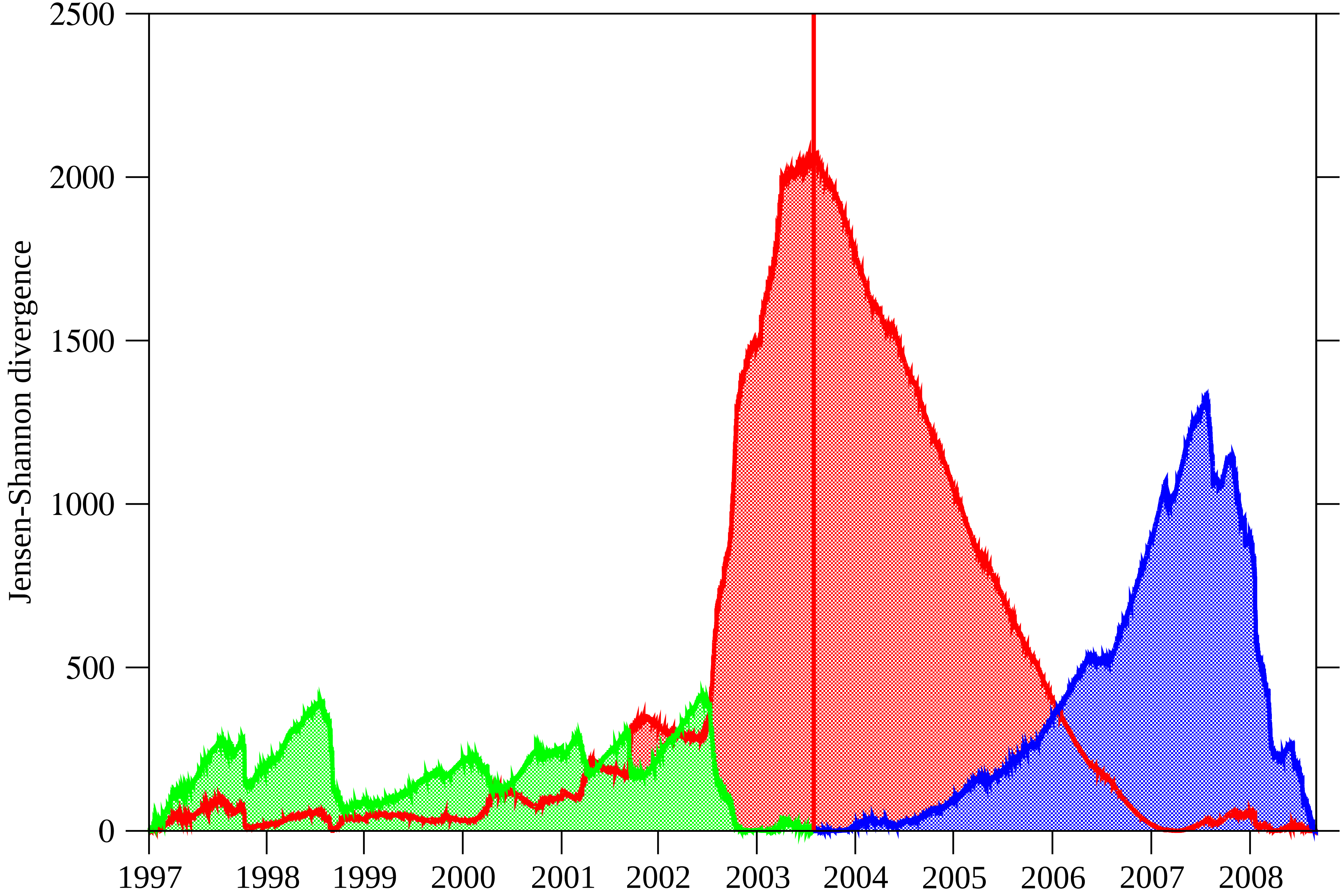
Recursive Segmentation



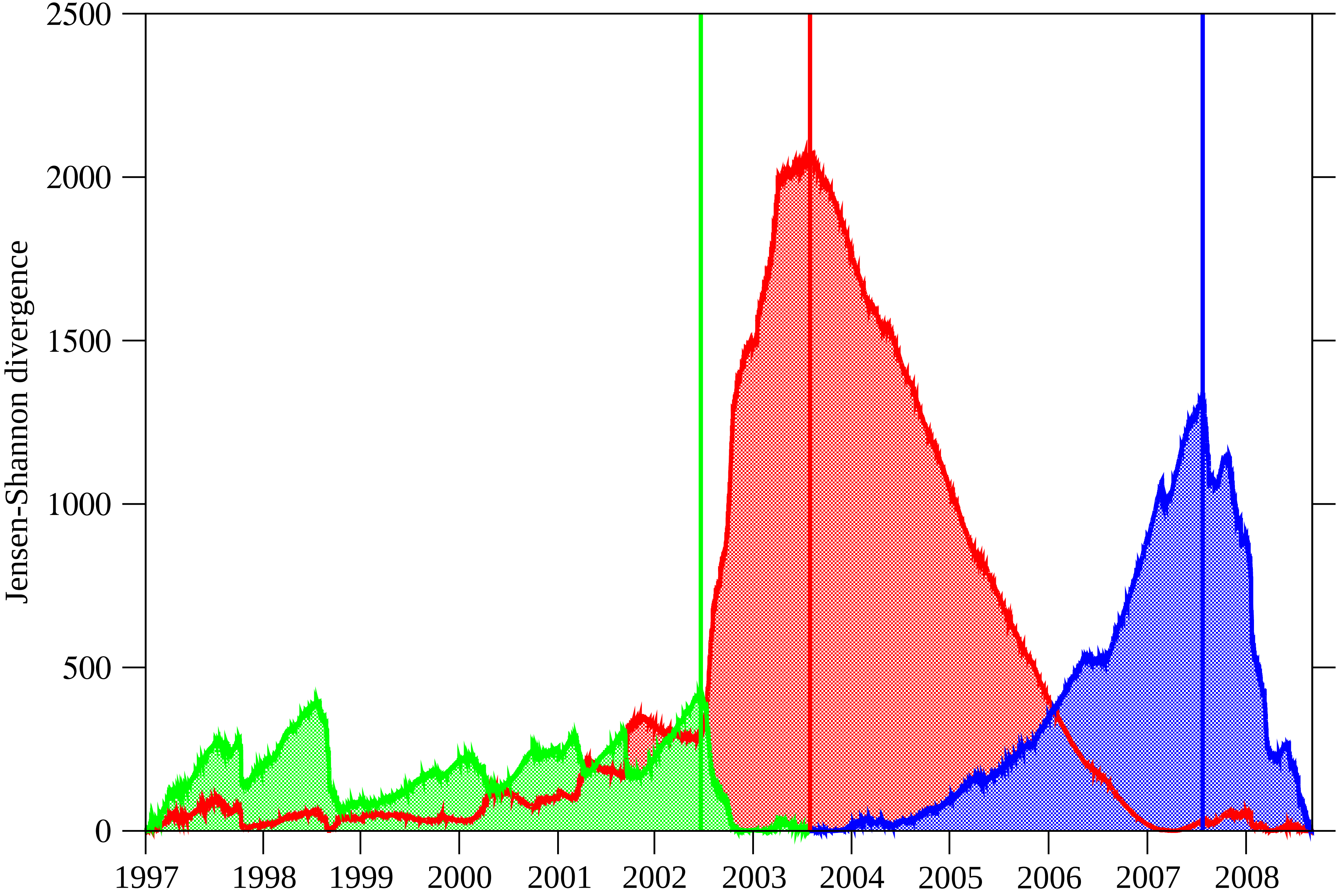
Recursive Segmentation



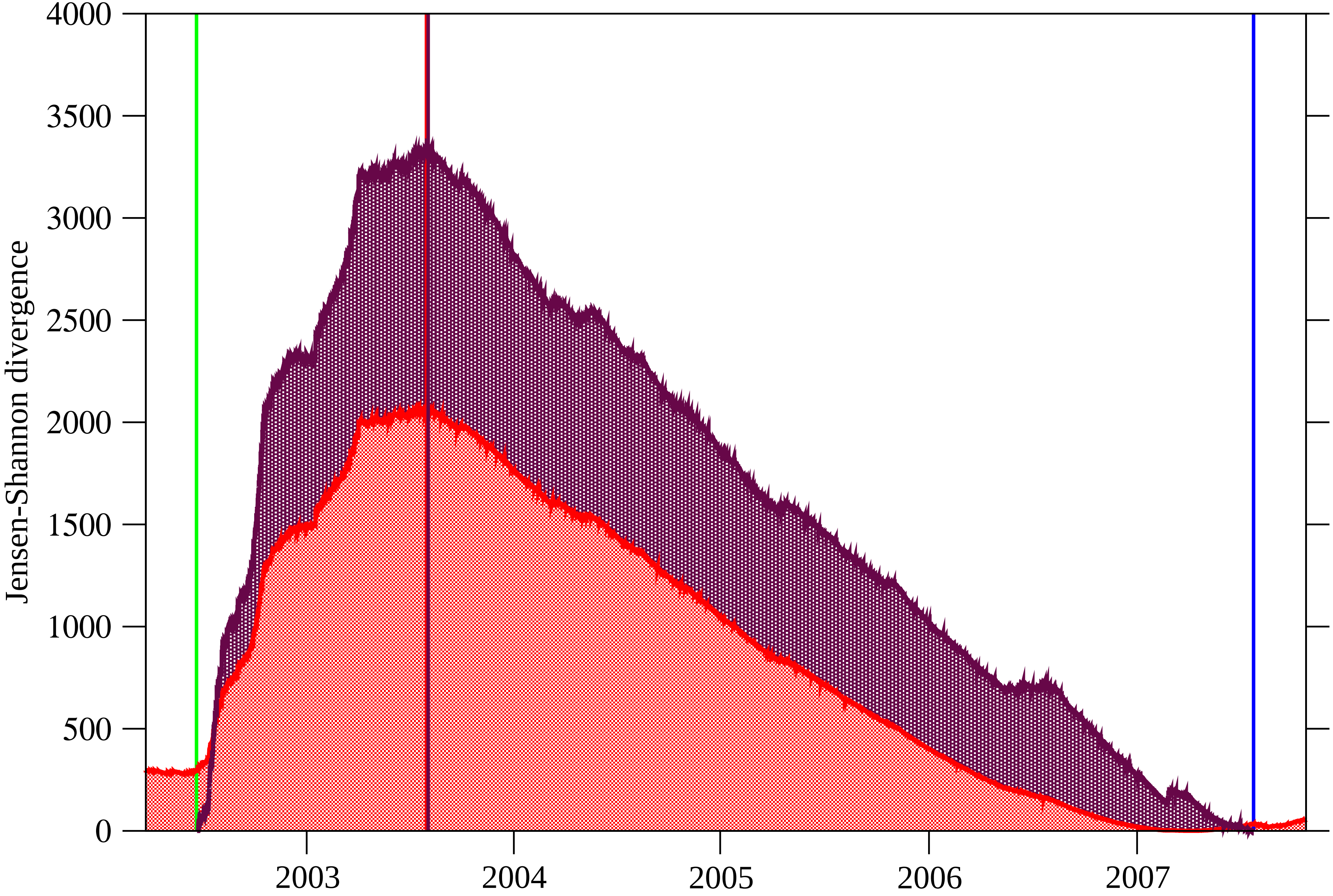
Recursive Segmentation



Recursive Segmentation



Segmentation Optimization



Overview of Segmentation Algorithm

- STEP 1a (Segmentation):
  - Given segment $d\mathbf{x} = (dx_1, \ldots, dx_N)$, compute Jensen-Shannon divergence $\Delta(i)$ as function of cursor position i.
  - Find i^* such that $\Delta(i^*) = \max_i \Delta(i)$. Best 2-segment model for $d\mathbf{x}$ is $d\mathbf{x}_L = (dx_1, \ldots, dx_{i^*})$ and $d\mathbf{x}_R = (dx_{i^*+1}, \ldots, dx_N)$.
- STEP 1b (Optimization).
- STEP 2 (Recursion): Repeat STEP 1 for $d\mathbf{x}_L$ and $d\mathbf{x}_R$.
- STEP 3 (Termination): 1-segment model selected over 2-segment model if:
  - Hypothesis Testing: probability of obtaining divergence beyond $\Delta_{\max}$ greater than prescribed tolerance ϵ; or
  - Model Selection: information criterion (e.g. AIC, BIC) for 2-segment model greater than 1-segment model; or
  - Signal-to-Noise Ratio: $\Delta(i)$ contains more noise than signal.

Segmentation Results

- Number of segments:

NIM	LIM
116	119

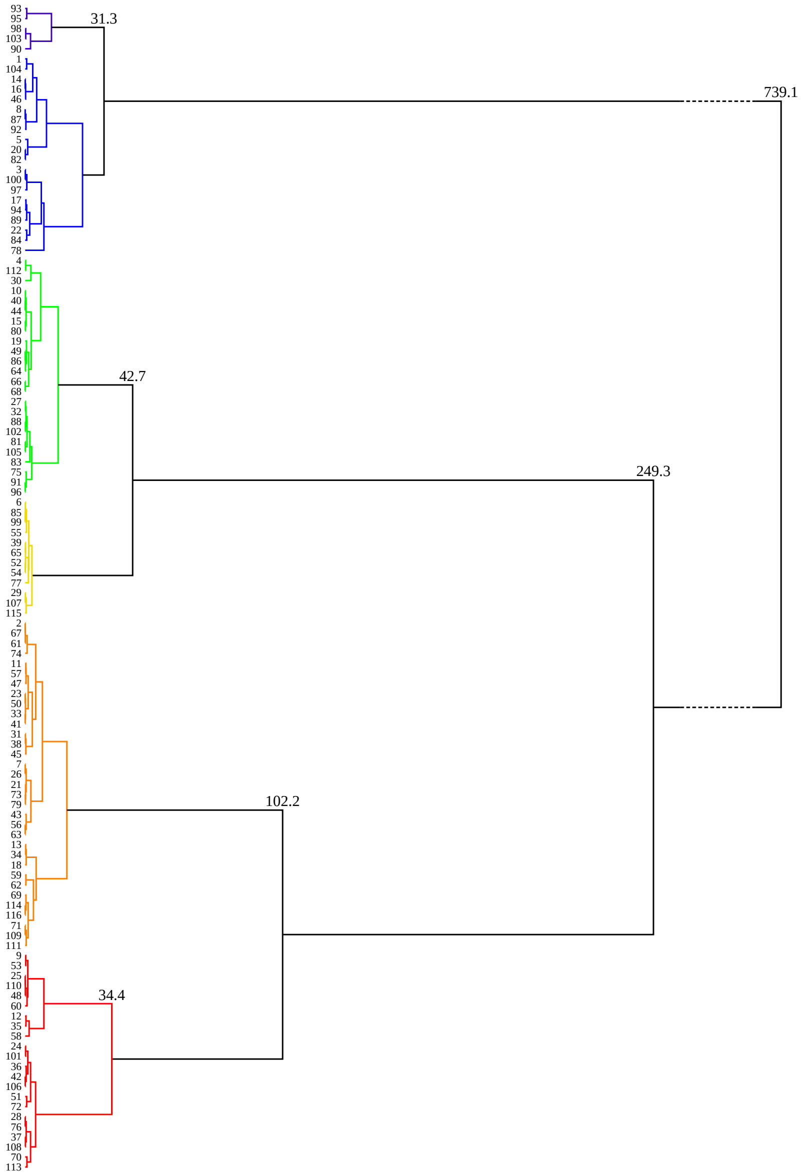
- 85 boundaries in common: segment boundaries statistically robust.
- Disagreement intervals bound by very robust segment boundaries:

start date	end date	number of segments		common
		NIM	LIM	boundaries
Nov 3, 1997	Mar 31, 1998	4	5	0
Aug 26, 1998	Oct 20, 1998	3	2	0
Jan 13, 1999	Nov 5, 1999	3	7	0
Mar 9, 2001	Jun 3, 2002	18	10	6
Oct 16, 2002	Aug 6, 2003	9	6	2
Mar 10, 2004	Oct 18, 2005	3	8	1
Jul 28, 2006	Aug 15, 2006	1	2	0
Sep 5, 2006	Dec 27, 2006	4	1	0
Jul 25, 2007	Mar 10, 2008	7	14	4

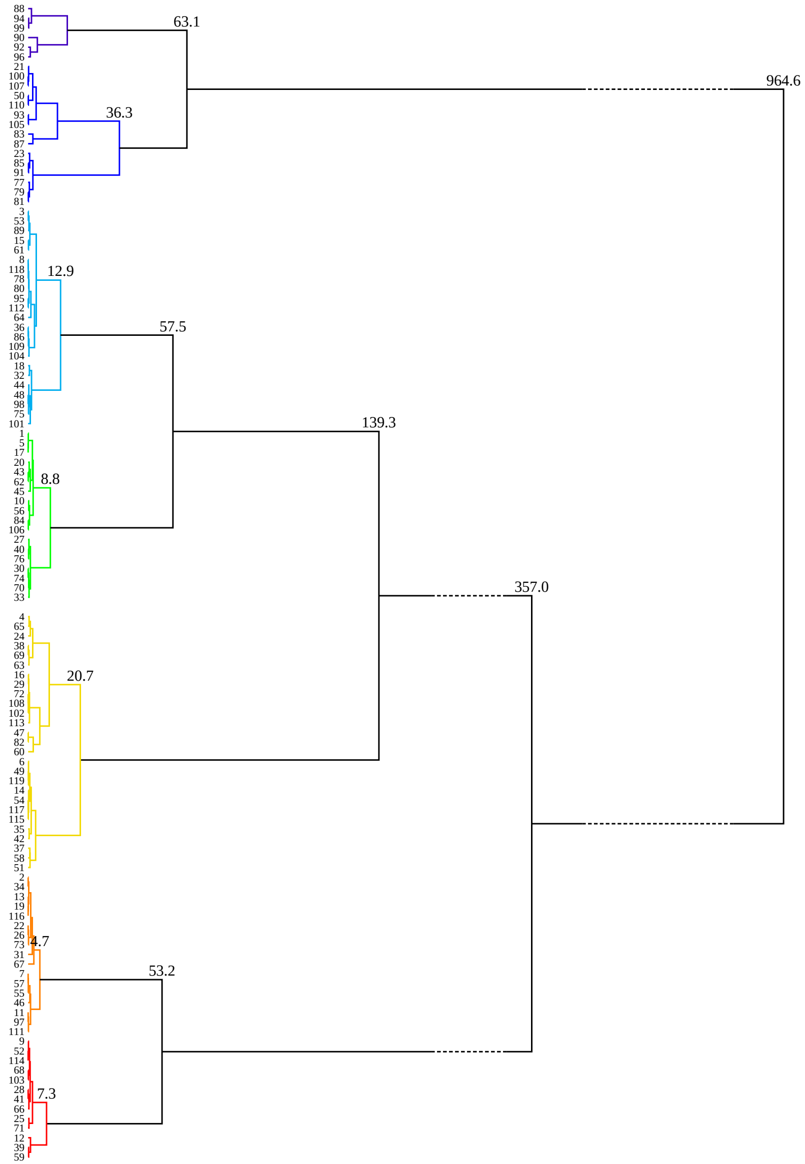
Statistical Clustering

- Statistical clustering of segments to determine P.
  - Jensen-Shannon divergence as statistical distance between segments;
  - agglomerative hierarchical clustering;
  - complete link algorithm.
- Early works assume small P. [Goldfeld & Quandt, J. Econometrics **1**, 3 (1973); Hamilton, Econometrica **57**, 357 (1989); Sims & Zha, Am. Econ. Rev. **96**, 54 (2006)]
- Textbook macroeconomic phases:
  - expansion;
  - contraction;
  - correction;
  - crash.

Clustering Results

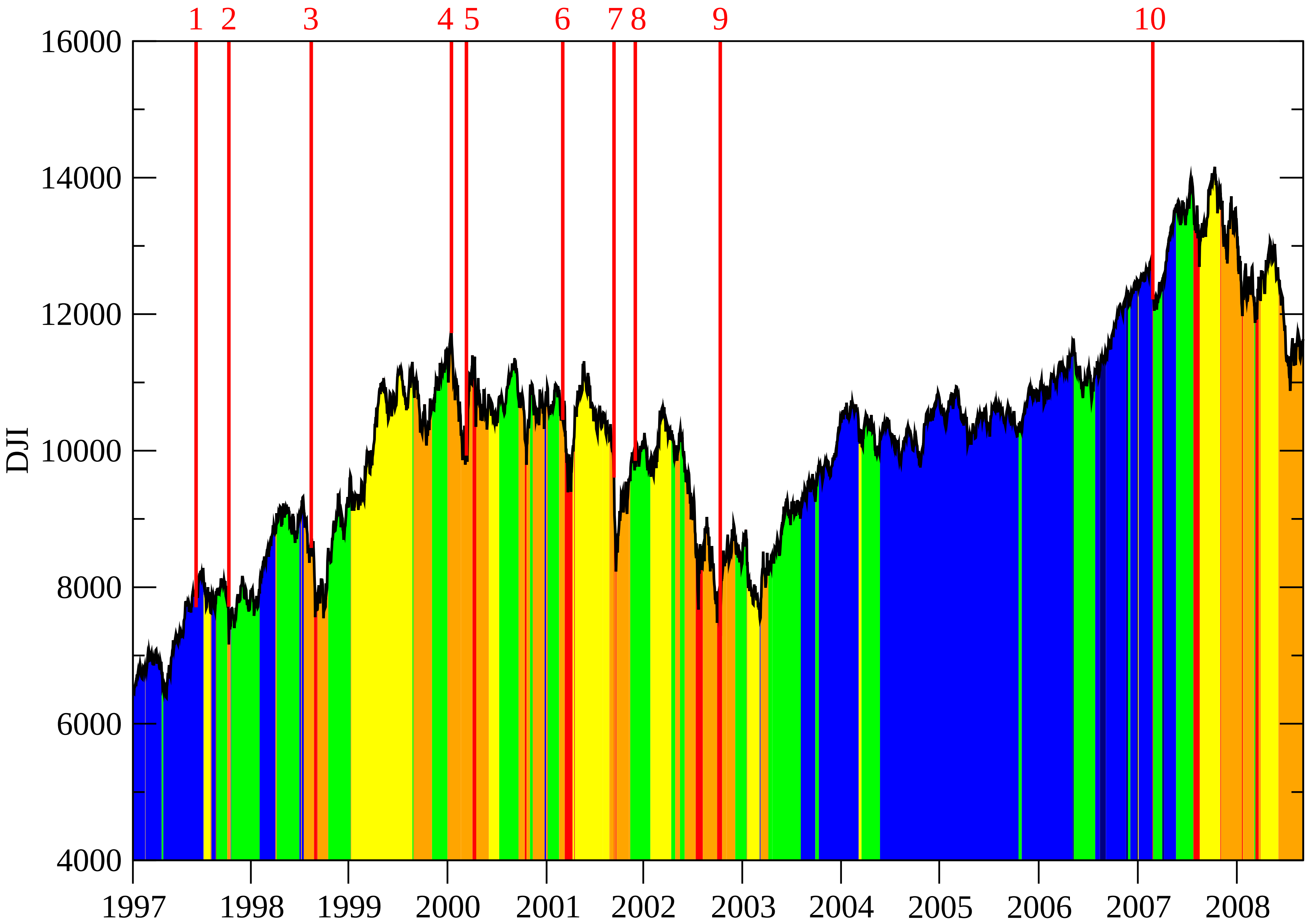


(NIM)



(LIM)

Temporal Distribution of Clustered Segments



Story Told by Temporal Features

- Two high-volatility phases:
  - mid-1998 to mid-2003.
  - mid-2007 to present.
- 1-year series of precursor shocks prior to low-to-high transitions, and 1-year series of inverted shocks prior to high-to-low transition.
- First low-to-high transition triggered by Asian Financial Crisis.
- Second low-to-high transition triggered by Chinese Correction.
  - Strange coincidence between US housing market correction and Chinese market correction in May 2006.
- Detection:
  - look out for precursor shocks, and discount isolated shocks;
  - if two consecutive shocks observed, then 3 months into precursor shock, 6 to 9 months early warning.

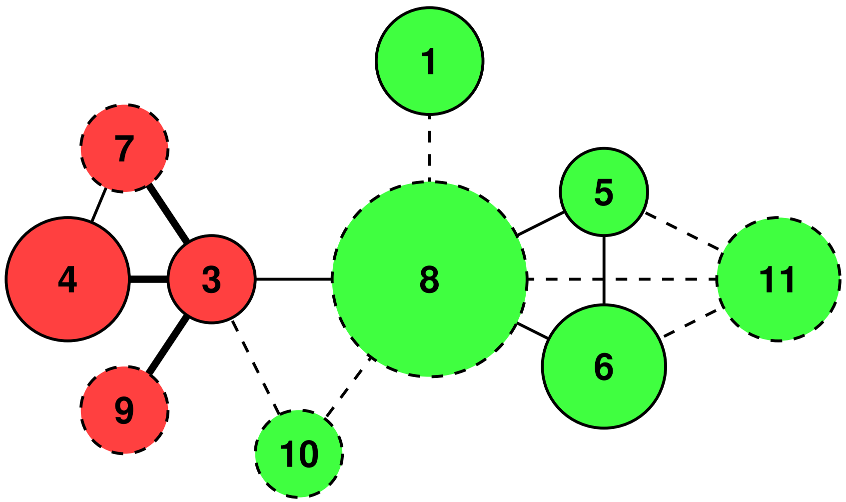
Intervention Measures

- Can detect, can prevent?
  - Must understand causal links in order to break them.
- Two lines of inquiry:
  - macroeconomic: segmentation/clustering study of US economic sectors.
    - Sequence of sectors into decline?
    - Effective intervention measures?
    - In progress. . . .
  - microeconomic: what really happened at the start of a financial crisis?
    - Short time scale study of the Feb 2007 Chinese Correction.
    - Whole-market analyses.

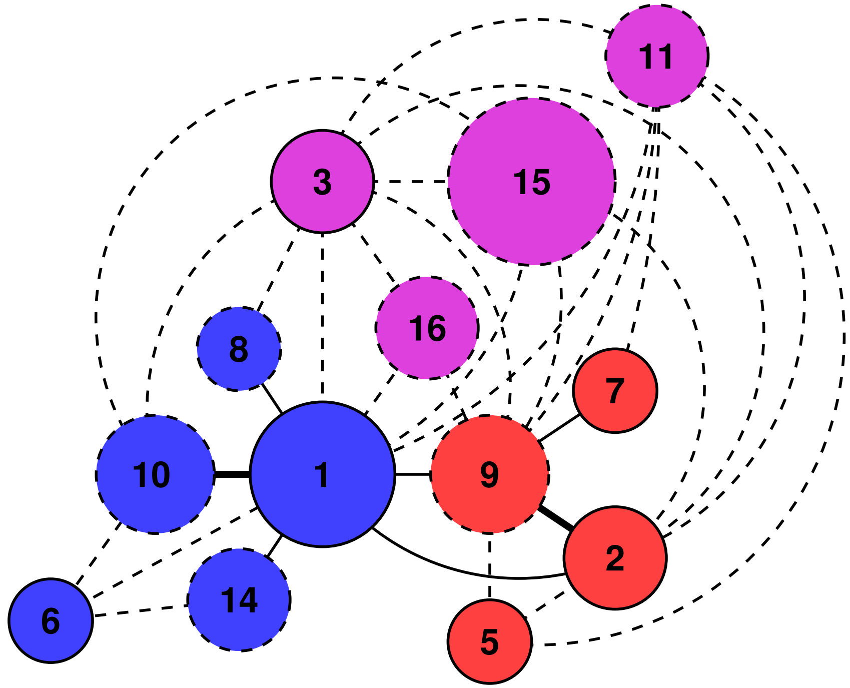
Effective Variables and Effective Dynamics

- Market crash is a cooperative phenomenon.
  - Study not individual stocks, but collections of stocks.
  - But what collections?
- Previous study on extracting effective variables from financial markets: [Goo *et al.*, q-fin/0903.2099]
  - whole-market analyses of daily price movements for 2006–2007.
  - hierarchical organization of effective variables:
    - financial atoms: collections of strongly-correlated stocks.
    - financial molecules: collections of strongly-correlated financial atoms.
  - One financial molecule each in SGX and HKSE:
    - comprises roughly half local stocks, half Chinese stocks.
    - No apparent reason for this structure apart from Chinese Correction.

Financial Molecules

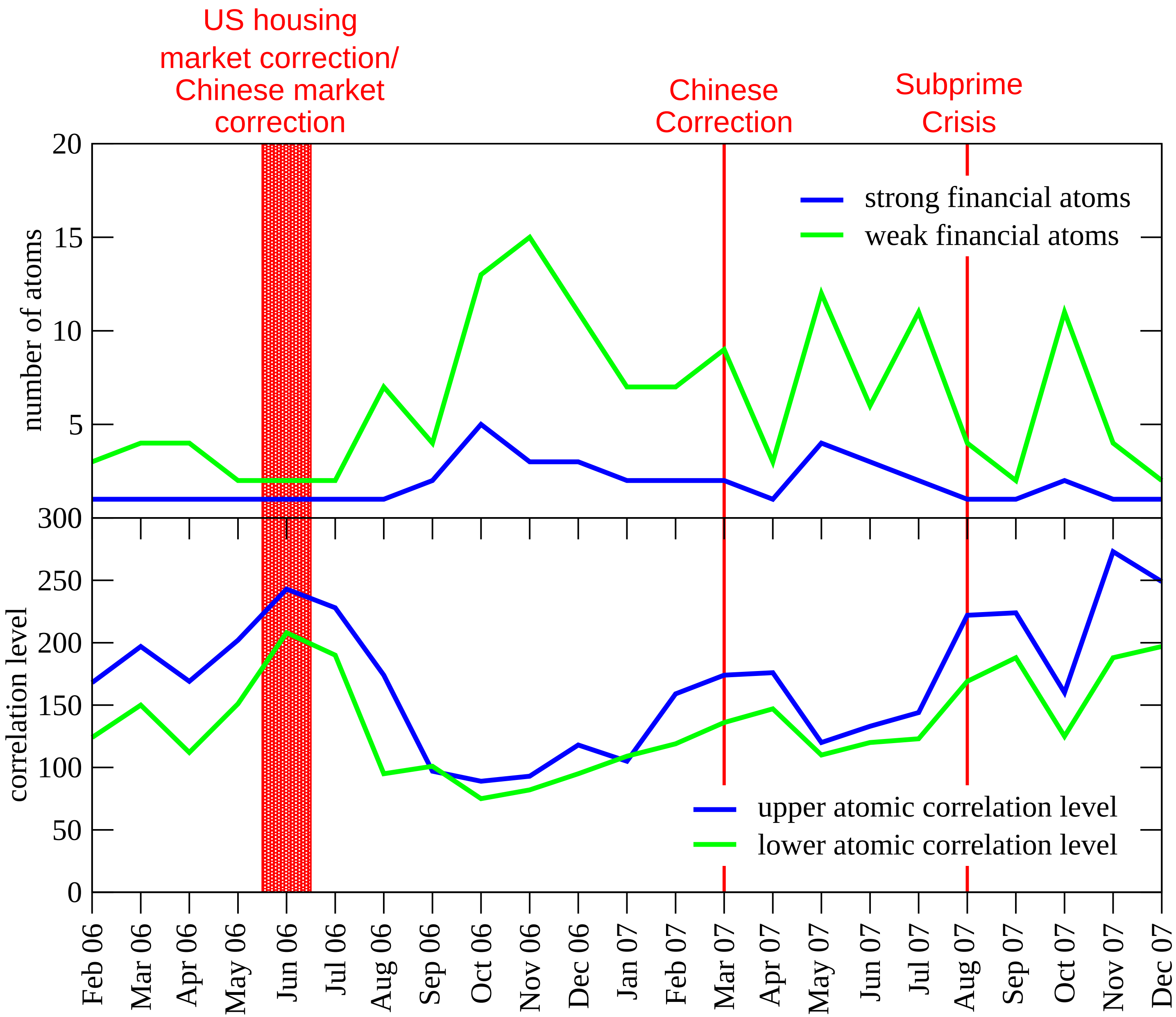


SGX

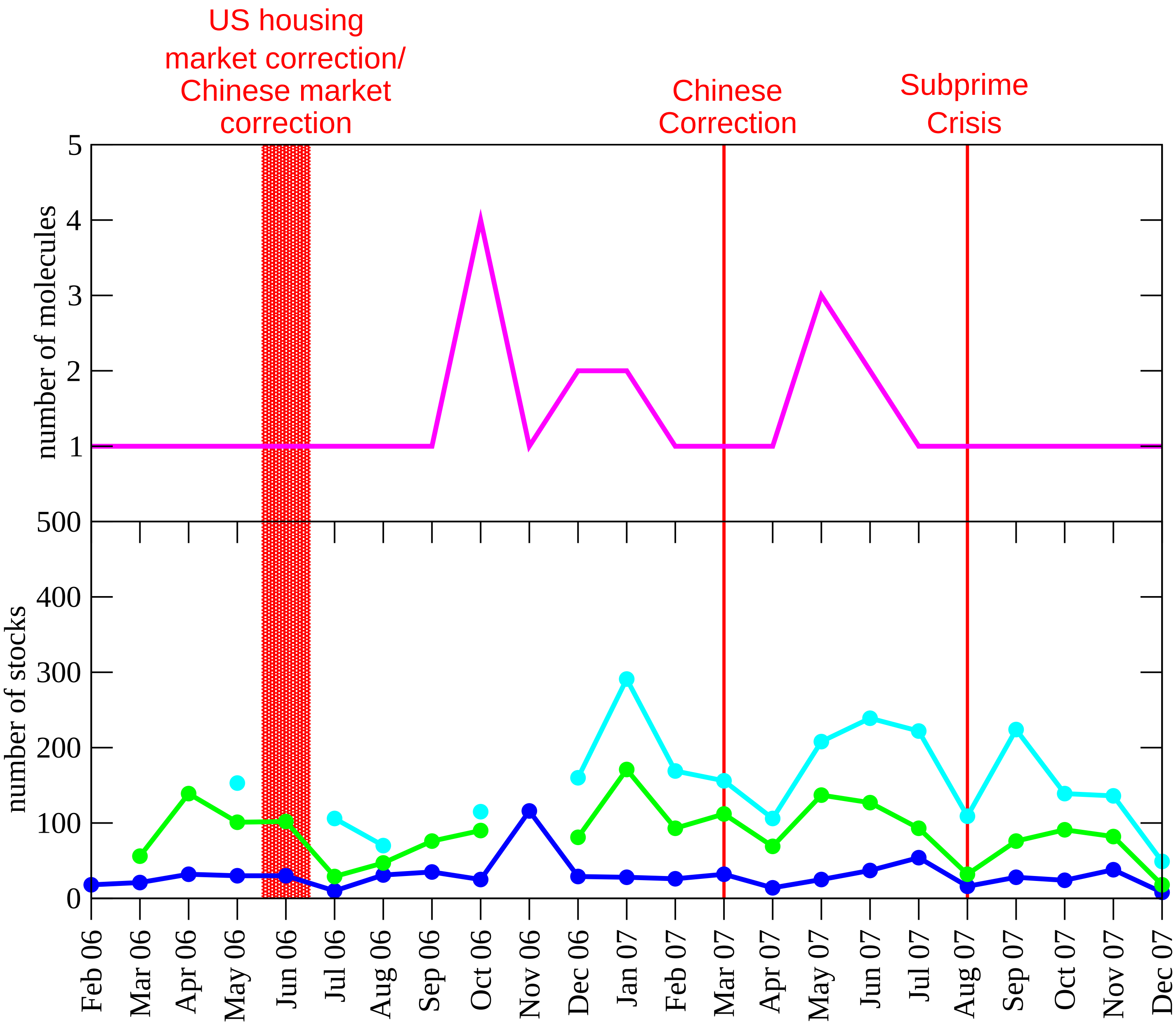


HKSE

Financial Atoms & Atomic Correlation Levels



Financial Molecules & Molecular Sizes



Summary & Conclusions

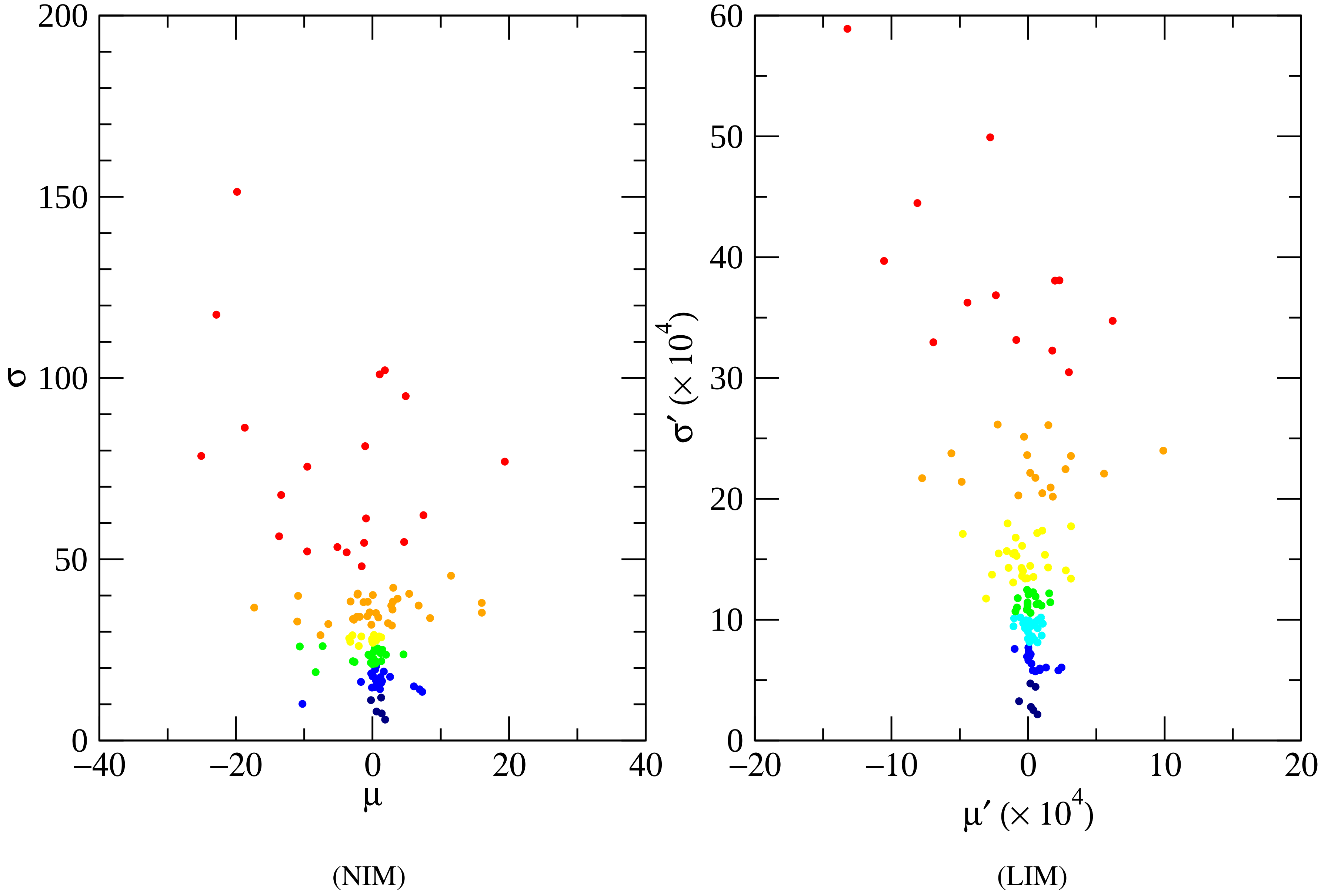
- Segmentation-clustering analysis of high-frequency DJI time series:
  - Discovery of phases with straightforward macroeconomic interpretations.
  - High-volatility phase: mid-1998 to mid-2003, and mid-2007 to present.
  - Year-long precursor shocks prior to low-to-high transitions, and year-long inverted shocks prior to high-to-low transition.
  - Mid-1998 low-to-high transition triggered by Asian Financial Crisis.
  - Mid-2007 low-to-high transition triggered by Chinese Correction.
- High-frequency, whole-market correlational analysis of SGX:
  - Market-level correlations peak around May 06 US/Chinese market corrections, Feb 07 Chinese Correction, and Aug 07 Subprime Crisis.
  - Giant financial molecule whose size increases up to 1–2 month before major market events.
  - Clear statistical signatures of giant financial molecule breaking up after market crashes.

Summary & Conclusions

- Applications to forecasting:
  - 6–9 months lead time based on empirical precursor shock patterns.
  - 1–2 months lead time based on growth of giant financial molecule to critical size.
- Applications to intervention & stimulus:
  - Detailed compositional analysis currently underway.
  - Understand detailed dynamics of giant financial molecule formation and dissociation:
    - Force early dissociation? Soft landing?
    - Conscious restoration of pre-crash correlational structure?

Thank You!

Mean-Variance Scatter Plot



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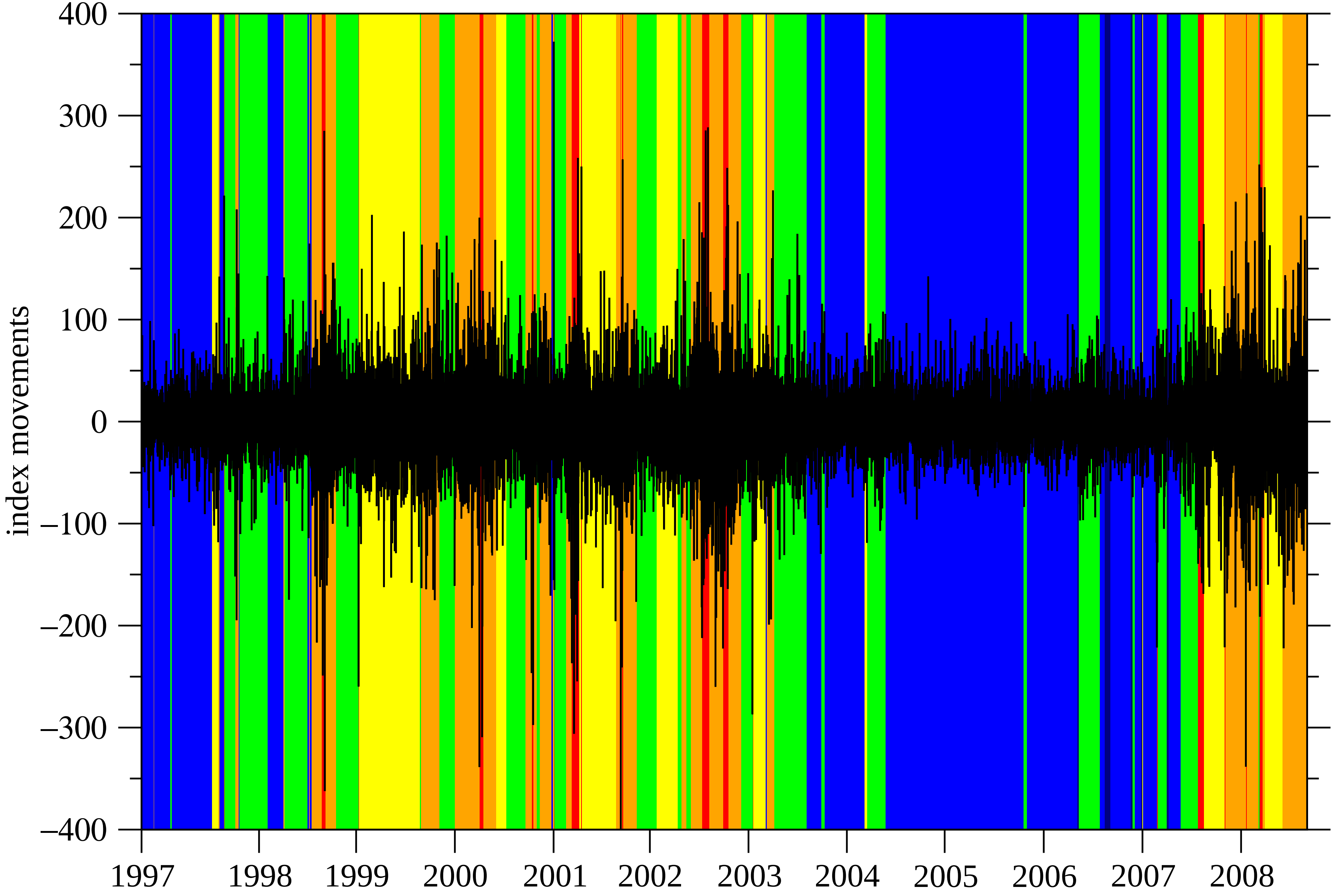

Summary of Main Features

- Two dominant phases:
  - low-volatility phase (economic expansion).
  - high-volatility phase (contains economic contraction).
- Interrupted by:
  - moderate-volatility phase (market correction).
    - consistent 20-point NIM standard deviations;
    - short (1–2)-week segments (mostly in low-volatility phase);
    - long (1.5–2)-month segments (mostly in high-volatility phase).
  - extremely-high-volatility phase (market crash).
    - NIM standard deviations from 50 to 150 index points;
    - short (1–3)-day segments;
    - intermediate 1-week segments;
    - long (2–3)-week segments.

Sliding Window Analysis

- Repeat whole-market analysis of SGX at higher temporal resolution: half-hourly price movements within 2-month window.
- Slide 2-month window in 1-month steps to get 23 overlapping 2-month windows between 2006 and 2007.
- Find financial atoms and molecules in each 2-month window.
- See how these evolve over time.
  - Correlation level analysis;
  - Giant component analysis;
  - Compositional analysis.