Early Signs of Financial Crises

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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 $\mu_m$ and variance $\sigma_m^2$;
  – actual changes in index.

• Log-normal index movement (LIM) model:
  – log-index movements within segment $m$ normally distributed with mean $\mu'_m$ 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


- If $\mathbf{x} = (x_1, \ldots, x_i, x_{i+1}, \ldots, x_N)$ single segment with mean $\mu$ and variance $\sigma^2$, 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 $\mu_L$ and variance $\sigma^2_L$, and $\mathbf{x}_R = (x_{i+1}, \ldots, x_N)$ with mean $\mu_R$ and variance $\sigma^2_R$, likelihood
  \[ L_2(i) = P(\mathbf{x}_L|\mu_L, \sigma^2_L)P(\mathbf{x}_R|\mu_R, \sigma^2_R) \]
  \[ = \prod_{j=1}^{i} \frac{1}{\sqrt{2\pi\sigma^2_L}} \exp \left[ -\frac{(x_j - \mu_L)^2}{2\sigma^2_L} \right] \prod_{j=i+1}^{N} \frac{1}{\sqrt{2\pi\sigma^2_R}} \exp \left[ -\frac{(x_j - \mu_R)^2}{2\sigma^2_R} \right]. \]

- Define Jensen-Shannon divergence to be
  \[ \Delta(i) = \log \frac{L_2(i)}{L_1} \geq 0. \]
Recursive Segmentation

Jensen-Shannon divergence

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Recursive Segmentation

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Recursive Segmentation

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Overview of Segmentation Algorithm

• STEP 1a (Segmentation):
  – Given segment $d\mathbf{x} = (d_{x_1}, \ldots, d_{x_N})$, 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 $d\mathbf{x}_L = (d_{x_1}, \ldots, d_{x_{i^*}})$ and $d\mathbf{x}_R = (d_{x_{i^*}+1}, \ldots, d_{x_N})$.

• 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 $\Delta_{\text{max}}$ greater than prescribed tolerance $\epsilon$; 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:

<table>
<thead>
<tr>
<th>NIM</th>
<th>LIM</th>
</tr>
</thead>
<tbody>
<tr>
<td>116</td>
<td>119</td>
</tr>
</tbody>
</table>

- 85 boundaries in common: segment boundaries statistically robust.

- Disagreement intervals bound by very robust segment boundaries:

<table>
<thead>
<tr>
<th>start date</th>
<th>end date</th>
<th>number of segments</th>
<th>common boundaries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nov 3, 1997</td>
<td>Mar 31, 1998</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Aug 26, 1998</td>
<td>Oct 20, 1998</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Jan 13, 1999</td>
<td>Nov 5, 1999</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Mar 9, 2001</td>
<td>Jun 3, 2002</td>
<td>18</td>
<td>10</td>
</tr>
<tr>
<td>Oct 16, 2002</td>
<td>Aug 6, 2003</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>Mar 10, 2004</td>
<td>Oct 18, 2005</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Jul 28, 2006</td>
<td>Aug 15, 2006</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Sep 5, 2006</td>
<td>Dec 27, 2006</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Jul 25, 2007</td>
<td>Mar 10, 2008</td>
<td>7</td>
<td>14</td>
</tr>
</tbody>
</table>
• 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)
Story Told by Temporal Features

- Two high-volatility phases:
  - 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:
    * 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]
  - 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

US housing market correction/
Chinese market correction

Chinese Correction
Subprime Crisis

Strong financial atoms
Weak financial atoms

Upper atomic correlation level
Lower atomic correlation level

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Financial Molecules & Molecular Sizes

US housing market correction/
Chinese market correction

Chinese Correction
Subprime Crisis

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Summary & Conclusions

• Segmentation-clustering analysis of high-frequency DJI time series:
  
  – Discovery of phases with straightforward macroeconomic interpretations.
  – 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:
  
  – 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

(NIM)

(LIM)
Temporal Distribution of Clustered Segments

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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.