Credit Networks and Systemic Risk

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Why “economic networks” are important?

a lá “Pareto-Zipf” and fluctuations

a few giants and many dwarfs

and

they are mutually dependent for growth/failure
a few giants and many dwarfs

Pareto-Zipf

\[ P(x) \sim x^{-\mu - 1} \]

or heavy-tailed distrib.
ex.

\[ X(t) = \sum_i x_i(t) \]

fluctuation

\[ \frac{\delta X(t)}{X(t)} = \frac{\delta x_i(t)}{\sum_k x_k(t)} = \frac{x_i(t)}{\sum_k x_k(t)} \cdot \frac{\delta x_i(t)}{x_i(t)} \]

\( share \ s_i \)

\[ \text{Var} \left( \frac{\delta X(t)}{X(t)} \right) \sim \sum_i s_i^2 \text{Var} \left( \frac{\delta x_i}{x_i} \right) \]

if uncorrelated and trivial conditions

e.g.

\( s_i \sim 0.1 \)

\( s_{j \neq i} \sim 0.9/N \)

\[ \rightarrow \text{The giant dominate.} \]

Gabaix, “The granular origins of aggregate fluctuations.”
NBER working paper (2008)
\[ X(t) = \sum_i x_i(t) \]

fluctuation

\[
\text{Var} \frac{\delta X(t)}{X(t)} \sim \sum_i s_i^2 \text{Var} \frac{\delta x_i}{x_i} + \sum_{i<j} s_i s_j \text{Cor} \left( \frac{\delta x_i}{x_i}, \frac{\delta x_j}{x_j} \right)
\]

\[ s_i \sim 0.1 \]
\[ s_{j\neq i} \sim 0.9/N \]

\[ \rightarrow \text{clustered dwarfs can be comparable.} \]
生産と金融とそれらの関係網

稲岡・二宮・谷口・清水・高安(2003)
Iori, Roberto, De Masi, Caldarelli (2007)
副島・今久保(2007) etc.

De Masi, Fujiwara, Gallegati,
Greenwald, Stiglitz (2008)
Fujiwara et al.(2010)

this talk

生産
Example 1/2
credit network
(firms-banks NW)
Firms’ debt from banks

~160B yen
#L-firms= 1.25%
#S-firms= 98.75%

Large: capitalized at 100M yen or more
Small-Medium: otherwise

Source: Small & Medium Enterprise Agency (2008)
A small fraction of firms account for nearly all loans due to **long-tailed distribution of debt.**

Listed firm’s debt
And similarly for long-tailed distribution of banks’ lending amount.

![Cumulative PDF of bank's lending amount](chart)

- city
- regional
- trust
- insurance
- others

Bank’s lending
Goal

Credit network between banks and firms
= bipartite graph with weights

Quantify dependency / influence between banks & firms
1. based on Structure of Credit NW in Japan
2. Temporal Change for the past 25 years
References (selected)

● Kano, Uchida, Udell, Watanabe, W.
  “Information verifiability, bank organization, bank competition and bank-borrower relationships”,
  RIETI-DP (2006) 06-E-003
  特に中小企業の借入に関して
● Uchida, Udell, Watanabe, W.
  “Bank size and lending relationships in Japan”
  企業サイズと信用関係の関係など
● Ogawa, Sterken, Tokutsu
  Economic Systems 31 (2007) 49
  複数信用取引(multiple lending)について

and many …
Data

- **firms**: listed in Japanese stock-exchange markets covering **large firms**
- based on financial statements & surveys by *Nikkei, Inc.*
- short-term + long-term borrowings from financial institutions

- **banks**: **commercial** banks are selected
  - long-term and city banks
  - regional (primary/secondary) trust banks
  - insurance companies
  - others (credit associations, agricultural, Shoko Chukin)
- annual snapshots: from 1980 to 2005
- bankrupted or merged banks included; #banks ~ 230
- surviving firms included; #firms ~ 2,000
- bank supplies credit in anticipation of interest margin
- firm uses credit as a source of financing in anticipation of growth in its business
→ *edge of credit* = *dependency* of one agent on the other

A same amount of credit has different importance to bank *μ* and firm *i*
Dependency

bank \( \mu \) on firm \( i \)  
\[
A_{\mu i} := \frac{w_{\mu i}}{w_{\mu}}
\]

\[\sum_i A_{\mu i} = 1 \quad \text{for all } \mu\]

firm \( i \) on bank \( \mu \)  
\[
B_{i\mu} := \frac{w_{\mu i}}{w_i}
\]

\[\sum_\mu B_{i\mu} = 1 \quad \text{for all } i\]

\( w_{\mu} := \sum_i w_{\mu i} \) \( \text{total lending} \)

\( w_{i} := \sum_\mu w_{\mu i} \) \( \text{total borrowing} \)
dependency = potential influence between banks and firms

Suppose one can quantify

\[ x_\mu : \text{level of bank } \mu \text{'s financial deterioration} \]

corresponding to

\[ \checkmark \text{shrinking amount of supplied credit} \]
\[ \checkmark \text{increasing interest-rate} \]
\[ \checkmark \text{shortening the due time of repayment} \]

\[ y_i : \text{level of firm } i \text{'s financial deterioration} \]

causing

\[ \checkmark \text{delaying repayment to banks} \]
\[ \checkmark \text{default / bankruptcy} \]

propagation on credit NW

N.B. based on topology alone
Stiglitz and Greenwald,

“the high rate of bankruptcy is a cause of the high interest rate as much as a consequence of it”

Towards a new paradigm of monetary economics (Cambridge, 2003)
banks’ fragility = solution of eigenvalue problem
Mathematical properties

- spectrum
  \[ 0 < \lambda \leq 1 \]
- largest eigenvalue corresponds to trivial mode
  \[ \lambda = 1 \text{ if and only if } x_\mu = \text{constant} \]
- sum of eigenvalues
  \[ \sum_k \lambda_k = \sum_{\mu,i} A_{\mu i} B_{i \mu} = \text{tr } P \]
propagation of fragility-profile

\[ \tilde{\mathbf{x}} := \mathbf{x} \] without trivial-mode

expand by eigen-modes

\[ 1 = \lambda_1 \geq \lambda_2 \geq \lambda_3 \cdots \lambda_n > 0 \]

\[
\begin{align*}
P^r \tilde{\mathbf{x}} &= \lambda_2^r a_2 \tilde{x}^{(2)} + \lambda_3^r a_3 \tilde{x}^{(3)} + \cdots + \lambda_n^r a_n \tilde{x}^{(n)} \\
&= \lambda_2^r \left[ a_2 \tilde{x}^{(2)} + \left( \frac{\lambda_3}{\lambda_2} \right)^r a_3 \tilde{x}^{(3)} + \cdots + \left( \frac{\lambda_n}{\lambda_2} \right)^r a_n \tilde{x}^{(n)} \right]
\end{align*}
\]

larger eigenvalues ~ more robust modes
random graph
= cut every edges and rewire them randomly

$w_{\mu i} \rightarrow w_{\mu j}$

The same credit is supplied to different firm with total amount of lending being invariant.

\[ \{ \begin{array}{ll} A & \text{invariant} \\ B & \text{randomized} \end{array} \]
\[ \tilde{\lambda}_k = \frac{\lambda_k}{n} \sum_{\ell=1}^{n} \lambda_{\ell} \]

Only the first two non-trivial eigenvalues are significant..
components of eigenvector $|x^{(2)}_\mu|$ corresponding to 2nd largest eigenvalue
✓ strong peak in the late 80s
✓ drop in 1990
✓ peaks in 1992 and 1997
Credit relationship changed in Japanese bubble in the late 80s up to 1990 and after it.

1. Firms became to be less dependent on bank loans, by issuing public debt, e.g., after financial deregulation.

2. After bubble collapse, banks had non-performing loans degrading the intermediary role of banks.
   --- During the bubble (late 80s),
   large firms tended to rely on single relation to banks.
   --- In the long stagnation after the bubble collapse (1990), percentage of multiple lending increased.

3. Banks spent a decade in 90s to recover from bad loans experiencing a financial crisis for a couple of years from 1997, which results in credit shrink during the period.

components of eigenvectors \[ x^{(2)}_\mu + x^{(3)}_\mu \]

- stable patterns 80-85, 00-05
- change in late 80s
- bubble collapse and 90s
- back to previous profile with more peaks in late 90s
Part Ⅰまとめ

- 銀行・企業間信用ネットワークを重み(借入貸出金)付きの2部グラフとして解析する手法を提案
  1980年～2005年について, その構造と変化を解析した
- 借手から貸手, 貸手から借手への依存度合いと影響度合いを2部グラフからself-consistentに計算する手法
  → これにより脆弱性指標を固有値問題として計算できる
- 帰無仮説としてランダム2部グラフを用いると,
  上位数個の固有値とそれに対応する固有ベクトルが有意
- 過去25年間について脆弱性指標を解析して
  その変化と金融構造の変化について議論
  → comparison with financial states of banks necessary
  → firms’ fragility relation to bankruptcy to be studied
Example 2/2
production network
(supplier-customer NW)
cluster (community) structure

0.14M manufacturing sector
Modularity optimization (Yutaka Leon Suematsu)
Force-directed spring+Coulomb+resistence
N-body simulation by GRAPE (gravity pipeline)
(with Yuji Fujita, Atsushi Kawai)
<table>
<thead>
<tr>
<th>Chemistry</th>
<th>Electronics</th>
<th>Heavy Industry</th>
<th>Chemicals</th>
<th>Metal Industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>旭化成, 大日本インキ化学工業, 東洋インキ製造, レンゴー三菱化学, 三井化学, サカタインクス, 住友化学...</td>
<td>松下電器産業, 東芝, 三菱電機, 日立製作所, 富士通, シャープ松下電工, ソニー, 三洋電機, 京セラ...</td>
<td>三菱重工業, 川崎重工業, 本田技研工業, トヨタ自動車, 神戸製鋼所石川島播磨重工業, 王子製紙, 住友重機械工業, クボタ...</td>
<td>東レ, 日本製紙, 東洋紡績, ヤマハ, ユニチカ, 丸紅グンゼ, クラレ, 三菱レイヨン...</td>
<td>三菱マテリアル, 太平洋セメント, 宇部興産, フルサト工業, 住友大阪セメント長府製作所, タキロン, JFE建材, フェニックスコーポレ...</td>
</tr>
<tr>
<td>イトーキ, 松下エコシステムズ, 関包スチール, 明道メタル, 北海道サッシ工業ヤマトインダストリー 台和, 日本調理機, 日本金屬工業...</td>
<td>仙台味噌醤油, だい久製麺, 山形朝日そば, 星栄商店, 大塚樽店宮城クミアイ醤油, 松尾, 石渡商店, オリヒロマテリアル</td>
<td>cf. Fortunato, Barthelemy (2007) “resolution limit in community detection”</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
再帰的なコミュニティ解析

| ソニー, 京セラ, キヤノン, シャープ, セイコーフィルム, オムロン, TDK, 富士写真フィルム, リコー, ... |
| 三菱電機, 松下電工, 日本電気, 古河電工, 日立電工, 八幡電工, 住友電工, 鳥取電産, ... |
| トステム, 新日鉄, 大和ハウス工業, 旭硝子, 三和シャッター工業, 三協立山アルミ, 日本軽金属, 立山アルミニウム工業, 不二サッシ, ... |
| 松下電器産業, 三洋電機, パナソニック, 日立製作所, アルプス電気, 日立ハイテクノロジー, 日立国際電気, アルバック, 東京エレクトロン, 東北パイオニア, 東京エレクトロンAT, 長野日本無線, ... |
| 東芝, 富士通, 横河電機, 東芝セラミックス, 東京エレクトロン九州, 日本インター, 信越半導体, 富士通アクセス, 鷺宮製作所, ... |
| パナソニックエレクト, パナソニックモバイル, パナソニックコミュニ, 山武, パナソニックCC宮崎, アダマンド工業, オムロン岡山, 東立通信工業, 山武コントロールプロ, ... |

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References

論文(mostly downloadable)

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Economics E-Journal (2009); arxiv/0901.2377

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Evolutionary and Institutional Economics Review (2011); arxiv/0901.2384

Y. Fujiwara and H. Aoyama,
Lage-Scale Structure of a nation-wide production network, 2010
European Physical Journal B (2010); arxiv/0806.4280

Y. Fujiwara,
Visualizing a large-scale structure of production network by N-body simulation, 2009.
Progress of Theoretical Physics Supplement (2009); arxiv/0901.2381

Y. Fujiwara,
Chain of firms bankruptcy: a macroscopic study of link effect in a production network.
and, this book (2010) of course!

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