Large-scale structure of a nation-wide production network and chain of bankruptcy

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production network
Two other essential inputs:
2. labors
3. financing
not focused here
Studies on models of production notably in overlapping communities between physics and economics e.g.

- inventory dynamics: Bak, Chen, Sheinkman, Woodford (1992)
  Sheinkman, Woodford (1994); Nirei (2000)
- suppliers/consumers NW: Weisbuch, Battiston (2007)
- credit NW: Battiston, Dell Gati, Gallegati, Greenwald, Stiglitz (2007)

Random NW or Regular NW assumed due to lack of empirical study
Data: Production NW
Nation-wide production network

Data: archived for credit-risk management (Tokyo S. Research)
Idea for collecting links:
A link is recorded when considered as “crucial” either by A or B

- 1 million firms (most all active firms) in japan
- 4 million directional links
- September 2006
- firm-size data and misc information provided
degree distributions

\[ \langle k_{\text{in}} \rangle \sim 4.5 \]

\[ P>(k) \propto k^{-\mu} \]

\[ \mu \sim 1.45 \]

Cumulative probability \( P_{>}(k) \)

Data (2006)
correlation to firm-size

Sales

Profit (pos./neg.)

data (2006)
clustering coefficient

\[ C_g \approx 1.87 \times 10^{-3} \]

cf. randomized NW with same deg. seq.

\[ C_g = \frac{\langle k \rangle}{N} \left[ \frac{\langle k^2 \rangle - \langle k \rangle}{\langle k^2 \rangle} \right]^2 \approx 1.81 \times 10^{-2} \]

A supplier of your suppliers is not your supplier.

Degree correlation

\[ r = -0.0747 \pm 0.0002 \quad (p < 10^{-7}) \]

Disassortative
community structure

0.14M manufacturing sector
Modularity optimization (Yutaka Leon Suematsu)
Force-directed spring+Coulomb+resistence
N-body simulation by GRAPE (gravity pipeline)
(Yuji Fujita, Atsushi Kawai)
Modularity optimization for undirected graph of 0.14 million manufacturers

<table>
<thead>
<tr>
<th>no.</th>
<th>annotation</th>
<th>firms (major groups; primary/secondary/tertiary), ...</th>
<th>[community-size]</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>heavy industry</td>
<td>Mitsubishi Heavy Industries (30/26), Kawasaki Heavy Industries (26/30), Ishikawajima-harima Heavy Industries (30/26), Sumitomo Heavy Industries (26), Nipponbashi Heavy Industries (30/27/23), Mitsui Engineering and Shipbuilding (30), Hitachi Zosen Shipbuilding (26), Sumitomo Metal Industries (23), ...</td>
<td>7,447</td>
</tr>
<tr>
<td>02</td>
<td>foods</td>
<td>Itoham Foods (09), Prima Meat Packers (09), Yamazaki Baking (09), Nissin Seifun (09), Maruha Nichiro Foods (09), Nippon Flour Mills (09), Q.P. Foods (09), Nihon Shokken Foods (09), Ichiyoshi Suisan Foods (09), Ichiban-foods (09), ...</td>
<td>7,115</td>
</tr>
<tr>
<td>03</td>
<td>transportation equipment</td>
<td>Honda (30/27), Nissan (30), Toyota Motor (30), Aisin (25/30/27), Mitsubishi Motors (30), Suzuki Motor (30), Isuzu Motors (30), ...</td>
<td>3,697</td>
</tr>
<tr>
<td>04</td>
<td>construction material</td>
<td>Sumitomo Osaka Cement (22), Air-Water Industrial Gas (17/18), Kyowa Conform (22), Hokusai Concrete (22), Marukin Steel Materials (23), Mitsubishi Construction Materials (25/22), Hitachi Steel/Manhole (23/22), Nihon Kogyo Industrial (22/13), Lafarge Aso Cement (22), Maeta Concrete (22), ...</td>
<td>3,082</td>
</tr>
<tr>
<td>05</td>
<td>pulp/paper</td>
<td>Oji Paper (15), Rengo Paper (15), Nippon Paper (15), Oji Chiyoda Container (15), Toyoda Morishigyo Paper (15), Settsu Carton (15), Morishigyo Paper Sales (15), Crown Package (15), Yamanotoshi Paper (15/19), ...</td>
<td>2,692</td>
</tr>
<tr>
<td>06</td>
<td>electronics(a)</td>
<td>Hitachi (28/29/27), Fujitsu (32/28), NEC (28/29), TDK (27/29), Oki Electric (28/29), Hitachi High-Technologies (31/26), Rohm Semi-conductors (29), Murata Electronics (27), IBM Japan (28), Japan Radio Communication Equipment (28/27), ...</td>
<td>2,320</td>
</tr>
<tr>
<td>07</td>
<td>electronics(b)</td>
<td>Matsushita (Panasonic) (27/31), Sharp (29/27/28), Sanyo (27/25), Panasonic (29/27/28), Pioneer (27/28), Matsushita Battery (27), Sanyo Tottori (28), Matsushita (27/26), Kenwood (28), CMK Electronic Devices (29), ...</td>
<td>1,567</td>
</tr>
<tr>
<td>08</td>
<td>electronics(c)</td>
<td>Canon (28/26/31), Seiko Epson (28/29), Omron (27), Nikon (31/26), Ricoh (26/28), Hoya Optics (31), Casio (26/31/28), Pentax Optics (31/28), Sony EMCS Electronic (27/28), ...</td>
<td>1,567</td>
</tr>
<tr>
<td>09</td>
<td>electronics(d)</td>
<td>Toshiba (27/28/29), Stanley Electric (27/26), Toshiba Lighting and Technology (27/26/29), Ushio Electric (25/27/26), Hamamatsu Photonics (29/27), Nippon Electric Glass (22), Toshiba Tec (26/27), GS Yuasa Industry (27/29), Iwasaki Electric (27), Topcon Electric (31), ...</td>
<td>1,567</td>
</tr>
<tr>
<td>10</td>
<td>apparel</td>
<td>Renoun Apparel (12), Onward Kashiyama Apparel (12), MC Knit Apparel (12), YKK Fastening and Accessories (12), World Apparel (12), ...</td>
<td>1,567</td>
</tr>
</tbody>
</table>
Data: Bankruptcy
#bankruptcies in 1-yr

- exhaustive
debt when bankrupt

> $10^7 \text{yen} \sim 10^5 \text{euro}$

- 0.13M / 2M firms

$\approx 1\% / yr$
black: failed triangle: entry of new firm (ignored)

Chain of bankruptcy
1. accounts receivable lost

Supplier-customer links

Nodes all bankrupted
Links: PN
at the time of 0411 / 2006
2. Failures of sibling firms

Creditor-debtor relation
Ownership relation

Nodes all bankrupted
Links: PN
3. depression in a same sector / a same geographical region

Modules/correlation structure

supplier-customer links relevant in many cases

Nodes all bankrupted
Links: PN
$B_m$ \#clusters of failed nodes surrounded by active nodes
Avalanche-size distribution
Ripple effect of avalanche
debt when bankrupted

\[ P_>(d) \propto d^{-\mu} \]

\begin{figure}
\centering
\includegraphics[width=\textwidth]{debt_distribution}
\caption{Cumulative distribution of debt when bankrupted.}
\end{figure}

Secondary effect example: bankrupted firm (regional retailer)

<table>
<thead>
<tr>
<th>classification</th>
<th>#creditors</th>
<th>amounts (thousand yen)</th>
</tr>
</thead>
<tbody>
<tr>
<td>accounts payable</td>
<td>firms upstream</td>
<td>65</td>
</tr>
<tr>
<td>leasing receivable</td>
<td>12</td>
<td>3,539,466</td>
</tr>
<tr>
<td>deposits</td>
<td>11</td>
<td>1,195,855</td>
</tr>
<tr>
<td>borrowing financial institutes</td>
<td>financial institutes</td>
<td>8</td>
</tr>
<tr>
<td>expenses</td>
<td>7</td>
<td>443,006</td>
</tr>
<tr>
<td>borrowing from non-financial</td>
<td>2</td>
<td>1,754,211</td>
</tr>
<tr>
<td>bonds</td>
<td>2</td>
<td>3,220,000</td>
</tr>
<tr>
<td>other obligation</td>
<td>1</td>
<td>125,000</td>
</tr>
<tr>
<td>sum</td>
<td>108</td>
<td>4,754,568</td>
</tr>
</tbody>
</table>
A bankrupted firm (center) and creditors
2-link upstream

ripple effect
1. Most vulnerable nodes are for firms who have only a limited number of customers (out-degrees) depending on modular structure of industrial sectors / geographical locations.

2. Large firms are not irrelevant to those small failures. Due to the heavy tail distribution of degrees, the vulnerable paths that influenced small-sized firms would be abundant in two or more links away from each of the large firms.
summary

Production network

- 1M nodes / 4M supplier-customer links
- Heavy-tail degree distribution, relation to firm-size
- Modular structure depending on industries and locations

Chain of bankruptcies on PN

- Distribution of chain-size
  - Much more frequent than accidental-chain-size
- Vulnerable paths and nodes in PN
acknowledgment

● data
Tokyo Shoko Research (Tokyo)
Datasets for intra-firms transactions, firm-size data, bankruptcy

● tools
Hideaki Aoyama  Theoretical calculation of accidental chain-size
Yutaka I. Leon Suematsu  Implementation of fast modularity optimization
Yuji Fujita, Atsushi Kawai  Force-directed large-graph-drawing by GRAPE

● comments/discussions
Yuichi Ikeda, Hiroshi Iyetomi, Wataru Souma
Mauro Gallegati, Stefano Battison

Y. Fujiwara and H. Aoyama
arXiv: 0806.4280
Link effect occupies 20% of total debts
Causes of bankruptcy

1. “Solo” failure
   - poor performance (business depression, excessive competition)
   - loose management (speculative investment)
   - accumulated deficit in long-term
   - insufficient working capital
   - etc.

2. “link” effect
   - secondary effect from bankruptcy of customer, subsidiary or collateral companies and failure of business-related firms
   - failure of accounts receivable

N.B. a bankruptcy can have more than one causes. classified according to largest weight in investigation.