Bank Networks: Contagion, Systemic Risk and Prudential Policy

Iñaki Aldasoro\textsuperscript{1} Domenico Delli Gatti\textsuperscript{2} Ester Faia\textsuperscript{3}

\textsuperscript{1}Goethe University Frankfurt & SAFE
\textsuperscript{2}Università Cattolica Milano
\textsuperscript{3}Goethe University Frankfurt, CFS & SAFE

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Financial Risk & Network Theory
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Motivation

- Trade off: *efficiency* (maximize banks’ investment in non-liquid risky assets) and *financial stability* (minimize systemic risk).
- Contribute to measurement and analysis of *systemic risk*, to help devise an ”appropriate” regulatory framework.
- Replicate stylized facts about real world interbank networks with a micro-founded model and market equilibrium
- Effects of different matching mechanisms on systemic risk
(Most closely) related literature

- Cifuentes, Ferrucci & Shin 2005 (CFS): network model of the interbank market (à la Eisenberg & Noe 2001) with endogenous price adjustment (see also Bluhm & Krahnen, 2014).
- Bluhm, Faia & Krahnen (current draft: 2014) (BFK) extend CFS introducing
  - *risk neutral optimizing banks*,
  - *ex post (after shocks) measure of systemic risk*
- Halaj & Kok (2014) + others on endogenous networks
Our contribution

- We extend BFK introducing
  - Risk averse optimizing banks,
  - Ex ante measures of systemic importance: network centrality & input-output measures (see Aldasoro and Angeloni 2013)
  - Ex post (after shock) measures of systemic risk: Shapley value.
  - Network metrics for different matching mechanisms

- Effects of changes in prudential policy
  - On systemic risk
  - Banks’ investments, interest rate, etc.
Financial contagion

- Channels of financial contagion (risk transmission):
  1. Credit interlinkages (network externalities)
  2. Fire sale of common non-liquid assets (pecuniary externalities)
  3. Liquidity hoarding

- Systemic risk is due to the spreading of defaults through these channels.
The connections of bank $i$

\[
c_i + n_i p + l_{i1} + l_{i2} + \ldots + l_{iN} = d_i + b_{i1} + b_{i2} + \ldots + b_{iN} + e_i \quad \text{(BSI)}
\]

\[\equiv l_i \equiv b_i\]
Shock: exogenous increase in nla supply $\Rightarrow \downarrow p$

Exogenous drop of the price of nla. Shock on all the banks holding nla.

Banks 1 and 3 violate capital requirement. They start selling nla.
Self-reinforcing downward pressure on price of nla

Further (endogenous) drop of the price of nla.

Banks i violates capital requirement. She starts selling nla

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Collapse in mkt value of banks’ assets might lead to default

Further (endogenous) drop of the price of nla.

Banks 1 and 3 default. Bank i experience further losses.
A bird’s eye view of the model

Banks optimize
\[ \text{ib tâtonnement} \]

\[ \text{ib mkt equilibrium} \]

Banks re-optimize (cash and nla)

Matching Algorithms

Financial System complete

\[ \text{Shock hits} \]

Compute network metrics & systemic importance

\[ \text{ib transmission} \]

Fire sales of nla

\[ \text{nla tâtonnement} \]

Compute systemic risk
The problem of the bank

- Choose $c_i$, $n_i$, $l_i$, $b_i$ to maximize CRRA utility of expected profits:

$$V_i = V(E(\pi_i)) = \frac{\left(n_i \frac{r_i^n}{p} + l_i r^l - b_i r_i^b \right)^{1-\sigma}}{1 - \sigma}$$

- Subject to (BSI), liquidity and equity requirements (+ n.n.c.)

$$c_i \geq \alpha d_i$$ (LR)

$$\epsilon_i := \frac{c_i + n_i p + l_i - d_i - b_i}{\omega n p n_i + \omega l i} \geq \gamma + \tau$$ (ER)

- Given $d_i$ and $e_i$, optimization yields supply and demand for interbank loans $l_i$ and $b_i$ given the current rate $r^l$ (price of nla $=1$ in setting up financial system)
Tâtonnement on the interbank market

- Why? Demand and supply will not be mutually consistent after initial optimization (given starting value of $r^l$)
- Auctioneer evaluates total demand ($B$) and supply ($L$) of ib loans
  - If $B > L$ ($B < L$) $\implies$ ↑ $r^l$ ($\downarrow r^l$)
  - Let banks optimize again given the new $r^l$
  - continue until equilibrium is achieved
- We obtain two vectors $l = [l_1, l_2, .., l_N]$ and $b = [b_1, b_2, .., b_N]$ that are mutually consistent, such that $B = L$
- But ...who is lending to whom and who is borrowing from whom? (i.e. how does the matrix of ib exposures look like?)
Matching and the formation of the network

- To answer this we experiment with three matching algorithms:
  - **Maximum Entropy (MEA):** distributes lending and borrowing as evenly as possible,
  - **Closest Matching (CMA):** associates closest demand and supply,
  - **Random Matching (RMA):** random pairing of banks with a load factor.

- The algorithm determines the *topology of the network*.

- By construction, MEA yields very high density, CMA yields very low density, RMA yields a density which falls in between.
Life after a shock: *nla* mkt tâtonnement

- Pre-shock, $p = 1$
- Post-shock, supply and price of *nla* are affected
- Banks sell *nla* to fulfill ER
- $s_i'(p) < 0 \implies s_n'(p) < 0$
- CFS inverse demand
  $\rightarrow p = \exp(-\beta d_n)$
- Equilibrium $s_n = d_n$
  $\rightarrow \Theta(p) = \exp(-\beta s(p))$
Systemic importance and systemic risk

- *Ex ante* measures of vulnerability
  - Network centrality measures (degree (in, out), closeness, betweenness, eigenvector)
  - Input-output based measures (Aldasoro & Angeloni (2014))

- *Ex post* measure: ratio of the value of assets of defaulting banks (grouped in the set $\Omega$) to total assets:

$$\Phi = \frac{\sum_{\Omega} \text{assets}_\Omega}{\sum_{i} \text{asset}_i}$$

- Contribution of each bank to systemic risk → *Shapley value*:

$$\Xi_i(v^\Psi) = \frac{1}{N!} \sum_{O \in \pi_N} (v^\Psi(\Delta^i(O) \cup i) - v^\Psi(\Delta^i(O)))$$
## Calibration

<table>
<thead>
<tr>
<th>Par./Var.</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N$</td>
<td>Number of banks in the system</td>
<td>20</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Liquidity requirement ratio</td>
<td>0.10</td>
</tr>
<tr>
<td>$\omega_n$</td>
<td>Risk weight on non-liquid assets</td>
<td>1</td>
</tr>
<tr>
<td>$\omega_l$</td>
<td>Risk weight on interbank lending</td>
<td>0.20</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>Equity requirement ratio</td>
<td>0.08</td>
</tr>
<tr>
<td>$\tau$</td>
<td>Desired equity buffer</td>
<td>0.01</td>
</tr>
<tr>
<td>$d_i$</td>
<td>Bank deposits</td>
<td>Top20 EA</td>
</tr>
<tr>
<td>$e_i$</td>
<td>Bank equity</td>
<td>Top20 EA</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>Bank risk aversion</td>
<td>2</td>
</tr>
<tr>
<td>$r^n_i$</td>
<td>Return on non-liquid assets</td>
<td>$U(0, 0.15)$</td>
</tr>
<tr>
<td>$\Psi$</td>
<td>Shocks to non-liquid assets</td>
<td>$\mathcal{N}(5, 25 \times \mathbb{I})$</td>
</tr>
</tbody>
</table>

**Table 1**: Baseline calibration
## Network metrics

<table>
<thead>
<tr>
<th></th>
<th>RAS</th>
<th>CMA</th>
<th>RMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (%)</td>
<td>35.53</td>
<td>6.05</td>
<td>17.11</td>
</tr>
<tr>
<td>Degree (Av.)</td>
<td>6.75</td>
<td>1.15</td>
<td>3.25</td>
</tr>
<tr>
<td>Av. Path Length</td>
<td>1.20</td>
<td>2.66</td>
<td>1.58</td>
</tr>
<tr>
<td>Betweenness Cent. (Av.)</td>
<td>0.25</td>
<td>4.05</td>
<td>8.55</td>
</tr>
<tr>
<td>Eigenvector Cent. (Av.)</td>
<td>0.13</td>
<td>0.14</td>
<td>0.08</td>
</tr>
<tr>
<td>Clustering Coeff. (Av.)</td>
<td>0.14</td>
<td>0.0003</td>
<td>0.07</td>
</tr>
<tr>
<td><strong>Assortativity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>out-in degree</em></td>
<td>-0.94</td>
<td>-0.31</td>
<td>-0.39</td>
</tr>
<tr>
<td><em>in-out degree</em></td>
<td>-0.05</td>
<td>0.09</td>
<td>-0.12</td>
</tr>
<tr>
<td><em>out-out degree</em></td>
<td>-0.52</td>
<td>-0.65</td>
<td>-0.43</td>
</tr>
<tr>
<td><em>in-in degree</em></td>
<td>-0.40</td>
<td>-0.19</td>
<td>-0.32</td>
</tr>
</tbody>
</table>

**Table 2**: Network characteristics - Baseline setting
Example of network configuration

(a) CMA
(b) RAS (Maximum Entropy)

Figure 1: Baseline network configuration examples
Figure 2: Contribution to systemic risk (mean SV), by bank and network.
Shapley value vs. bank characteristics

Figure 3: RAS network
IO measures vs. bank characteristics

Figure 4: RAS network - RH Backward index
Figure 5: RAS network

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Systemic risk as a function of LR and ER

**Figure 6**: Total Systemic Risk for different values of $\alpha$

**Figure 7**: Total Systemic Risk for different values of $\gamma$
Nla/equity and iblend/ta as a function of LR and ER
Ib rate and IO measures as a function of LR and ER

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To do list (to name just a few...)

- Study the effects of risk coming from the liability side
  → liquidity crises (information-based bank runs)
  → arrival of information dependent on post-shock ability of the bank to service depositors
- Refine the partner’s choice
- Endogenize net worth (go dynamic)
- Study interaction of fiscal/monetary policy measures with capital/liquidity requirement
THANK YOU!

✉️ aldasoro@safe-uni.frankfurt.de
✉️ domenico.delligatti@unicatt.it
✉️ faia@wiwi.uni-frankfurt.de