Application of Systemic Risk Early Warning Indicators for (Polish) Macroprudential Policy

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Outline

1. Introduction and motivation
2. Polish banking sector
3. Stress testing framework
4. Systemic risk early warning indicator model
5. Testing for early warning
6. Data
7. Results
8. Conclusions
9. References
Introduction

- The last financial crisis (2007-?) pointed out deficiencies in the policy-makers response to systemic risk
- Duality and complexity of systemic risk sources for small open emerging economies (SOEE):
  - Macroprudential level:
    - Expansionary domestic monetary or/and fiscal policy used to be a catalyst of excessive credit supply and permissive risk management policies that generate system-wide risks for financial system
    - Integration of global financial markets and deregulation of cross-border capital movements open a gate for transmission of foreign macroeconomic policy shocks
  - Microprudential level:
    - Opaque and oligopolistic interconnections between large financial institutions amplify externalities stemming from excessive leverage and procyclical financial institutions business models
    - Broad group of the banks reacts in the very similar way to the external shocks (one-approach-fits-all) what is a source of inefficiency of the individual answers to the distress
- Risks tackling financial sector cannot be perceived as aggregations of individual institution’s risks
Systemic risk analysis

- Filling key analytical gaps of the systemic risk analysis of the Polish banking sector:
  - Developing and improving National Bank of Poland’s (NBP) systems of financial and prudential data collection to close systemic risk information gap
  - Designing analytical toolkit to support systemic risk identification, modelling and measurement in a forward-looking manner as a part of common stress-testing framework

- Using output of the analytical toolkit in the process of developing in cooperation with Polish Financial Supervisory Authority (FSA) fully-fledged national macroprudential policy framework:
  - To proactively detect shocks affecting Polish banking sector
  - To intervene as early as possible to reduce the impact of potential stresses on the whole Polish financial system
Closing data gaps

- Ensuring access to accurate and reliable financial and prudential statistics of Polish banking sector and Polish financial markets:
  - Measures of interconnections: gauging interlinkages among institutions (especially systemically important ones), sectors and countries,
  - Indicators of institutions and sectors cross-border dependencies and cross-border investment flows
  - Measures of common exposures and funding concentrations
  - Statistics of leverage
  - Measures financial markets risks (assets prices volatility)
  - Banks balance sheets data and ratios
  - Data on banks’ collateral practices
  - Measures of maturity mismatches and financial imbalances

- Special attention paid to highly leveraged foreign investors on domestic capital markets (hedging funds, foreign bank’s trading desks)
Motivation - developing systemic risk toolkit

- Developing toolkit of systemic risk identification and measurement as a part of National Bank of Poland’s common stress-testing framework

- Trying to integrate analysis of time and cross-sectional nature of systemic risk:
  - Time dimension: addressing evolution of system-wide risk over time taking into account risk stemming from banking sector procyclicality, amplifications of credit action, assets prices bubbles, excessive leverage and maturity mismatches
  - Cross-sectional dimension: addressing distribution of risk in the financial system at a certain point of time analysing risk concentrations caused by similarity of banking sector institutions’ exposures of the and direct balance and off-balance sheet interlinkages among banks

- Output of the NBP’s analytical toolkit (set of systemic risks indicators) used to conduct macroprudentially motivated interventions of Polish Financial Supervisory Authority in the inter-agency cooperation.
From the results of the analysis to policy making

- NBP’s expertise is used to provide background for FSA recommendations restraining activities with extraordinary returns: e.g. caps on LtV and Ltl/Dtl ratios in mortgage lending
- Polish FSA direct interventions when particular bank breaches capital or liquidity requirements, when it aggressively increases its appetite on particular risk type or engages too much in cross-currency founding
- Close cooperation of National Bank of Poland and Financial Supervisory Authority strongly required as application of macroprudential instruments influences the monetary policy transmission mechanism. Ongoing initiative to institutionalize inter-agency systemic risk management in Poland: establishing Systemic Risk Council (National Bank of Poland, Financial Supervisory Authority, Ministry of Finance)
- Analytical background of Polish Systemic Risk Council: Division in the NBP’s Department of Statistics that in cooperation with academics and practitioners collects financial and prudential data related to systemic risk and provides research frameworks
Characteristics of the Polish banking sector con’t

Key ratios for 2012, percentages:

Sources: NBP and IMF’s FSI database
Characteristics of the Polish banking sector con’t

Key ratios for 2012, percentages:

![Graph showing key ratios for 2012, percentages for Poland, France, Italy, and UK.]

Sources: NBP and IMF’s FSI database
## Polish Systemically Important Institutions

<table>
<thead>
<tr>
<th>Bank Name</th>
<th>Country</th>
<th>31 Dec 2012 ($Mn)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HSBC</td>
<td>UK</td>
<td>2,671,318</td>
</tr>
<tr>
<td>BNP Paribas</td>
<td>FR</td>
<td>2,482,950</td>
</tr>
<tr>
<td>Credit Agricole</td>
<td>FR</td>
<td>2,353,553</td>
</tr>
<tr>
<td>Deutsche Bank</td>
<td>DE</td>
<td>2,222,620</td>
</tr>
<tr>
<td>Barclays</td>
<td>UK</td>
<td>2,161,889</td>
</tr>
<tr>
<td>Societe Generale</td>
<td>FR</td>
<td>1,703,809</td>
</tr>
<tr>
<td>Groupe BPCE</td>
<td>FR</td>
<td>1,549,682</td>
</tr>
<tr>
<td>Banco Santander</td>
<td>SP</td>
<td>1,538,811</td>
</tr>
<tr>
<td>Lloyds Banking Group</td>
<td>UK</td>
<td>1,395,436</td>
</tr>
<tr>
<td>PKO Bank Polski</td>
<td>PL</td>
<td>66,410</td>
</tr>
<tr>
<td>Bank Pekao (UniCredit S.p.A., 50.10%)</td>
<td>PL/IT</td>
<td>52,837</td>
</tr>
<tr>
<td>Bank Zachodni WBK (Banco Santander, 75.19%)</td>
<td>PL/SP</td>
<td>35,364</td>
</tr>
</tbody>
</table>

Sources: NBP and The Banker database
National Bank of Poland’s Stress Testing Framework

1. Introduction
2. Polish banking sector
3. Stress testing framework
5. Testing for early warn.
6. Data
7. Results
8. Conclusions
9. References
National Bank of Poland’s Stress Testing Framework

1. Introduction
2. Polish banking sector
3. Stress testing framework
5. Testing for early warning
6. Data
7. Results
8. Conclusions
9. References

- NBP’s Stress Testing Framework (NBP-STF) is an assembly of econometric models that provide consistent quantitative framework of risk assessment in the Polish banking sector.
- It allows to examine the impact of the most important types of risk on the whole Polish banking sector and in bank-by-bank manner.
- The NBP-STF models the dynamics of the Polish banking sector entities’ balance sheets in the response to macroeconomic and financial shocks.
- It is a class of models developed by Aikman et al. (Risk Assessment Model for Systemic Institutions - RAMSI) for the Bank of England and the system developed for Oesterreichische Nationalbank (OeNB) for the Austrian banking system.
National Bank of Poland’s STS – satellite models

• Financial/macroeconomic scenarios generators:
  • Mixed Frequencies Dynamic Factor Models – MF-DFMs
  • Uni- and Multivariate Markov Switching Models - U/M-MSMs
  • Markov Switching Dynamic Factor Models – MS-DFMs
  • Structural models
  • Dynamic Stochastic General Equilibrium Models
National Bank of Poland’s STS – credit risk

• The measure of the credit risk exposure of asset $i$ of bank $b$ at time $t$ is Bank-Specific Credit Loss Rate (BSCLR)
• It is modelled with set of equations:

\[
BSCLR_{t}^{b,i} = \alpha_{t}^{b,i} + \beta_{t}^{b,i} (ACL_{t}^{i} - \bar{ACL}^{i})
\]

\[
\alpha_{t}^{b,i} = (1 - \rho^{b})\mu^{b,i} + \rho^{b} \alpha_{t-1}^{b,i}
\]

where:

- $ACL_{t}^{i}$ is the aggregate credit loss rate of asset class $i$
- $\bar{ACL}^{i}$ is the long-run aggregate of $ACL_{t}^{i}$
- $\alpha_{t}^{b,i}$ is the actual write-off rate of bank $b$’s asset class $i$
- $\mu^{b,i}$ is historical average of $BSCLR_{t}^{b,i}$
- $\rho^{b}$ is the bank $b$’s speed of convergence to the historical average $\mu^{b,i}$
National Bank of Poland’s STS – household credit risk

- The measure of the aggregate household credit risk for the whole banking sector at time $t$ is household Aggregated Credit Loss rate (ACL)
- It is modelled with the following formula:

$$ACL_t^h = \alpha^h + \beta^h PD_t^{h-2} + \gamma^h \left( \frac{P_t^{res}}{P_t^{res-8}} - 1 \right)$$

where:
- $PD_t^{h}$ is the probability of default for households loans
- $P_t^{res}$ is residential property price index

- The probability of default of household loans is modelled with separate equation:

$$PD_t^{h} = \alpha^{PD,h} + \beta^{PD,h} IG_{t-4} + \gamma^{PD,h} UEQ_{t-2} + \chi^{PD,h} UNEMP_{t-2}$$

where IG is income gearing, UEQ is undrawn equity (one minus the ratio of household mortgage debt to housing wealth) and UNEMP is unemployment rate
1. Introduction
2. Polish banking sector
3. Stress testing framework
5. Testing for early warning
6. Data
7. Results
8. Conclusions
9. References

National Bank of Poland’s STS – corporate credit risk

• The measure of the aggregate corporate credit risk for the whole banking sector at time t is corporate Aggregated Credit Loss rate (ACL)

• It is modelled with the equation:

\[ ACL_{t}^{corp} = \alpha^{corp} + \beta^{corp} \cdot PD_{t-2}^{corp} + \gamma^{corp} \left( \frac{P_{t}^{comm}}{P_{t-8}^{comm}} - 1 \right) \]

where:
- \( PD_{t}^{corp} \) is the probability of default for corporates
- \( P_{t}^{comm} \) is commercial property price index

• The probability of default of corporates is modelled separately:

\[ PD_{t}^{corp} = \alpha^{PD,corp} + \beta^{PD,corp,L4} \cdot \Delta \ln RGDP_{t-4} + \beta^{PD,corp,L8} \cdot \Delta \ln RGDP_{t-8} \]

\[ + \gamma^{PD,corp} \cdot \Delta \ln P_{t-8}^{com} + \chi^{PD,corp} \cdot \left( \frac{M_{4}L}{NGDP} \right)_{t-4} + \eta^{PD,corp} \cdot r_{t}^{corp} \]

where RGDP is real GDP, M4L is M4 lending, NGDP is nominal GDP and \( r_{t}^{corp} \) is nominal effective corporate interest rate
National Bank of Poland’s STS – profit/loss model

• The profit/loss model consists of four modules:
  • Net interest income module
  • Non-interest income less trading module
  • Trading income module
  • Operating expenses module
• The net interest income (NII) of bank $b$ at time $t$ is described with equation:

$$NII_t^b = \sum_i r_{l_t}^{b,i} A_t^{b,i} - \sum_j r_{b_t}^{b,j} L_t^{b,j}$$

where

- $r_{l_t}^{b,i}$ is bank $b$’s lending rate asset class $i$
- $r_{b_t}^{b,j}$ is bank $b$’s borrowing rate asset class $j$
- $A_t^{b,i}$ is bank $b$’s amount of assets class $i$
- $L_t^{b,j}$ is bank $b$’s amount of liability class $j$

- The bank $b$’s lending rate for asset $i$ is a function of risk free rate at time $\tau$ and bank-specific credit loss rate
- The $r_{b_t}^{b,j}$ is a function of WIBOR and bank rating
National Bank of Poland’s STS – profit/loss model con’t

- The non-interest income less trading income (NIILTI) of bank \( b \) is represented with the equation:

\[
\frac{NIILTI_t^b}{A_{t-1}^b} = \alpha^{NIILT,b} + \beta^{NIILT} \frac{NIILTI_{t-1}^b}{A_{t-2}^b} + \gamma^{NIILT} \Delta \ln RGDP_t
\]

\[
\alpha^{NIILT,b} = (1 - \beta^{NIILT}) \frac{NIILTI_{t-1}^b}{A_{t-2}^b} + \gamma^{NIILT} \Delta \ln RGDP_t
\]

where \( \overline{NIILTI}_{t-1}^b \) and \( \Delta \ln RGDP_t \) are long-run averages of the variables.

- The bank \( b \)’s trading income (TI) is given with the equation:

\[
\frac{TI_t^b}{TA_{t-1}^b} = \alpha^{TI} + \beta^{TI} \frac{TI_{t-1}^b}{TA_{t-2}^b} + \gamma^{TI} \frac{\Delta TA_t^b}{TA_{t-1}^b} + \chi^{TI} (\Delta \ln EI_t)^2
\]

where

- \( TA_t^b \) is value of bank \( b \)’s net trading asset
- \( EI_t \) is equity index from Warsaw stock exchange
National Bank of Poland’s STS – profit/loss model con’t

- The last module, operating expenses (OPEX) model, consists of two equations:

\[
\frac{OPEX_t^{b}}{NIILTI_t^{b}} = \alpha^{OPEX,b} + \beta^{OPEX} \frac{OPEX_{t-1}^{b}}{NIILTI_{t-1}^{b}} + \gamma^{OPEX} \Delta \ln RGDP_t
\]

\[
\alpha^{OPEX,b} = (1 - \beta^{OPEX}) \frac{OPEX_t^{b}}{NIILTI_t^{b}} + \gamma^{OPEX} \Delta \ln RGDP_t
\]

where \(OPEX_t^{b}\) and \(\Delta \ln RGDP_t\) are long-run averages of the variables.
National Bank of Poland’s STS – liquidity model

• The liquidity risk model consists of three components:
  • The first one applies Monte Carlo method to assess impact of the negative macroeconomic and financial scenarios on the liquidity buffers of the selected banks
  • The second one tries to mimics the reaction of the banks tackled with the liquidity shock, that starts fire sales of the available assets to restore the initial liquidity buffer size. In the case of negative shocks convolution the fire sales and crowded trading generate systemic risk for a group of financial entities
  • The third component quantifies the second round effect stemming from systemic risk materialization. The bigger entities are involved in the process, the greater is their amount and the more similar reactions are taken, the more more prominent systemic risk impact is observed.
National Bank of Poland’s STS – network model

1. Introduction
2. Polish banking sector
3. Stress testing framework
5. Testing for early warn.
6. Data
7. Results
8. Conclusions
9. References

- Network model of systemic risk allows modelling direct relations among banking sector entities resulting from financial instruments exposures and structure of the capital.
- Banking sector at time $t$ consists of $N$ entities (network nodes). Particular financial entity $i$ balance sheet at time $t$ consists of:
  - Liabilities:
    - Aggregated equity capital $\sum_{j=1}^{N} CS_{t}^{i,j} EV_{t}^{j}$ where $CS_{t}^{i,j}$ is fraction of share (range $[0,1]$) of the bank $j$ belonging to the bank $i$ ($CS_{t}^{i,j} \geq 0$) and $EV_{t}^{j}$ is equity capital of bank $j$
    - External liabilities with the net due value $EL_{i}^{j}$
    - Interbank liabilities owed to the institution $j$ with net due value $L_{i}^{j} (L_{i}^{j} \geq 0)$
  - Assets
    - External assets replenished with net income $NI_{i}^{j} L_{i}^{k,j} (L_{i}^{k,j} \geq 0)$
    - Interbank assets replenished with net receivables.
1. Introduction
2. Polish banking sector
3. Stress testing framework
5. Testing for early warning
6. Data
7. Results
8. Conclusions
9. References

Capital channel:

\[ \sum_{j=1}^{N} CS_{t,j}^{i,j} EV_{t}^{j} \]

Interbank liabilities channel:

\[ \sum_{j=1}^{N} L_{t}^{i,j} \]
National Bank of Poland’s STS – network model con’t

Banks’ interlinkages network:

1. Introduction
2. Polish banking sector
3. Stress testing framework
5. Testing for early warn.
6. Data
7. Results
8. Conclusions
9. References
National Bank of Poland’s STS – network model con’t

1. Introduction
2. Polish banking sector
3. Stress testing framework
5. Testing for early warn.
6. Data
7. Results
8. Conclusions
9. References

• Stream of supposed (contractual) payments of the bank $i$ at time $t$:

$$P_t^i = \sum_{j=1}^{N} L_{t}^{i,j} + EL_{t}^{i}$$

• If bank $i$ net exogenous income and receivable from other entities are not enough to cover its net due liabilities to other entities from the sector and outside, it pays proportionally:

$$\Pi_{t}^{i,j} = \begin{cases} 
\frac{L_{t}^{i,j}}{P_{t}^{i}} & \text{if } P_t^i > 0 \\
0 & \text{in the other case}
\end{cases}$$

• Actual payments of the bank $i$ at time $t$:

$$AP_{t}^{i} = \begin{cases} 
P_t^i & \text{if } P_t^i \leq \sum_{k=1}^{N} L_{t}^{k,i} + NI_{t}^{i} \\
\sum_{k=1}^{N} L_{t}^{k,i} + NI_{t}^{i} & \text{in the other case}
\end{cases}$$
National Bank of Poland’s STS – network model con’t

- Values of capital shares at period $t$ ($CS^i_{t:j}$) are stored in matrix $CS_t$ ($N\times N$)
- Value of banks’ equity capital at period $t$ ($EV^i_t$) are stored in a vector $EV_t$ ($N\times 1$)
- Mutual net due liabilities ($L^i_{t:j}$) of the banking sector entities at period $t$ are gathered in a matrix $L_t$ ($N\times N$)
- Values of banks’ external net income at period $t$ ($NI^i_t$) are stored in a vector $NI_t$ ($N\times 1$)
- Values of banks’ external net due liabilities at period $t$ ($EL^i_t$) are stored in a vector $EL_t$ ($N\times 1$)
- Supposed due payments of the banks ($P^i_t$) are stored in vector $P_t$ ($N\times 1$)
- Proportional payments of the banks ($\Pi^i_t$) are stored in matrix $\Pi_t$ ($N\times N$)
- Actual payments of the banks at period $t$ are stored in vector $AP_t$ ($N\times 1$)
- The model is defined with set of matrices/vectors $\{CS_t, EV_t, L_t, NI_t, EL_t\}$. At period $t = 0$ elements of the mentioned matrices’ set are calculated (or approximated) with help of prudential statistics.
- Supposed due payments vector ($P^i_t$) proportional payments matrix ($\Pi_t$) and actual payments vector ($AP^i_t$) are derived from them.
National Bank of Poland’s STS – network model con’t

- For the above set of matrices a map of projection is constructed ($\mathbf{0}$ is a vector of nulls sized Nx1):

$$M(NI^i_t, \Pi^t_i, CS^i_t, EV^i_t, AP^t_i) = [NI^i_t + \Pi^t_i AP^t_i - AP^t_i + CS_t EV^i_t] \times \mathbf{0}$$

- For a given vector of real payments $AP^t_i$, exists one fixed point $M$ corresponding to a vector of values of the share capital of particular banks ($EV(\overline{AP^t_i})$) computed as:

$$EV(\overline{AP^t_i}) = [NI^i_t + \Pi^t_i AP^t_i - AP^t_i + CS_t EV_t(\overline{AP^t_i})] \times \mathbf{0}$$

- The selected fixed point corresponds to a vector of actual payments $AP^i_t$, called also clearing payment vector

$$AP^i_t = \begin{cases} 
0 & \text{if } NI^i_t + \sum_{j=1}^{N} (\Pi_{I}^{i,j} \overline{AP^j_t} + CS_{I}^{i,j} EV_{I}^{j}(\overline{AP^j_t})) < P^i_t \\
NI^i_t + \sum_{j=1}^{N} (\Pi_{I}^{i,j} \overline{AP^j_t} + CS_{I}^{i,j} EV_{I}^{j}(\overline{AP^j_t})) & \text{if } 0 < NI^i_t + \sum_{j=1}^{N} (\Pi_{I}^{i,j} \overline{AP^j_t} + CS_{I}^{i,j} EV_{I}^{j}(\overline{AP^j_t})) < P^i_t \\
P^i_t & \text{if } P^i_t \leq NI^i_t + \sum_{j=1}^{N} (\Pi_{I}^{i,j} \overline{AP^j_t} + CS_{I}^{i,j} EV_{I}^{j}(\overline{AP^j_t}))
\end{cases}$$
1. Introduction
2. Polish banking sector
3. Stress testing framework
5. Testing for early warn.
6. Data
7. Results
8. Conclusions
9. References
Mixed-measurement dynamic factor model (MM-DFM)

• Mixed-measurement dynamic factor model (MM-DFM, Koopman, Lucas, Schwaab, 2011)

• Allows to compute coincident and leading measures of systemic risk based on latent systemic risk factors using a panel of time series observations

• The MM-DFM assumes that systemic risk stems mainly from the credit risk materialized in the banking books

• The input dataset consists of:
  • \( N \) macroeconomic and financial variables grouped in the vector:
    \[
    x_t = (x_{1t}, \ldots, x_{Nt})'
    \]
  • Historical default frequencies (HDF) for \( R \) regions (cross-section \( j=1,\ldots,J \) represents different categories of firms):
    \[
    y_t = (y_{1,1t}, \ldots, y_{1,Jt}, \ldots, y_{R,1t}, \ldots, y_{R,Jt})'
    \]
  • Expected default frequencies (EDF) for \( S \) financial entities from each region \( r=1,\ldots,R \):
    \[
    z_t = (z_{1,1t}, \ldots, z_{1,S_{1t}}, \ldots, z_{R,1t}, \ldots, z_{R,S_{Rt}})'
    \]
Mixed-measurement dynamic factor model (MM-DFM) con’t

- All variables \((x_t, y_t, z_t)\) are driven by a vector of common dynamic factors
- Conditional on latent factors, the variables \((x_t, y_t, z_t)\) are independent over time and within the cross-section
- The factors in the vector are divided to macro (shared business cycle), regional frailty (region-specific), and industry-specific (affecting firms from specific industry) subgroups:

\[
 f'_t = (f'_t^m, f'_t^d, f'_t^i)
\]

- The model assumes that macroeconomic and financial variables are determined only by macro factors

\[
x_{nt} \mid f^m_t \sim \text{Gaussian}(\mu_n, \sigma^2_n)
\]

- The other variables \((y_t, z_t)\) are determined by all types of factors:

\[
 y_{rtj} \mid f^m_t, f^d_t, f^i_t \sim \text{Binomial}(k_{rtj}, \pi_{rtj})
\]

\[
 z_{rst} \mid f^m_t, f^d_t, f^i_t \sim \text{Gaussian}(\mu_{st}, \sigma^2_s)
\]

where \(k_{rtj}\) is number of trials with point-in-time default probability \(\pi_{rtj}\)
and \(z_{rst} = \log(z_{rst} / (1 - z_{rst}))\).
Mixed-measurement dynamic factor model (MM-DFM) con’t

- The dynamics of \((x_t, y_t, z_t)\) depends on time-varying parameters that can be written as functions of dynamic factors \(f_t\):

\[
\mu_{nt} = c_n + \beta_n^t f_t^m
\]

\[
\theta_{r,jt} = \lambda_{r,j} + \beta_{r,j}^t f_t^m + \gamma_{r,j}^t f_t^d + \delta_{r,j}^t f_t^i
\]

\[
\mu_{r,jt} = c_{r,s} + \beta_{r,s}^t f_t^m + \gamma_{r,s}^t f_t^d + \delta_{r,s}^t f_t^i
\]

Where \(\lambda_{r,j}, c_n\) and \(c_{r,s}\) represent fixed effects, \(\beta, \gamma\) and \(\delta\) factor loadings respectively.

- The dynamics of the latent factors' vector \(f_t = (f_t^m, f_t^d, f_t^i)'\) follows the independent autoregressive dynamics:

\[
f_t = \Phi f_{t-1} + \eta_t \quad \eta_t \sim NID(0, \Sigma_\eta)
\]

- As the input data cross-section dimension is reduced with the following restriction imposed on initial parameters:

\[\chi_{r,j} = \chi_0 + \chi_{1,d,j} + \chi_{2,s,j} + \chi_{3,r,j} \quad \text{for} \quad \chi = \lambda, \beta, \gamma, \delta, \beta, \gamma, \delta\]

- The identification of the factor loading is ensured with the condition \(\Sigma_\eta = I - \Phi \Phi'\)
Mixed-measurement dynamic factor model (MM-DFM) con’t

- The state-space representation of the MM-DFM allows easy handling of missing values
- The analytical form of the MM-DFM (log) likelihood function cannot be found easily because of embedded binomial density
- Therefore the parameters of the presented model are estimated with the simulated maximum(log) likelihood (SML) approach
- SML applies the Monte Carlo simulations to evaluate approximation of the likelihood function
- Numerical optimizers are used to maximize the Monte Carlo likelihood function
Mixed-measurement dynamic factor model (MM-DFM) con’t

- The output of MM-DFM allows to compute a set of coincident and early warning indicators of systemic risk.
- The two simple coincident indicators are implied by parameters of the model:
  - The fraction of financial entities that are expected to fail over the next three months – it is interpretation of time-varying default probabilities $\pi_{r,jt}$.
  - The probability of simultaneous failure of a large group of financial entities – the joint probability of failure computed with binomial cumulative distribution function applied to the financial sector failure rates.
- The composite coincident indicators:
  - Systemic Credit Risk Indicator (SCRI), given for firms of type $j$ in the region $r$ at time $t$ as:
    $$ SCRI_{r,jt} = \Phi(z_{r,jt}^{\theta}) $$
  where $\Phi(z)$ is standard normal cumulative distribution function applied to the time-varying parameters estimated in the model
  $$ z_{r,jt}^{\theta} = (\theta_{r,jt} - \lambda_{r,j}) / \sqrt{Var(\theta_{r,jt})} $$
Mixed-measurement dynamic factor model (MM-DFM)
con’t

• The early warning indicators:
  • Expected Number of Financial Defaults (ENFD) over the next year conditional of at least one financial default observed
  \[ ENFD_{r,j} = k_{r,j} \pi_{r,j} / (1 - \text{Binomial}(0; k_{r,j}, \pi_{r,j})) \]
  • “Surprise measure” based on a signal whether probability of the default in the particular industry and region is unexpectedly different from the default measure derived from the macro fundamentals. This indicator is called credit risk deviation (CRD) early warning indicator and is defined as:
  \[ CRD_{r,j} = \left| \gamma'_{r,j} f_t^d + \delta'_{r,j} f_t^i \sqrt{\gamma'_{r,j} \gamma_{r,j} + \delta'_{r,j} \delta_{r,j}} \right| \]
Testing for early warning – Granger causality

- The Granger Causality test is based on two subtests: p-value score and lag-length score and computed as their average.
- The p-value score is computed with the results of the four tests between early warning indicator (EWI) and coincident indicator CI, proving that the last one Granger causes the EWI at selected lag-length (LL)

\[ EWI_t = \alpha + \sum_{l=1}^{LL} \beta_{l} EWI_{t-l} + \sum_{l=1}^{LL} \gamma_{l} CI_{t-l} + \epsilon_t \]

- The positive weight is given for the lags for which the p-values are less than 0.01 and if there is no reverse Granger-causality from the EWI to CI
- The assigned weight is equal to the length of the lag
- The final p-value score is computed as the sum of the scores on each lag length divided by the sum of the lag length
- The lag-length score is computed with OLS regression applied to EWI and CI with different lags specified in the particular equation

\[ EWI_t = \alpha + \sum_{l=1}^{LL} \beta_{l} EWI_{t-l} + \sum_{l=1}^{LL} \gamma_{l} CI_{t-l} + \epsilon_t \]

- The p-values of t-tests on the coefficients of each of the \( l_l \) lags of the CI are used to construct the weighting scheme similar to the one described above
Testing for early warning – predicting extreme events

- Extreme systemic risk events are depicted with values of early warning indicators exceeding certain threshold TR (EWI ≥ TR)
- The binary variable:
  \[ y = \begin{cases} 
  1 & \text{for } EWI \geq TR \\ 
  0 & \text{in the other case} 
\end{cases} \]

is an approximation of probability of extreme systemic risk event
- Probability of extreme systemic risk event is estimated as logit regression for particular set of lag-lengths (LL)
  \[
  \Pr ob(EWI_t \geq TR \mid CI_t, B; ll) = \frac{e^{X'B}}{1 + e^{X'B}} \quad \text{where} \quad X'B = \alpha + \sum_{ll=1}^{LL} \beta_{ll} EWI_{t-ll} + \sum_{ll=1}^{LL} \gamma_{ll} CI_{t-ll}
  \]
- The total score of the test is the average the p-values of the Wald-test and the p-values of McFadden R-squares from each regression.
  - The Wald test component is computed as one minus weighted average of p-values obtained for each lag-length, with weights equal to the lag value.
  - The McFadden R-square component is computed as lag-length weighted average of the obtained McFadden R-squares
Testing for early warning – turning points detection

- Autoregressive regressions with 4 lags (AR(4)) are estimated for surveyed indicator

\[ EWI_t = \alpha + \sum_{l=1}^{4} \beta_{ll} EWI_{t-l} + \epsilon_t \]

- The Quandt-Andrews break point (QABP) test (a test for identifying an unknown break point) is conducted for each of the regressions. Mentioned test provides the possible break point date for each of the analyzed indicators for each test.

- If the turning points are statistically significant (at the 5% level), turning points are assigned a score based on how far ahead they occurred before arbitrary set of TPs, with earlier dates receiving higher ranks.
## Data

Sample: 2008Q4-2013Q4

<table>
<thead>
<tr>
<th>Polish macroeconomic/Financial Data</th>
<th>EU macroeconomic/Financial Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real GDP</td>
<td>Analogously to given above plus:</td>
</tr>
<tr>
<td>Nominal GDP</td>
<td>Euro Share Price Index,</td>
</tr>
<tr>
<td>Industrial Production Index</td>
<td>Euro Interbank Offered Rate (EURIBOR), 3M</td>
</tr>
<tr>
<td>Inflation (harmonized CPI)</td>
<td>Euro Area Industrial Confidence Indicator</td>
</tr>
<tr>
<td>Unemployment Rate</td>
<td></td>
</tr>
<tr>
<td>WIG20 (Warsaw Stock Exchange Price Index)</td>
<td></td>
</tr>
<tr>
<td>Warsaw Interbank Offered Rate (WIBOR), 3M</td>
<td></td>
</tr>
<tr>
<td>M4 lending</td>
<td></td>
</tr>
<tr>
<td>Government Bond Yield, 3Y</td>
<td></td>
</tr>
<tr>
<td>Government Bond Yield, 10Y</td>
<td></td>
</tr>
<tr>
<td>House/Commercial property prices</td>
<td></td>
</tr>
<tr>
<td>Commercial properties prices</td>
<td></td>
</tr>
<tr>
<td>Income gearing/Mortgage debt to housing wealth</td>
<td></td>
</tr>
<tr>
<td>Corporate lending</td>
<td></td>
</tr>
<tr>
<td>Oil prices</td>
<td></td>
</tr>
<tr>
<td>Business Climate Indicator PL</td>
<td></td>
</tr>
</tbody>
</table>

1. Introduction
2. Polish banking sector
3. Stress testing framework
4. Systemic risk EWI model
5. Testing for early warning
6. Data
7. Results
8. Conclusions
9. References
Data con’t

<table>
<thead>
<tr>
<th>Polish/EU Bank’s ratings</th>
<th>Moodys’ rating transition histories</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Moody’s KMV Credit Edge EDF</td>
</tr>
<tr>
<td>Polish/EU Bank’s balance sheets: 5 maturity buckets, 5 repricing buckets</td>
<td>100 assets’ classes entries</td>
</tr>
<tr>
<td></td>
<td>50 liabilities’ classes entries</td>
</tr>
</tbody>
</table>
# General plan of the survey

<table>
<thead>
<tr>
<th>Phase</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data extraction and transformation</td>
<td>Prepare data for both frameworks</td>
</tr>
<tr>
<td></td>
<td>Compute Expected Default Frequencies for largest 20 Polish/EU banks and their 1st principal component</td>
</tr>
<tr>
<td>Application of NBP’s Stress-testing framework</td>
<td>Estimate a multivariate density of distress connected with credit, liquidity and systemic risk</td>
</tr>
<tr>
<td></td>
<td>Compute time-varying joint probability of distress (JPoD EWI) of all analysed institutions by estimating distress-dependence by copula function</td>
</tr>
<tr>
<td>Application of MM-DFM</td>
<td>Compute composite coincident indicator (Systemic Credit Risk Indicator)</td>
</tr>
<tr>
<td></td>
<td>Compute composite early warning indicator (Expected Number of Financial Defaults) – MM-DFM EWI</td>
</tr>
<tr>
<td>Testing computed indicators’ characteristics</td>
<td>Use three selected testing procedures to check characteristics of two computed early warning indicators and their competitor (output of multivariate logit model LM)</td>
</tr>
</tbody>
</table>
Extracting common pattern from EDF data for largest 20 Polish banks

- Log-odds from EDF data for the largest 20 Polish financial banks

Source: own estimations
Extracting common pattern from EDF data for largest 20 Polish banks

- First PC from 20 largest Polish financial institutions’ EDFs,

Source: own estimations
## MM-DFM parameter estimates

<table>
<thead>
<tr>
<th>Intercepts $\lambda_j$</th>
<th>Loadings $f_i^{cm}$</th>
<th>Loadings $f_i^{d}, f_i^{i}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>param.</td>
<td>value</td>
<td>t-value</td>
</tr>
<tr>
<td>$\lambda_0$</td>
<td>-4.91</td>
<td>10.21</td>
</tr>
<tr>
<td>$\lambda_{1,fin}$</td>
<td>-1.12</td>
<td>4.95</td>
</tr>
<tr>
<td>$\lambda_{1,POL}$</td>
<td>-1.41</td>
<td>5.09</td>
</tr>
<tr>
<td>$\lambda_{1,EU}$</td>
<td>-1.03</td>
<td>4.18</td>
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<tr>
<td>$\beta_{2,0}$</td>
<td>0.11</td>
<td>1.15</td>
</tr>
<tr>
<td>$\beta_{2,1,fin}$</td>
<td>0.14</td>
<td>1.35</td>
</tr>
<tr>
<td>$\beta_{2,2,POL}$</td>
<td>0.09</td>
<td>1.11</td>
</tr>
<tr>
<td>$\beta_{2,2,EU}$</td>
<td>-0.12</td>
<td>2.03</td>
</tr>
<tr>
<td>$\beta_{3,0}$</td>
<td>0.13</td>
<td>1.91</td>
</tr>
<tr>
<td>$\beta_{3,1,fin}$</td>
<td>-0.09</td>
<td>1.62</td>
</tr>
<tr>
<td>$\beta_{3,2,POL}$</td>
<td>-0.07</td>
<td>1.11</td>
</tr>
<tr>
<td>$\beta_{3,2,EU}$</td>
<td>0.13</td>
<td>1.52</td>
</tr>
<tr>
<td>$\beta_{4,0}$</td>
<td>0.43</td>
<td>5.48</td>
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<tr>
<td>$\beta_{4,1,fin}$</td>
<td>-0.21</td>
<td>2.04</td>
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<tr>
<td>$\beta_{4,2,POL}$</td>
<td>-0.03</td>
<td>0.53</td>
</tr>
<tr>
<td>$\beta_{4,2,EU}$</td>
<td>0.18</td>
<td>1.42</td>
</tr>
</tbody>
</table>
1. Introduction
2. Polish banking sector
3. Stress testing framework
4. Systemic risk EWI model
5. Testing for early warning
6. Data
7. Results
8. Conclusions
9. References

Source: own estimations
1. Introduction
2. Polish banking sector
3. Stress testing framework
4. Systemic risk EWI model
5. Testing for early warning
6. Data
7. Results
8. Conclusions
9. References

Source: own estimations
Performance of Systemic Risk Early Warning Indicators for Poland

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Granger Causality (GC)</th>
<th>Forecasting Extreme Value Event (FEV)</th>
<th>Turning Point Detection (TPD)</th>
<th>Aver.</th>
</tr>
</thead>
<tbody>
<tr>
<td>MM-DFM</td>
<td>0.49</td>
<td>0.61</td>
<td>0.58</td>
<td>0.56</td>
</tr>
<tr>
<td>JPoD</td>
<td>0.44</td>
<td>0.68</td>
<td>0.34</td>
<td>0.49</td>
</tr>
<tr>
<td>LM</td>
<td>0.12</td>
<td>0.52</td>
<td>0.46</td>
<td>0.37</td>
</tr>
</tbody>
</table>

Source: own estimations
Conclusions

- The MM-DFM model based early warning indicators is a very good supplement of the early warning systemic risk measures (JPoD) computed as the output of the NBP’s Stress Testing Framework.
- MM-DFM EWI is stable ex-ante approximation of the Polish banking sector systemic risk coincident indicator. It mimics all three key peaks of the systemic risk materialization in 2009, 2011 and 2012.
- MM-DFM EWI outperforms JPoD measure in two of three early warning power tests, namely Granger Causality (GC) and Turning Point Detection (TPD). Both indicators are superior to Multivariate Logit Model (LM) competitor.
- It is worthy to noticed that even in the case of extreme systemic risk materialization in the Polish banking sector the (standardized) values of the coincident and (three) EWI’s didn’t exceeded the threshold of 0.8.
Conclusions con’t

- The observed moderate systemic risk tackling Polish banking sector is a consequence of traditional model of running business by vast majority of the banks operating in Poland the domestic banking sector is generally immune to endogenous and exogenous sources of systemic risk.

- Relative low value of liabilities of Polish banks resulting from (secured and unsecured) interbank loans, balanced structure of assets (with extremely small share of structured instruments like ABS, MBS, etc.), adequate level of leverage of the majority of institutions and excessed liquidity of the Polish banking sector are strong pillars of the Polish banking sector stability.

- However the ownership structure of the Polish banks and high proportion of foreign currencies (mainly CHF) denominated mortgages are the main factors that can affect Polish banking sector stability in the future.
Literature overview

- Sources of systemic risk:

- Alternative models of systemic risk measurement: