Shock Amplification in an Interconnected Financial System of Banks and Investment Funds

2021 Federal Reserve Stress Testing Research Conference

7-8 October 2021

Matthias Sydow
European Central Bank
Disclaimer

The views expressed in this presentation are those of the authors and do not necessarily represent the views of the European Central Bank and the Eurosystem.
Motivation and overview
Overview

• **Workstream on system-wide stress testing (SWST):**
  Developing an operational framework using **firm-level data** to model sector-specific stress at the granular level and allow capturing the **effects of interconnectedness** within the financial system.

• **Until now: Evaluation of (i) the Covid-19 severe scenario of the 2020 ECB Vulnerability Analysis and of (ii) NGFS climate risk scenarios:**
  – ‘Shock amplification in an interconnected financial system of banks and investment funds’ by Sydow et al. (2021), ECB Working Paper No. 2581
  – ‘Amplification of climate scenarios in an interconnected financial system of banks and investment funds’ (Box 8) in ‘Climate-related risk and financial stability’, ESRB Report (2021)
Granular, granular, granular…
The need for a fine-grained yet holistic perspective

Monitoring an interconnected financial system involves the availability of detailed and granular data.

Mario Draghi, Welcome remarks ESRB annual conference 27 September 2018
International cooperation is needed to develop tools for stress testing but now at system-wide level.

Luis de Guindos, Global financial regulation 21 May 2019

The big picture was too blurry [aggregate]. […] Better and more granular data are necessary.

Sabine Lautenschläger, 20 years of ECB Statistics 07 October 2018

A system-wide perspective is a key advantage […].

Yves Mersch, Appointment hearing 4 September 2019

System-wide stress tests have been established as an important tool for monitoring financial stability.

Luis de Guindos, The evolution of stress-testing in Europe 4 September 2019

A holistic assessment of the impacts on systemic stability […] is needed.

Benoît Cœuré, Policy analysis with big data 3 May 2016

It is time to rethink the design of stress tests.

Andrea Enria, ESRB annual conference 26 September 2019

Only a holistic view of the system will allow potential contagion channels to be identified and modelled. […] Developing the analytical toolkit to adequately monitor interconnectedness and contagion requires granular datasets, and the ability to map and link data across entities and markets.

Mario Draghi, ESRB annual conference 26 September 2019
SWST: a step-by-step approach

Conceptual framework (2019)
- All financial sectors
- High-level description

Initial operational framework (2020)
- Banks and funds
- Based on data
- Detailed mechanisms
- Full set-up for results production
- Understanding of results
- Documentation via ECB WP (VA Covid-19 scenario)

Augmented op. framework (2021)
- Add other sectors (insurers, HF)
- New data consistency
- New detailed mechanisms
- Understanding of results
- Documentation via new ECB WP (use e.g. climate risk scenario)

Final operational framework (2022)
- tbd…
## Literature I.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Sectors</th>
<th>Multi-variate shock</th>
<th>Multi-country</th>
<th>Liquidity and solvency</th>
<th>Overlapping portfolios</th>
<th>Fire sales</th>
<th>Security-level price impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aikman et al. (2019)</td>
<td>Banks, funds, ICPF (representative agents)</td>
<td>✓</td>
<td>✗</td>
<td>✓</td>
<td>✗</td>
<td>✓</td>
<td>✗</td>
</tr>
<tr>
<td>Caccioli et al. (2020)</td>
<td>Banks, funds, insurers</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✓</td>
<td>✓</td>
<td>✗</td>
</tr>
<tr>
<td>Chretien et al. (2020)</td>
<td>Banks, funds, insurers</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✓</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Farmer et al. (2020)</td>
<td>Banks, (hedge) funds</td>
<td>✗</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✗</td>
</tr>
<tr>
<td>Roncoroni et al. (2021)</td>
<td>Banks, funds</td>
<td>✓</td>
<td>✗</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✗</td>
</tr>
<tr>
<td>Our framework</td>
<td>Banks, funds</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
## Literature II.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Time horizon</th>
<th>Correlated defaults</th>
<th>Income channel</th>
<th>Default contagion</th>
<th>Funding shock</th>
<th>Derivatives/ margin calls</th>
<th>Portfolio opt.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aikman et al. (2019)</td>
<td>1 month</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Caccioli et al. (2020)</td>
<td>Instantaneous</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Chretien et al. (2020)</td>
<td>Instantaneous</td>
<td>X</td>
<td>X</td>
<td>✓</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Farmer et al. (2020)</td>
<td>&lt;1 month</td>
<td>X</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Roncoroni et al. (2021)</td>
<td>35 years (uncertainty)</td>
<td>X</td>
<td>X</td>
<td>✓</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Our framework</td>
<td>Quarterly and high frequency</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
Sectors and data
Sectors and data

Sectors currently covered by our framework (2020)
- Banks (COREP, FINREP, SHS-G, Moody’s, RIAD, GLEIF, CSDB)
- Investment funds (Lipper IM by Refinitiv)

Sectors to be included at the next development stage
- Insurance companies (2021)
- Hedge funds, money market funds (at a later stage)

Other sectors are included in order to “close the system”
- Other financial agents
- NFCs
- Households
Our exposure networks: 377 banks, 12655 funds

Loans

An edge represents a loan from a bank to another entity in a given sector. Granular loan data are covering 21% of total bank assets.

Securities holdings

An edge shows that a bank/fund holds assets issued by another entity in a given sector. Granular securities data are covering 7% of total bank assets.
3

Scenario and exogenous shocks
Scenario and exogenous shocks

Scenario:
Covid-19 adverse severe scenario used in the 2020 ECB VA exercise with a GDP decline of 12.6% y-o-y in 2020

Default shocks:
Merton model geometric Brownian motion parameters regressed on scenario variables using Bayesian Model Averaging (BMA) + ECB top-down models by country/sector for aggregate exposures (Gross and Población (2017))

Market shock:
Country-level stock market shocks

Redemption shock:
Fund-level exogenous redemptions using BMA approach (Gourdel et al. (2019))
Model dynamics
Stress testing framework for banks and funds

**Plan**

- **Shocks**
  - Deterministic shocks
  - Stochastic shock

- **Initial system**
  - Satellite models

- **Quarterly model**
  - High frequency dynamics
  - Credit risk
  - Liquidity risk
  - Market risk

- **System after Q1**
- **System after Q2**
- **System after Q3**
- **System after Q4**

- **End of quarter changes**

**Status quo**

- **Scenario**
  - Q1

- **Shocks**
  - Deterministic shocks
  - Stochastic shock

- **Initial system**
  - Satellite models

- **System in Q1**
- **System in Q2**
- **System in Q3**
- **System in Q4**

- **High frequency dynamics**
- **Credit risk**
- **Liquidity risk**
- **Market risk**

**Sectors:** Banks, funds and insurers (hedge funds)
Modelling summary

- **Effects of defaults**: loan losses and price decline of corresponding issued securities
- **Price equilibrium**: price changes in tradable assets reflected in fund prices + then all holdings
- **Interbank withdrawals**: short-term funding withdrawn from/by defaulted/distressed banks
- **Unsecured borrowing**: well-capitalized banks able to provide liquidity
- **Redemptions, fire sales**: pro rata depending on liquidity shortfalls leading to price declines

\*Income channel is approximated from ECB VA exercise results and FINREP data
Results
## Median losses

<table>
<thead>
<tr>
<th>System</th>
<th>Default losses</th>
<th>Market losses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Exogenous</td>
<td>Exogenous</td>
</tr>
<tr>
<td>Banks</td>
<td>0.7</td>
<td>* 0.2</td>
</tr>
<tr>
<td>Funds</td>
<td>** 0.9</td>
<td>0.05</td>
</tr>
</tbody>
</table>

| Note: Median losses expressed as a percentage of total system assets. |

**Default losses**: loan losses and price decline of corresponding issued securities

- No policy response (relief measures or moratoria): more endogenous bank defaults*
- Funds directly exposed to real economy**

**Market losses**: stock market shocks and endogenous fire sale losses

- Banks’ portfolio changes mainly due to funds’ fire sales
- Endogeneity matters (scenario design)
Drivers of bank losses

- Banks’ exogenous default losses are the main driver of losses (credit risk channel)
- All other channels combined lead to a similar amount of losses
- Endogenous market losses are persistent due to fire sales, which are caused by investment funds
- Losses from endogenous defaults exhibit a multi-modal property due to stochastic bank defaults

Histogram of losses from exogenous shocks and from endogenous reactions (contagion) for banks based on 10000 Monte Carlo simulations (in percentage of total banking sector assets).

'Defaults, Exogenous' refer to NFC defaults. 'Market, Exogenous' refers to exogenous market losses both from the market scenario and from the price drop of exogenously defaulting NFCs issuing securities. 'Endogenous' losses are model-driven.
Drivers of fund losses

- Funds losses due to exogenous shocks are larger compared to the ones observed for the banking sector.
- Only a few leveraged funds (via bank loans) default in our simulations but persistently.
- Given their portfolio structure, funds are not exposed to defaulting banks in our sample but **losses from fire sales** are significant.

Histogram of losses from exogenous shocks and from endogenous reactions (contagion) for funds based on 10000 Monte Carlo simulations (in percentage of total investment fund sector assets).

'Defaults, Exogenous' refer to NFC defaults. 'Market, Exogenous' refers to exogenous market losses both from the market scenario and from the price drop of exogenously defaulting NFCs issuing securities. 'Endogenous' losses are model-driven.
Funds’ impact on banks’ capital ratios

• Somewhat higher **loan loss impact** than in ECB VA from:
  o COREP PDs
  o Correlated default events

• **Endogenous reactions:**
  o Significant additional losses (bottom row)

• **One percentage point higher capital depletion** in the presence of funds
  o Impact on funds primarily driven by fire sale effects

Distribution of average bank capital depletion along the 10000 Monte Carlo simulations. VA results on credit losses refer only to the first two quarters of 2020.
Conclusions

• **Stress testing tool** for the analysis of the short-term dynamic reaction of a granular network of banks and investment funds conditional on a macro-financial shock scenario

• We show that **inter-sectoral contagion** significantly increases losses in the system

• Joint asset **fire sales** of banks and funds have the largest systemic effect in our model

• **Application** of the model for macroprudential policy, climate risk and potentially monetary policy

• **Model extension** with regard to other financial sectors such as insurance corporations, hedge funds, money market funds
Thank you for your attention!
Appendix: System-wide stress testing

For more details, see ECB WORKING PAPER SERIES - No. 2581:
‘Shock amplification in an interconnected financial system of banks and investment funds’
by Sydow et al. (2021)
https://www.ecb.europa.eu/pub/pdf/scpwps/ecb.wp2581~63c8ff07dc.en.pdf?8a567f4ed1bba41721c678c32e6ab09

For a climate risk application, see Box 8 ‘Amplification of climate scenarios in an interconnected financial system of banks and investment funds’ in ESRB Report (July, 2021):
‘Climate-related risk and financial stability’
https://www.esrb.europa.eu/pub/pdf/reports/esrb.climateriskfinancialstability202107~79c10eba1a.en.pdf?71a273dc36a85ef05c8bed530466f900
Banks

Scope
• Significant and less significant banks domiciled in the EA

Data sources
• COREP
  o Large Exposures dataset: bilateral exposures; breakdown along two dimensions: (i) original exposure and net or unsecured exposure (LGD proxy) and (ii) long-term and short term (with 30 days as threshold)
  o Large Liabilities dataset: Top 10 bilateral liabilities with a value > 1% TA
• FINREP
  o Aggregate exposure on country-sector basis towards CI, FC, NFC, GOV, HH
  o Provisions, balance sheet and income statements
  o Disclosure of financial assets and liabilities, off-balance sheet activities, non-financial instruments
• Securities Holding Statistics by banking group (SHS-G)
Investment funds

Scope
- Funds domiciled in the EA
  - Open-ended investment funds. Prone to redemption risk, thus, play an active role in our model
  - Closed-end funds. Standard price impact, thus, only intervene in form of securities whose price is changing

Data sources
- Granular securities holdings from Lipper IM by Refinitiv:
  - Market value of exposure amount security-by-security (ISIN)
  - Cash information
Entities and securities

Scope
• Entities reported as counterparty by any bank or investment fund
• ISIN-level securities
• PDs for passive NFCs and FCs in the SWST

Data sources
• RIAD and GLEIF:
  o Identification via LEI and RIAD code and check of country-sector information
  o Groups consolidation
• CSDB:
  o Identification of securities via ISIN code and check information about type and issuer
• Moody’s:
  o Market asset value (AVL) and PDs to generate correlated random defaults in the counterparty subsample of NFCs and FCs
  o Use of country-sector averaging to account for missing values
Modelling correlated defaults

- Capture firm-by-firm default correlations.

- Estimate parameters of the asset market value generating processes.

- Simulate series in a Monte Carlo environment to generate real-economy defaults realisations.

- Allow for dependencies to macro-financial variables.
Scenario translation

Formally, ARDL models of the following form are used for both PDs and redemptions:

\[ Y_t = \alpha + \rho_1 Y_{t-1} + \cdots + \rho_p Y_{t-p} + \sum_{X^k \in M} \left( \sum_{q=0}^{p_k} \beta_{k,q} X^k_{t-q} \right) + \varepsilon_t \]

With \( X^1, \ldots, X^K \) being predictor variables (macro-economic series from the scenario), \( M \) a subset of \( \{X^1, \ldots, X^K\} \) and all variables in a given equation being country-specific.
Mechanisms at play (*simplified scheme*)

**Exogenous shocks** from HH / NFC / GOV

- **Solvency defaults**
  - Loan defaults
  - Portfolio depletion

- **Initial liquidity needs**
  - Funds redemptions

**Q1**

**Q2**

**Endogenous reactions**

- Bank defaults
  - Defaults on loans and securities
  - Interbank withdrawals

- Funds need cash
  - Additional interbank loans
  - Additional redemptions

- Fire sales
  - Price impact + portfolio depletion

- New bank defaults
- New fund defaults

- Banks need cash
Fire sale assumptions

- **Driven by liquidity shortfalls:** banks/funds cover their liquidity shortfalls by selling their tradable assets

- **Pro rata approach:** amounts sold are proportional for all securities held

- **Price equilibrium:** price impacts recalculated until no further change in market values of holdings

- **Price impact functions:** estimation at ISIN/issuer level (hull or quantile approach)
Price impact calibration - results

The calibrated securities contain bonds and equity.

A clear relation exists between a bonds’ residual maturity and the price impact.

Impact parameter (%/Mln EUR) by sector and maturity

issuer_sector

6M 1Y 3Y 5Y 8Y 10Y 20Y
Results
Loss distributions for banks and funds

- After the first shock, the dispersion of subsequent losses is extremely low across the simulations: **similar sets of defaulting entities**
- Contagion mechanisms imply losses for banks both due to defaults and fire sales
- Market shocks hit funds more severely
- Funds only suffer losses due to market fire sales and are not exposed to endogenously defaulting banks

Distribution of losses for banks and funds based on 10000 Monte Carlo simulations (in percentage of total assets in the system).
'Q1E' initial exogenous shocks in the first quarter.
'Q2R1' to 'Q2R12' represent the iterations until convergence.
Funds’ impact on banks’ losses

• The existence of funds in our model increases exogenous bank losses much less than endogenous losses (reason for exogenous losses: NFC defaults already have a price impact)

• Endogenous losses are high, confirming that funds have a very large impact on the market and on banks

• Funds may have a mitigating role for some banks (negative additional losses; higher market liquidity)

Histogram of losses from exogenous shocks and from endogenous reactions (contagion) for banks based on 10000 Monte Carlo simulations (in percentage of total banking sector assets).

‘Defaults, Exogenous’ refers to NFC defaults ‘Market, Exogenous’ refers to exogenous market losses both from the market scenario and from the price drop of exogenously defaulting NFCs issuing securities. ‘Endogenous’ losses are model-driven.
Aggregate endogenous outflows from banks and funds

- High amount of liquidity withdrawals driven by the information contagion assumption
- Funds do not face severe endogenous liquidity problems in the model

Histogram of financial flows following endogenous reactions based on 10000 Monte Carlo simulations (in percentage of total assets of the respective sector).
System-level flows and losses

- Clusters for liquidity flows reflect the larger importance of stochastic bank defaults with common sets of large defaulting banks.

- Higher amounts of outflows do not necessarily mean higher losses: solvency also matters.

System-level flows and losses based on 10000 Monte Carlo simulations (in percentage of total assets).

'Flows' represent the total redeemed and withdrawn amount of liquidity in the endogenous loops. 'Losses' cover final losses from endogenous defaults and fire sales at the system level. Each dot represents the outcome of an individual Monte Carlo simulation.
Price impacts parameters

- Price impact parameters for more than 25K individual securities, aggregated to issuer level
- We use information at a security level

**Filling missing information:** When possible, we use the aggregated average
  - At an issuer level
  - At a country-sector-security-type level
  - At a continent-sector-security type level

Sold volumes over market capitalization (decimal) and equilibrium prices (decimal; a value of 1 means no price change) after convergence of the algorithm. Market capitalization is the total amount of holdings in the system for a given security, before the shock.
Equilibrium prices

- Equilibrium prices generally do not reach their calibrated price floors
- Only securities issued by defaulted NFCs reach zero prices
- Large fraction of securities are not sold at all

Distribution of tradable asset prices in equilibrium and distribution of estimated price floors after convergence of the algorithm (decimal; a value of 1 means no price change, a value of 0 the default of the issuer)
Drop in funds NAV

• Different behaviour of funds depending on their type
• Equity funds suffer more severe depreciations in their net asset values (NAV) consistent with our expectations
Bank loss distribution
No funds case

• Relevance of fund interaction only from a market portfolio perspective

• Without fund fire sales, market losses are strongly reduced and induce a much faster convergence

• The reduction in steps, in turn, induces also fewer defaults and associated losses

Distribution of market and default losses for 10000 Monte Carlo simulations, without funds (in percentage of total assets in the system of banks). 'Q1E' shows the reaction following the initial exogenous shocks in the first quarter. 'Q2R1' to 'Q2R5' represent the iterations in the second quarter until convergence of the algorithm. In 'Q1E', 'Defaults' refer to NFC defaults and 'Market' to exogenous market losses both from the market scenario and from the price drop of exogenously defaulting NFCs. From 'Q2R1' onward bank and fund defaults as well as market losses are model-driven.
Bank losses
No funds case

• Consistent with expectations, market endogenous losses are largely reduced

• Similarly and as predicted, fewer interactions cause a lower rate of bank defaults and implied losses

Histogram of losses from exogenous shocks and from endogenous reactions (contagion) for banks based on 10000 Monte Carlo simulations (in percentage of total banking sector assets). 'Defaults, Exogenous' refer to NFC defaults. 'Market, Exogenous' refers to exogenous market losses both from the market scenario and from the price drop of exogenously defaulting NFCs issuing securities. 'Endogenous' losses are model-driven.
Bank’s liquidity withdrawals
No funds case

• As a further consequence of the aforementioned decreased losses, also liquidity withdrawals are reduced by about 1% of the total assets

• The distribution shape remains multi-modal

• The results from this experiment strongly support the need for including investment funds in banking sector stress testing exercises

Funding flows for banks (without funds), following endogenous reactions, in form of liquidity withdrawal based on 10000 Monte Carlo simulations (in percentage of total assets of the respective sector)