Network Linkages to Predict Bank Distress

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Research Focus

**Question:** Does the predictive performance of bank early-warning models improve by augmenting them with estimated bank interdependencies?

**Motivation:**
- Banking systems are highly interconnected: vulnerability of one bank is also impacted by the vulnerability of its neighbors.
- Existing early-warning models have focused solely on individual bank distress.

This project incorporates pass-through effects via estimated networks into an early-warning model for European banks.
Implementation:

1. Estimate standard bank-level early-warning models
2. Estimate tail-dependence networks using banks’ return innovations to account for contagion risk
   - markets’ view accounts also for indirect sources of interdependence (e.g. common/correlated exposures and behavioral aspects.)
   - markets are forward-looking.
3. Provide a two-step approach to augment early-warning models with contagion variables that account for pass-through of distress.
4. Evaluate and compare the out-of-sample performance of early-warning models.
Related literature

1. Various approaches for deriving early-warning models:
   - Frankel and Rose (1996) - ‘Logit analysis’
   - Kaminsky and Reinhart (1999) - ‘Signaling approach’
   - Demirguc-Kunt and Detragiache (2000) - ‘Logit analysis & loss function’
   - Holopainen and Sarlin (2014) - ‘Horse race of 14 techniques’
   - Lang, Peltonen, Sarlin (2015) - ‘LASSO approach for variable selection’

2. Bank-level models of interbank contagion and network effects:
   - Poon, Rockinger, Tawn (2004); Hartmann, Straetmans and De Vries (2005) - ’Extreme value theory and contagion risk’

3. Country-level early-warning models with network effects:
   - Rose and Spiegel (2009) - ‘MIMIC’
   - Minoiu, Kang, Subrahmanian, Berea (2013) - ‘Cross-border connectedness’
   - Rancan, Sarlin, Peltonen (2014) - ’Domestic and cross-border connectedness’
   - Hale, Kapan, Minoiu (2014) - ’Crisis Transmission in the Global Banking Network’

4. To our knowledge, no work on pass-through effects in early-warning models:
   Extend the work of Betz, Oprică, Peltonen and Sarlin (2014)
Measuring bank distress

1. Bankruptcies, liquidations and defaults that capture direct bank failures (sources: Moody’s, Fitch and Bankscope)

2. State aid (sources: European Commission, Bloomberg and Reuters)
   A bank is defined to be in distress if:
   ▶ it receives a capital injection from the state or
   ▶ it participates in an asset relief programme (asset protection or asset guarantees). It does not capture central bank liquidity support or guarantees on banks’ liabilities

3. Mergers in distress (sources: Bloomberg and Bankscope)
   ▶ a parent receives state aid within 12 months after merger or
   ▶ if a merged entity has a negative coverage ratio within 12 months before the merger

The dependent variable will be equal to 1 eight quarters prior to distress events and 0 otherwise.
Data Samples

The analysis is based on two separate datasets, one for listed European banks used to construct the banking network and another used in the initial early-warning model for individual banks:

1. **Network dataset**
   - daily frequency, from 01/01/1999 to 15/04/2014
   - stock prices for 243 listed European banks (Bloomberg)
   - country-specific equity price index from Datastream
   - aggregate European banking sector equity price index from Datastream

2. **Early-warning model dataset**
   - quarterly frequency, from Q1/1999 to Q3/2014
   - balance sheet data for 469 European banks with more than 1bln euros in assets, from Bloomberg
   - country-specific banking sector indicators from ECB MFI Statistics
   - country-specific macro-financial indicators from Bloomberg, Eurostat, Alert Mechanism Report
Explanatory variables in the benchmark EWS

- **Bank-specific balance-sheet indicators**

- **Country-specific banking sector indicators**
  Variables such as banking system leverage, non-core liabilities, loans to deposits, debt securities to liabilities, mortgages to loans, etc.

- **Country-specific macro-financial indicators**
  - Structural internal and external imbalance indicators based on the EU Macroeconomic Imbalance Procedure (MIP) variables,
  - Asset prices (house and stock prices, government bond spread),
  - Business cycle variables (real GDP and inflation)
Tail dependence network

Use extreme value theory techniques to measure the tail dependence between banks $i$ and $j$, based on the innovations of their filtered equity returns pair $(u_i, u_j)$.

- Banks’ demeaned equity return series are regressed on their lag, country equity return index, and the European banking sector return index:

$$r_{i,t} = \beta_i r_{i,t-1} + \beta_{C_i} r_{C_i,t} + \beta_{S} r_{S,t} + e_{i,t}$$

- The residuals are filtered using an asymmetric GARCH model and return innovations $(u_i, u_j)$ are extracted:

$$e_{i,t} = \sigma_{i,t} + u_{i,t}$$

where $\sigma_{i,j}$ follows an asymmetric GARCH(1,1) process
We remove the influence of marginal aspects by transforming the pair of innovations \((u_i, u_j)\) to common unit Fréchet marginals \((S, T)\), which keep the same dependence structure as the innovations.

The degree of extremal/asymptotic dependence \(\bar{\chi}\) for the bivariate case \((S, T)\) is computed using the following representation (Ledford and Tawn (1996)):

\[
\bar{\chi} = 2\eta - 1,
\]

\[
\text{var}(\hat{\bar{\chi}}) = (\hat{\bar{\chi}} + 1)^2 / k.
\]

where \(\eta\) is the tail index of the variable \(Z = \min(S, T)\) and \(k\) is the tail threshold.

\(\eta\) is estimated using the modified Hill estimator proposed by Huisman et. al (2001).

Finally, we assign a link between banks \(i\) and \(j\) if \(\bar{\chi} = 1\) (or \(\eta = 1\)) at conventional levels of statistical significance.
Network of EU banks, 2013Q3, vis.risklab.fi/#/tailnet
CrisisMetrics, http://cm.infolytika.com/
### Methodology

**CrisisModeler, http://cm.infolytika.com/**

![CrisisModeler Screenshot](https://cm.infolytika.com)

#### Table: Recursive out-of-sample results of selected methods

<table>
<thead>
<tr>
<th>Method</th>
<th>TP</th>
<th>FP</th>
<th>TN</th>
<th>FN</th>
<th>PP</th>
<th>RP</th>
<th>PN</th>
<th>RN</th>
<th>ACC</th>
<th>FPPrate</th>
<th>FNPrate</th>
<th>U_a</th>
<th>U_r</th>
<th>AUC</th>
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<tr>
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<td>229</td>
<td>227</td>
<td>2</td>
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<td>0.963</td>
<td>0.591</td>
<td>0.502</td>
<td>0.958</td>
<td>0.547</td>
<td>0.502</td>
<td>-0.008</td>
<td>-0.097</td>
<td>0.788</td>
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<tr>
<td>Decision tree</td>
<td>31</td>
<td>106</td>
<td>350</td>
<td>23</td>
<td>0.226</td>
<td>0.574</td>
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<td>0.768</td>
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<td>0.089</td>
<td>0.615</td>
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<td>0.981</td>
<td>0.997</td>
<td>0.783</td>
<td>0.804</td>
<td>0.217</td>
<td>0.019</td>
<td>0.444</td>
<td>0.523</td>
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<tr>
<td>Random forest</td>
<td>49</td>
<td>93</td>
<td>363</td>
<td>5</td>
<td>0.345</td>
<td>0.907</td>
<td>0.996</td>
<td>0.796</td>
<td>0.808</td>
<td>0.204</td>
<td>0.093</td>
<td>0.400</td>
<td>0.477</td>
<td>0.843</td>
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<tr>
<td>Neural network</td>
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<td>98</td>
<td>358</td>
<td>1</td>
<td>0.351</td>
<td>0.981</td>
<td>0.997</td>
<td>0.785</td>
<td>0.806</td>
<td>0.215</td>
<td>0.019</td>
<td>0.445</td>
<td>0.528</td>
<td>0.931</td>
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<tr>
<td>Support vector machine</td>
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<tr>
<td>Mean</td>
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<td>1.000</td>
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<tr>
<td>Best-of</td>
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<td>0.907</td>
<td>0.986</td>
<td>0.794</td>
<td>0.806</td>
<td>0.206</td>
<td>0.093</td>
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<td>0.472</td>
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<td>1.000</td>
<td>1.000</td>
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<td>0.279</td>
<td>0.000</td>
<td>0.035</td>
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</tbody>
</table>

**Note:**
- TP = True positives, FP = False positives, TN = True negatives, FN = False negatives, PP = Precision positives = TP/(TP+FP), RP = Recall positives = TP/(TP+FN), PN = Precision negatives = TN/(TN+FP), RN = Recall negatives = TN/(TN+FN), ACC = Accuracy = (TP+TN)/(TP+TN+FP+FN), FNRate = Type I error rate = FN/(TP+FN), FPRate = Type II error rate = FP/(FP+TN), U_a = absolute usefulness, U_r = relative usefulness, AUC = Area under the ROC curve.
Network density for European banks
Signal evaluation framework

- Use the evaluation framework of Demirgüç-Kunt and Detragiache (2000), Alessi and Detken (2011) and Sarlin (2012)

<table>
<thead>
<tr>
<th>Predicted class</th>
<th>Actual class</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 True positive (TP)</td>
</tr>
<tr>
<td>-1</td>
<td>False negative (FN)</td>
</tr>
</tbody>
</table>

- Find the probability threshold that minimizes the loss function that depends on:
  - policymaker’s preference $\mu$ between $T_1$ (missing crises) and $T_2$ errors (false alarms)
  - unconditional probabilities of the events $P_C$:
    \[
    L_\mu = \mu P_C T_1 + (1 - \mu)(1 - P_C) T_2
    \]

- Absolute usefulness $U_a$: the extent to which a model performs better than no model at all.

- Relative usefulness $U_r$: the proportion of usefulness that a policymaker would obtain compared to a perfectly performing model
  \[
  U_r = \frac{\min[\mu P_C, (1 - \mu)(1 - P_C)] - L(\mu)}{\min(\mu P_C, (1 - \mu)(1 - P_C))}
  \]
EWS estimation and calibration

We use a pooled logit model with country fixed effects to predict vulnerable states of banks, i.e. pre-distress periods, for in-sample data.

We construct the following contagion variables:

- **Network Dummy**: indicates for each bank whether there are any vulnerable banks to which it is estimated to be connected.
- **Network Sum**: counts how many vulnerable neighboring banks the bank has in its estimated tail dependency network.
- **Country Dummy**: indicates for each bank whether there are other banks being signaled as vulnerable in the same country.
- **Country Share**: the share of vulnerable banks of total banks in the respective country.

Highly imbalanced sample: the share of pre-distress periods in the out-of-sample prediction sample is 18.8% (in the whole sample 7.9%).

Set the benchmark preference parameter $\mu = 0.85$; building an EWS with imbalanced data implicitly necessitates a policymaker to be more concerned about the rare class (need to have a preference to predict distress.)
Methodology

EWS estimation and calibration

Iterative estimation of out-of-sample distress probabilities, for each quarter $q$ from 2007Q1-2012Q3:

1. Estimate the benchmark early-warning model on the in-sample period:
   \[ p_i = Pr(y_{it} = 1) = \Lambda(\beta X_{it}) , \]

2. Choose the probability thresholds $\lambda$ that maximizes in-sample Usefulness:
   \[ y_{it} = \begin{cases} 1 & \text{if } \hat{p}_i > \lambda \\ 0 & \text{otherwise} \end{cases} \]

3. Collect signals $y_{it}$ from the previous estimation and signal the neighbours of vulnerable banks. Introduce contagion variable back in the benchmark model:
   \[ p_i^* = Pr(y_{it} = 1) = \Lambda(\beta X_{it} + \gamma NC_{it}) , \]

4. Choose the new optimal threshold $\lambda^*$ with respect to in-sample Usefulness and use it to signal out-of-sample vulnerable banks:
   \[ y_{it}^* = \begin{cases} 1 & \text{if } \hat{p}_i^* > \lambda^* \\ 0 & \text{otherwise} \end{cases} \]
## Estimation Results for in-sample data

**Full sample, country fixed effects**

### Intercept
- **Benchmark**: -6.07 ***
- **Country dummy**: -5.9 ***
- **Country share**: -5.58 ***
- **Network dummy**: -6.11 ***
- **Network sum**: -6.65 ***

### Total leverage ratio
- **Benchmark**: -4.55 ***
- **Country dummy**: -4.47 ***
- **Country share**: -4.38 ***
- **Network dummy**: -3.95 ***
- **Network sum**: -3.51 ***

### ROA
- **Benchmark**: 0.71 ***
- **Country dummy**: 0.69 ***
- **Country share**: 0.54 *
- **Network dummy**: 0.66 **
- **Network sum**: 0.54 *

### Cost to Income
- **Benchmark**: -4.03 ***
- **Country dummy**: -3.87 ***
- **Country share**: -3.89 ***
- **Network dummy**: -3.51 ***
- **Network sum**: -2.09 ***

### Net short-trem borrowing to Liabilities
- **Benchmark**: 0.51 ***
- **Country dummy**: 0.51 ***
- **Country share**: 0.48 ***
- **Network dummy**: 0.41 ***
- **Network sum**: 0.41 ***

### Share of trading income to Revenue
- **Benchmark**: -2.57 ***
- **Country dummy**: -2.49 ***
- **Country share**: -2.23 ***
- **Network dummy**: -2.44 ***
- **Network sum**: -2.09 ***

### Total assets to GDP
- **Benchmark**: 13.73 ***
- **Country dummy**: 12.45 ***
- **Country share**: 9.49 ***
- **Network dummy**: 13.15 ***
- **Network sum**: 10.63 ***

### Debt to equity
- **Benchmark**: -1.07 ***
- **Country dummy**: -1.06 ***
- **Country share**: -1.09 ***
- **Network dummy**: -1.05 ***
- **Network sum**: -0.86 **

### Loans to deposits
- **Benchmark**: 0.82 *
- **Country dummy**: 0.75 *
- **Country share**: 0.83 *
- **Network dummy**: 0.79 *
- **Network sum**: 0.82 *

### Debt securities to liabilities
- **Benchmark**: 1.03 **
- **Country dummy**: 0.82 
- **Country share**: 0.38
- **Network dummy**: 0.99 *
- **Network sum**: 1.16 **

### Real GDP
- **Benchmark**: 0.21 *
- **Country dummy**: 0.19
- **Country share**: 0.14
- **Network dummy**: 0.18
- **Network sum**: 0.11

### Long-term government bond yield
- **Benchmark**: 0.51 ***
- **Country dummy**: 0.49 ***
- **Country share**: 0.23 *
- **Network dummy**: 0.49 ***
- **Network sum**: 0.37 **

### Government debt to GDP
- **Benchmark**: -1.86 ***
- **Country dummy**: -1.66 ***
- **Country share**: -1.82 ***
- **Network dummy**: -1.82 ***
- **Network sum**: -1.53 ***

### Private sector credit flow to GDP
- **Benchmark**: 0.33 **
- **Country dummy**: 0.3 *
- **Country share**: 0.12
- **Network dummy**: 0.31 *
- **Network sum**: 0.19

### Country contagion dummy
- Benchmark: 8.51 ***

### Country contagion share
- Benchmark: 5.93 **

### Network contagion dummy
- Benchmark: 9.26 ***

### Network contagion sum
- Benchmark: 8.79 ***

### N
- 3150

### R squared
- 0.05
Model Evaluation

Contagion based on estimated vulnerabilities only, $\mu = 0.85$.

<table>
<thead>
<tr>
<th>Model</th>
<th>AUC</th>
<th>$U_r$</th>
<th>FN rate</th>
<th>FP rate</th>
<th>TN rate</th>
<th>TP rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-estimation Benchmark</td>
<td>0.8941</td>
<td>0.5800</td>
<td>0.1799</td>
<td>0.2095</td>
<td>0.7905</td>
<td>0.8201</td>
</tr>
<tr>
<td>2-estimation Benchmark</td>
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<td>0.5770</td>
<td>0.1799</td>
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<tr>
<td>Country Dummy</td>
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<td>0.1691</td>
<td>0.2214</td>
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<tr>
<td>Country Share</td>
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<td>0.5904</td>
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<tr>
<td>Network Dummy</td>
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<tr>
<td>Network Sum</td>
<td>0.8986</td>
<td>0.6444</td>
<td>0.1655</td>
<td>0.1620</td>
<td>0.8380</td>
<td>0.8345</td>
</tr>
</tbody>
</table>

(Peter Sarlin, Hanken & RiskLab)
Case study

DEXIA SA and its neighbours

- DEXIA SA
- BNP PARIBAS
- BANK OF IRELAND
- ALPHA BANK A.E.

Early warning signal

Distress event

(Peter Sarlin, Hanken & RiskLab)
Robustness

Change in $\mu$

<table>
<thead>
<tr>
<th>$\mu=0.80$</th>
<th>AUC</th>
<th>$U_r$</th>
<th>FN</th>
<th>FP</th>
</tr>
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<tbody>
<tr>
<td>1est Bm</td>
<td>0.8941</td>
<td>0.6295</td>
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<td>2est Bm</td>
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<td>0.1978</td>
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</table>

<table>
<thead>
<tr>
<th>$\mu=0.90$</th>
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</table>

Include historical distresses and impose convergence of signals ($\mu = 0.85$)

<table>
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<tr>
<th>hist. distress</th>
<th>AUC</th>
<th>$U_r$</th>
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Conclusion

Objective: to incorporate pass-through effects into an early-warning model to proxy for the interconnected European banking system.

This project...

▶ ...provides a two-step approach to account for pass-through effects
▶ ...empirically highlights the importance to complement standard early-warning indicators with measures of pass-through effects.

The approach is general in nature

▶ The framework for incorporating pass-through effects lends to various contexts, such as country-level models.
▶ The approach is not dependent on how the network is obtained; it helps comparing the efficiency of different network estimations.
Thank you for your attention
<table>
<thead>
<tr>
<th>Bank-specific balance sheet variables</th>
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