Interconnectedness of the banking sector as a vulnerability to crises

Peter Sarlin (Hanken School of Economics and RiskLab Finland)
joint with Tuomas Peltonen (ESRB) and Michela Rancan (European Commission)

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The views expressed in this presentation do not necessarily represent those of the ECB or the European Commission.
Financial activities occur in a complex network of agents
  - Important to shed light on dynamics implied by financial flows
    in a wider network than among banks

Systemic risk along time & cross-sectional dimensions
  - Early-warning models (EWMs) to identify build-up of risk
  - Networks to assess interdependence in the cross section

This paper...
  - ...enriches an EWM with network measures
  - ...studies interconnectedness as a vulnerability to crises
    - Domestic vs. international linkages?
    - Difference among instruments?
    - Non-linear effects?
Early-warning models

- To identify vulnerable states of a country’s banking system
- Estimate the probability of being in a vulnerable state
- Set a threshold on the probability to optimize a loss function

Macro-network

- Financial network of institutional sectors for many economies:
  - MFI, INS, OFI, NFC, GOV, HH and ROW
- Financial instruments
  - Loans, deposits, debt and shares
MFI as a nexus of risks

- Macroeconomic shocks in input-output
  - Demand-side shocks propagate upstream (input suppliers)
  - Supply-side ... propagate downstream (customer industries)

- Financial shocks in the macro-network:
  - Lability-side: propagate to shareholders, debtors, depositors
  - Asset-side: propagate (downstream) to creditors
  - MFI vulnerable to shocks on both sides of the balance sheet and the two are tightly intertwined.

- MFI a direct holder & intermediary depending on instrument:
  - Loans: Main sector extending (Credit risk)
  - Deposits: Important source of funding, yet depositors may easily withdraw money (Funding and liquidity risks)
  - Debt securities & shares: Hold assets valued at market prices (market risk) and issues bonds & equity (funding risk)
Cross-border linkages
Macro-network

Instrument: debt securities Q1 2009. [1]
Outline

- Related literature
- Data & methods
- Results
- Conclusion
Related literature

- **EWMs:**

- **Network analysis:**
  - Fagiolo et al. (2010), Kubelec & Sa (2010), Billio et al. (2012), Chinazzi et al. (2013), Minoiu et al. (2013)

- **Contagion effects via balance sheets:**
  - Adrian & Shin (2008), Castrén & Rancan (2014)
Sample spans 2000Q1–2013Q4 for 14 European countries

Crisis events: ESCB Heads of Research Initiative (Babecky et al., 2013)

Macro-financial indicators: international investment position, government debt and its yield and private sector credit flow, asset prices, business cycle variables (Eurostat and Bloomberg)

Banking sector indicators: measuring balance-sheet booms, securitization, and leverage (BSI and MFI from ECB)

Macro-network:
- the Euro Area Accounts (EAA from ECB)
- the Balance Sheet Items statistics (BSI from ECB)
We define a network as follows [1]

- Nodes are the institutional sectors of the economy
- Linkages
  - Cross-borders (i.e. $MFI_{AT} \Leftrightarrow MFI_{BE}$): observed information in the BSI data
  - Domestic (i.e. $NFC_{AT} \Leftrightarrow INS_{AT}$): estimated with an improved maximum entropy (ME) using the EAA data
Methods - Macro-network

- Cross-border linkages
  - Increased MFI cross-border flows with the single currency but less financial integration across other sectors
  - Exception: Cross-border links between MFI & GOV on debt securities, yet data scarce & discontinuities impact centrality
  - ROW partially accounts for ‘missing’ linkages across borders

- Domestic linkages
  - ME to estimate links with relative shares of total assets & liabilities for each sector, and accommodate possessed additional information as in Castrén & Rancan ('13)
  - Heterogeneity in links at country level due to structural differences (e.g., INS and OFI important in Ireland & Netherlands, much less in Spain & Italy)
  - ME assumptions are quite reasonable for sector-level data
Methods - Macro-network

Loans: \( \sim \) Complete network, large (MFI-NFC) & small (OFI-NFC)

Real

Estimated
Methods - Macro-network

Deposits: Incomplete network

Real

Estimated
Methods - Network measures

1. A macro-network for each time $t$ and financial instrument:
   - loans
   - deposits
   - debt securities
   - shares

2. For each macro-network we derive a set of network measures
   - Degree-in (out): sum of a node’s incoming (outgoing) links
   - Betweenness: a measure of influence of a node (“hub”)
   - Closeness: a measure the absolute position of a node

   Yet, centrality measures are highly correlated with each other

3. PCA reduces centrality to fewer but representative components
Methods - Evaluation criterion

- Apply usefulness criterion (Sarlin, 2013):

<table>
<thead>
<tr>
<th>Actual class $I_j$</th>
<th>Crisis</th>
<th>No crisis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>True positive (TP)</td>
<td>False positive (FP)</td>
</tr>
<tr>
<td>No signal</td>
<td>False negative (FN)</td>
<td>True negative (TN)</td>
</tr>
</tbody>
</table>

- Find the threshold that minimizes a loss function that depends on policymakers’ preferences $\mu$ between Type I errors ($T_1 = FN/(FN + TP)$) (missed crises) and Type II errors ($T_2 = FP/(TN + FP)$) (false alarms) and unconditional probabilities of the events $P_1$ and $P_2$

  \[
  L(\mu) = \mu T_1 P_1 + (1 - \mu) T_2 P_2
  \]

- Define absolute usefulness $U_a$ as the difference between the loss of disregarding the model (available $U_a$) and the loss of the model

  \[
  U_a(\mu) = \min \left[ \mu P_1, (1 - \mu) P_2 \right] - L(\mu)
  \]
Relative usefulness $U_r$ is the ratio of captured $U_a$ to available $U_a$, given $\mu$ and $P_1$

$$U_r(\mu) = \frac{U_a(\mu)}{\min[\mu P_1, (1 - \mu) P_2]}$$

Estimation:

- Pooled logit to identify vulnerable states (horizon: 8 quarters) with costs for missing a crisis > false alarms ($\mu = 0.8$)
- In-sample analysis to assess determinants
- Real-time analysis to assess predictability
  - Use investors' information set: quarterly data including publication lags
  - Estimation sample: 2000Q1-2005Q2, out-of-sample: 2005Q3-2013Q1 (t+1 projection)
# Results - Macro-network

<table>
<thead>
<tr>
<th>Baseline</th>
<th>PC1 - MN - All</th>
<th>PC2 - MN - All</th>
<th>PC3 - MN - All</th>
<th>PC4 - MN - All</th>
<th>AUC</th>
<th>$U_r(\mu = 0.7)$</th>
<th>$U_r(\mu = 0.8)$</th>
<th>$U_r(\mu = 0.9)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>0.35***</td>
<td>-0.13</td>
<td>0.06</td>
<td>0.69***</td>
<td></td>
<td>0.12</td>
<td>0.23</td>
<td>0.23</td>
</tr>
<tr>
<td>(2)</td>
<td>0.36***</td>
<td>-0.13</td>
<td>0.06</td>
<td>0.69***</td>
<td></td>
<td>0.25</td>
<td>0.37</td>
<td>0.23</td>
</tr>
<tr>
<td>(3)</td>
<td>0.37***</td>
<td>-0.16</td>
<td>-0.10</td>
<td>0.49</td>
<td></td>
<td>0.29</td>
<td>0.39</td>
<td>0.36</td>
</tr>
<tr>
<td>(4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.79</td>
<td>0.30</td>
<td>0.42</td>
<td>0.36</td>
</tr>
<tr>
<td>(5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.80</td>
<td>0.38</td>
<td>0.49</td>
<td>0.36</td>
</tr>
</tbody>
</table>

The baseline model 1 includes macro-financial and banking-sector indicators. In models 2–5, we add the 1–4 components computed with PCA on the centrality measures (Degree-in, Degree-out, Betweenness, Closeness) for the financial instruments.
### Results - Cross-border linkages

<table>
<thead>
<tr>
<th>MN</th>
<th>Cross-border variables</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
<th>(7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC1-All</td>
<td>0.32***</td>
<td>0.37***</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC2-All</td>
<td>-0.11</td>
<td>-0.14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC3-All</td>
<td>-0.48***</td>
<td>-0.68***</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC4-All</td>
<td>0.89**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loans</td>
<td></td>
<td></td>
<td>0.53***</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deposits</td>
<td></td>
<td></td>
<td></td>
<td>0.54***</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Debt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.40***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shares</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.37***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AUC</td>
<td>0.80</td>
<td>0.78</td>
<td>0.79</td>
<td>0.77</td>
<td>0.77</td>
<td>0.76</td>
<td>0.76</td>
<td>0.76</td>
</tr>
<tr>
<td>$U_r(\mu 0.7)$</td>
<td>0.38</td>
<td>0.21</td>
<td>0.21</td>
<td>0.18</td>
<td>0.15</td>
<td>0.17</td>
<td>0.14</td>
<td>0.14</td>
</tr>
<tr>
<td>$U_r(\mu 0.8)$</td>
<td><strong>0.49</strong></td>
<td><strong>0.36</strong></td>
<td><strong>0.32</strong></td>
<td><strong>0.31</strong></td>
<td><strong>0.31</strong></td>
<td><strong>0.31</strong></td>
<td><strong>0.30</strong></td>
<td><strong>0.30</strong></td>
</tr>
<tr>
<td>$U_r(\mu 0.9)$</td>
<td>0.36</td>
<td>0.32</td>
<td>0.34</td>
<td>0.33</td>
<td>0.35</td>
<td>0.29</td>
<td>0.31</td>
<td>0.31</td>
</tr>
</tbody>
</table>

Model 1 is the macro-net benchmark. Models 2-3 include for cross-border linkages PCs on all centrality measures for all financial instruments. Models 2-5 include PCs computed separately for each instrument.
Results - Financial instruments

- MFIs more vulnerable to credit and market risks, yet...
- accounting for all instruments provides more precise signals

<table>
<thead>
<tr>
<th>Baseline</th>
<th>Varying financial instruments (1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC1 - MN - Loans</td>
<td></td>
<td>0.64***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC1 - MN - Deposits</td>
<td></td>
<td></td>
<td>0.44***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC1 - MN - Debt</td>
<td></td>
<td></td>
<td></td>
<td>0.54***</td>
<td></td>
</tr>
<tr>
<td>PC1 - MN - Shares</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.41***</td>
</tr>
<tr>
<td>AUC</td>
<td>0.73</td>
<td>0.78</td>
<td>0.77</td>
<td>0.78</td>
<td>0.76</td>
</tr>
<tr>
<td>$U_r(\mu = 0.7)$</td>
<td>0.27</td>
<td>0.27</td>
<td>0.18</td>
<td>0.21</td>
<td>0.17</td>
</tr>
<tr>
<td>$U_r(\mu = 0.8)$</td>
<td><strong>0.23</strong></td>
<td>0.40</td>
<td><strong>0.31</strong></td>
<td><strong>0.35</strong></td>
<td><strong>0.31</strong></td>
</tr>
<tr>
<td>$U_r(\mu = 0.9)$</td>
<td>0.23</td>
<td>0.29</td>
<td>0.32</td>
<td>0.32</td>
<td>0.32</td>
</tr>
</tbody>
</table>

Model 1 is the baseline. Models 2–5 add the 1st PC on the centrality measures (Degree-in, Degree-out, Betweenness, Closeness) for separate financial instruments.
Results - Non-linearity

Structure of the financial network and the resilience of the system

- Non-conclusive evidence: Acemoglu et al. ('15) show non-monotonic contagion effects of shocks
- Non-linearity effects are confirmed also in our setting

<table>
<thead>
<tr>
<th></th>
<th>MN</th>
<th>Loans</th>
<th>Deposits</th>
<th>Securities</th>
<th>Shares</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC1*[above p75]</td>
<td>1.10***</td>
<td>0.38**</td>
<td>0.64***</td>
<td>0.60***</td>
<td></td>
</tr>
<tr>
<td>PC1*[between p25 – 75]</td>
<td>2.66***</td>
<td>2.69***</td>
<td>3.31***</td>
<td>3.54***</td>
<td></td>
</tr>
<tr>
<td>PC1*[below p25]</td>
<td>0.21</td>
<td>0.38</td>
<td>-0.10</td>
<td>-0.45</td>
<td></td>
</tr>
<tr>
<td>AUC</td>
<td>0.80</td>
<td>0.82</td>
<td>0.78</td>
<td>0.82</td>
<td>0.81</td>
</tr>
<tr>
<td>$U_r(\mu = 0.7)$</td>
<td>0.38</td>
<td>0.36</td>
<td>0.21</td>
<td>0.30</td>
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<td><strong>0.45</strong></td>
<td><strong>0.34</strong></td>
<td><strong>0.41</strong></td>
<td><strong>0.39</strong></td>
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<td>0.38</td>
<td>0.28</td>
<td>0.41</td>
<td>0.40</td>
</tr>
</tbody>
</table>

MN includes all centrality measures & all instruments. Others include all centrality measures for individual instruments interacted with dummies.
Robustness exercises:

- policymakers’ preferences $\mu$
- forecast horizon (12/24/36 months)
- threshold $\lambda$

![Diagram showing ROC curves for different forecast horizons (12, 24, 36 months) and different models (Baseline, Network)].

- The x-axis represents the False Positive (FP) rate.
- The y-axis represents the True Positive (TP) rate.
- Each line represents a different forecast horizon and model combination.
Results - Real-time analysis

- Real-time analysis to assess predictability:
  - Estimation sample: 2000Q1-2005Q2, out-of-sample: 2005Q3-2013Q1 ($t+1$ projection)

AUC: 0.72 vs. 0.78
Conclusion

Summary

- Interconnectedness of the banking sector entails a vulnerability
  - Cross-border linkages capture vulnerabilities to crises...
  - ...and larger domestic sectoral linkages amplifies vulnerability...
  - ...which yields useful predictions
- Most vulnerability descends from loans and debt securities
- Non-linearity effects are confirmed also in our setting

To conclude

- Macro-networks: MFI vis-à-vis domestic sectors & multi-layer
- But this is only a first step, future research is needed to
  - Better understand the underlined macro-financial linkages
  - Deeper investigate sources of bank risk & their interactions
  - Evaluate how risks are shared across sectors
  - More detailed cross-border exposures
Thanks for your attention!