EUROPEAN CENTRAL BANK

BANKING SUPERVISION

Systemic Risk in Finance

Public Lecture Series

Lecture 4
Stress tests and ways forward

Grzegorz Hałaj

Stress Test Experts Division, ECB & AI Lab SGH

Agenda

7. Stress Tests – practical tools to assess shock transmission channels

8. Ways forward – complex financial system as a whole, its regulation and open questions

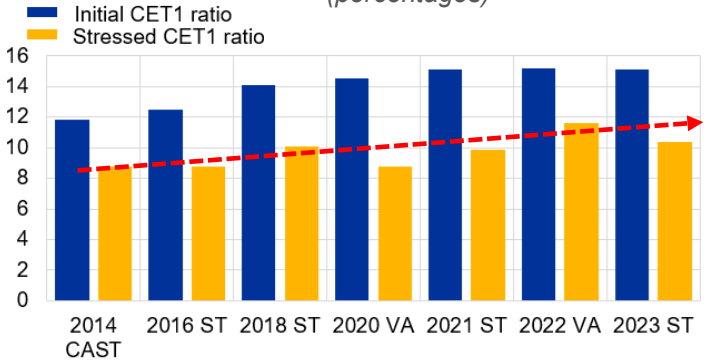
Map of Stress Testing

Stress tests are now well-established crisis prevention and crisis resolution tools

- The **Global Financial Crisis** illustrated that weakly capitalised banking systems are vulnerable to unexpected adverse shocks
- Stress testing emerged as **an important tool** to assess resilience and quantify capital shortfalls
  - US SCAP 2009 and subsequent CCAR/DFAST exercises
  - Recapitalisation exercises during the EA sovereign debt crisis
  - Since inception of SSM, the ECB runs annual stress tests to help determine capital requirements
  - Bank of England runs an annual concurrent stress test plus biennial exploratory scenario
- Macroprudential stress tests to support calibration of macroprudential buffers

Projected adverse evolution of CET1 ratio across ECB exercises (FL)[1]

(percentages)



Source: ECB.
[1]Aggregate results for SSM Significant Institutions. Some sample changes over time but coverage in terms of total banking sector assets broadly unchanged. "VA" refers to ECB's Vulnerability Analyses.

Types of stress test (EA focused)

To comply with EU law (CRD Art. 100) ECB as competent authority is required to run a stress test for SREP purposes at least once a year:

- Biennial EBA/SSM EU-wide Stress Test
- Biennial ECB Thematic Stress Tests (e.g., Cyber ST, Climate ST, Liquidity ST, IRRBB)

Other ECB stress test activities

- Comprehensive Assessment Stress Test (CAST): for new Significant Institutions
- Ad hoc stress test assessments (e.g., desktop-based Vulnerability Analyses)
- Sensitivity analyses to help identify institutions vulnerable to topical risks
- Macroprudential stress test for financial stability purposes incl. buffer calibration

Assessment of banks' internal stress tests

- Challenge of supervised institutions' own stress test projections (e.g., ICAAP, ILAAP,…)

How to extend stress testing, incl. networks? Example of liquidity stress testing

- From individual bank to system-wide tools
  - Starting small – cash flow under stress to understand business models
  - Scenario design – linking time series analysis and event studies of liquidity crises episodes
- Extension to cover management actions and system-wide externalities in the interconnected financial system
  - Address the following gaps:
    - Liquidity and solvency interactions: fire sales to raise cash implying asset revaluation losses (embedding one-way interaction)
    - Dynamic balance sheet: endogenize how banks choose assets to sell (relaxing typical pecking order assumption)
    - Second-round effects: fire-sale externalities through the **network of common asset holdings** and business model similarities
  - Measure liquidity risk also in terms of impact on solvency

Net Liquidity Position stress testing engine – simple operational framework

Objective: assess reliance of SSM institutions to shocks to cashflows and counterbalancing capacity, assuming static balance sheet and supervisory contractual maturity data

Hypothetical **idiosyncratic liquidity shocks,** calibrated based on **recent liquidity crisis episodes**

Example of shocks from 2019 LiST

			Baseline contractual CFs	LiST adverse shock	LiST extreme shock
1	Contractual maturity items	Term deposits (commercial counterparties)	Constant stock	18%-52% outflow rate[a]	27%-76% outflow rate[a]
		Term deposits (financial counterparties)	100% outflow rate	100% outflow rate	100% outflow rate
		Derivatives & FX swaps (inflow/outflow)	100% in/outflow rate	100% in/outflow rate	100% in/outflow rate
		Loans (commercial counterparties)	Constant stock	Constant stock	Constant stock
		Loans (financial counterparties)	100% inflow rate	100% inflow rate	100% inflow rate
		Own portfolio investments	100% inflow rate	100% inflow rate	100% inflow rate
		Others (inflow/outflow)	100% in/outflow rate	100% in/outflow rate	100% in/outflow rate
2	Open maturity items	Sight deposits (commercial clients)	Constant stock	12%-58% outflow[a]	18%-74% outflow[a]
		Sight deposits (financial counterparties)	100% outflow	100% outflow	100% outflow
		Sight loans	Constant stock	Constant stock	Constant stock
		Open repos & reverse repos	100% in/outflow	100% in/outflow	100% in/outflow
3	CBC	Coins banknotes and CB reserves	Nominal value	Nominal value	Nominal value
		HQLA (L1 & L2) and non tradable assets eligible for CB	Post-haircut value	Post-haircut value	Post-haircut value
		Other tradable assets	Post-haircut value	Post-haircut value	Post-haircut value
		Undrawn committed facilities received	Nominal value	Nominal value	Nominal value
4	Contingencies	Outflows from committed facilities		12%/ 60% outflow rate[b]	15%/ 75% outflow rate[b]
		Impact from own rating downgrade		1-notch ↓	3-notch ↓
	Net liquidity position computed as:		1+2+3	1+2+3+4	1+2+3+4

Output

The '**net liquidity position' (NLP)** at a given point in time is equal to the difference of the bank's available liquidity (i.e. its counterbalancing capacity) and the expected net outflows since the reference date

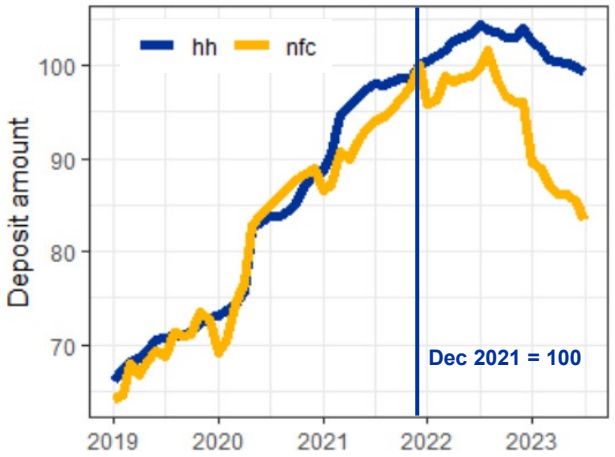
The '**survival period' (SP)** corresponds to the first day in which the NLP turns negative (i.e., when a bank would have no further available liquidity to counter the simulated net outflows)

Scenario design: Empirical deposit outflow rates

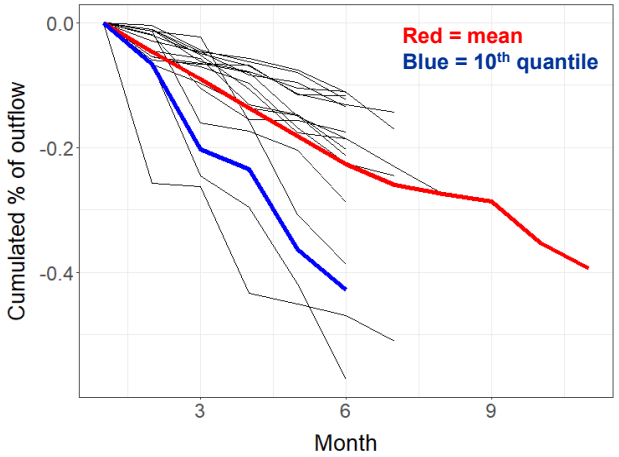
Selection of historical episodes of deposits outflows to model run-off rates

- Volume of deposits declining since 2022q2, especially for NFC
- Define stress episode as >6 consecutive months of negative deposit outflow
- Evidence of possibly more severe deposit outflows than in the current LiST extreme scenario
- However, impact depends on maturity profiles (buckets >1M have higher outflow rates) on whether shocks are applied simultaneously (as in LiST) or not

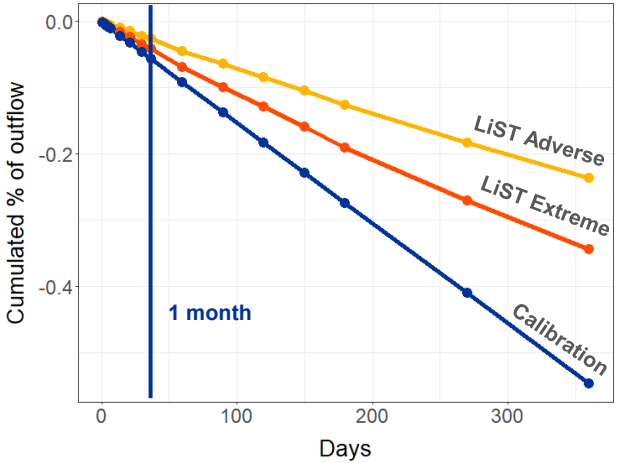
Volume of overnight deposits (Dec 2021 = 100)



Non-financial Corporates overnight deposits

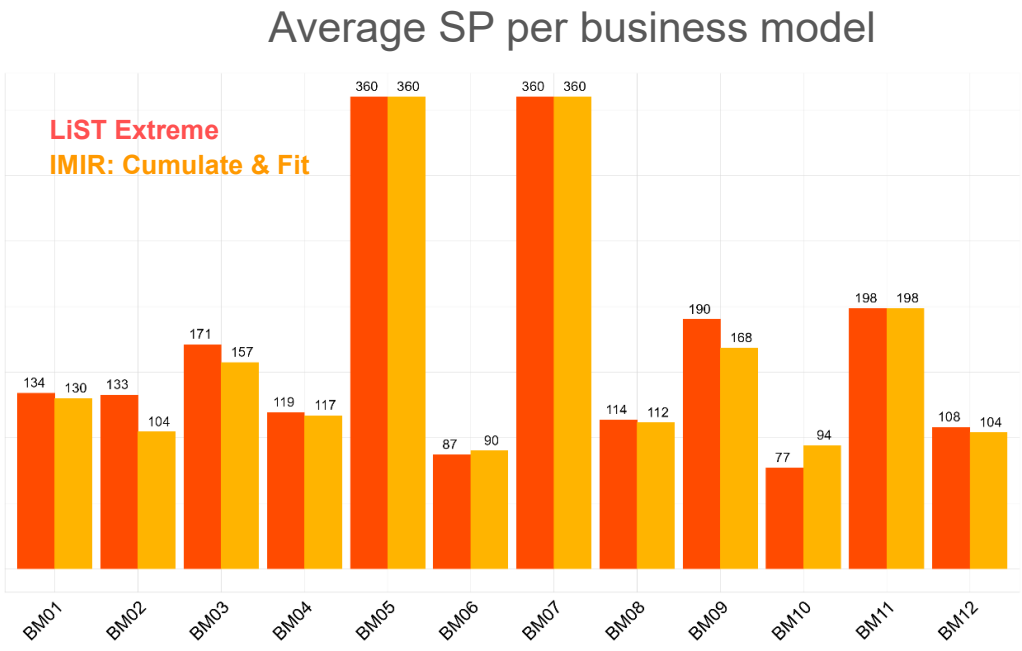


Comparison of parameters



Source: IMIR, monthly data 2004-2023
Note: 19 cases identified since 2004, 3 worse outliers removed from sample

Sensitivity of the adverse Survival Probability (SP) to historical calibration of deposit run-off rates



Scenarios:
LiST Extreme = 2019 FSAP liquidity scenario

IMIR-based scenario uses time series of deposit volumes from ECB interest rate statistics data
IMIR: Cumulate & Fit = fit a polynomial curve to a 10th worst quantile of cumulative outflow of deposits

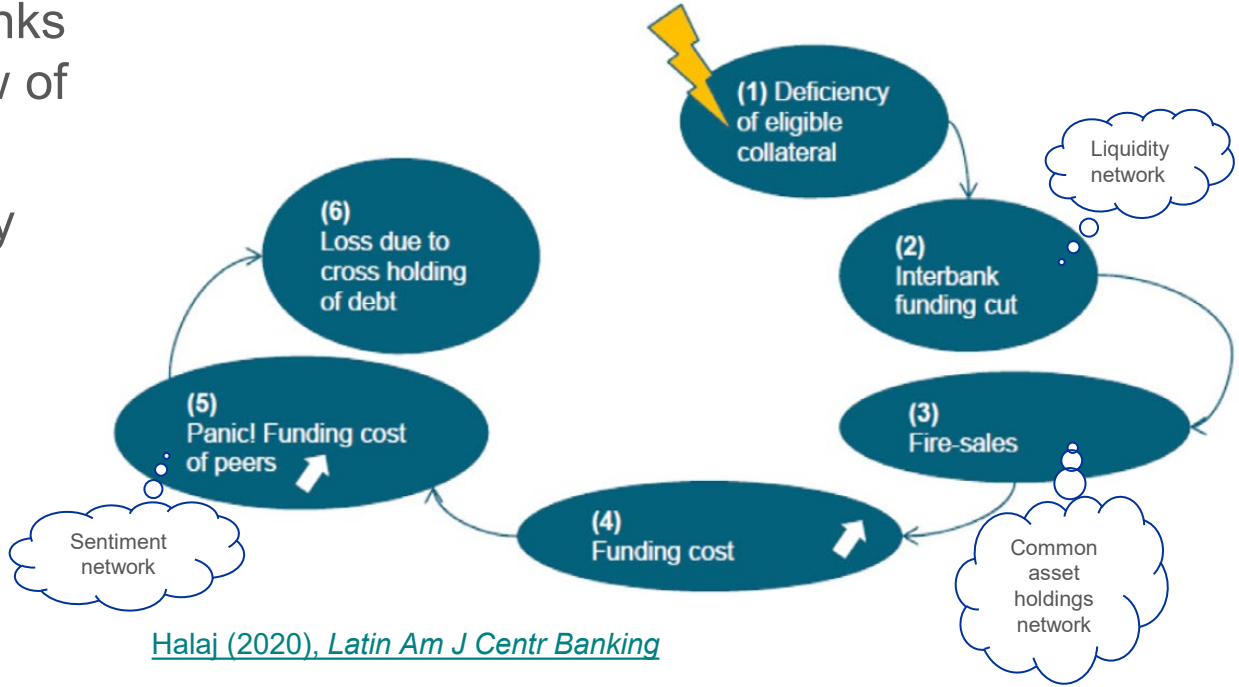
Results sensitive to methods applied to design funding shock scenarios and…

…missing the interactions in the market for liquidity (so, missing network representation)

Source: calculations based on IMIR, LiST parameters and COREP 66

Case study - Canada: agent-based model of liquidity contagion risk in (the network of) Canadian banking system

- What if a group of banks experience an outflow of deposits?
- A chain of events may happen
- 1st round (1->2->3): banks use assets to cover shocks
- 2nd round (4->5->6): banks' and market conditions deteriorate

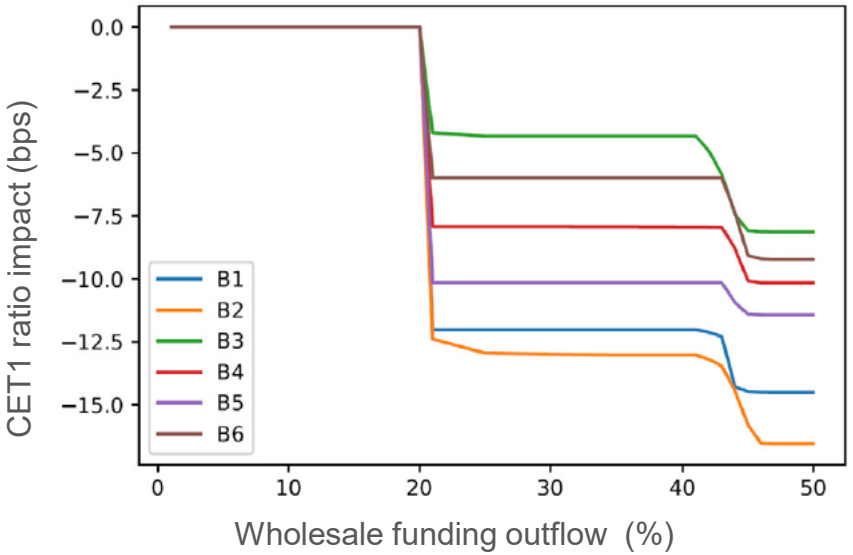


Halaj (2020), *Latin Am J Centr Banking*

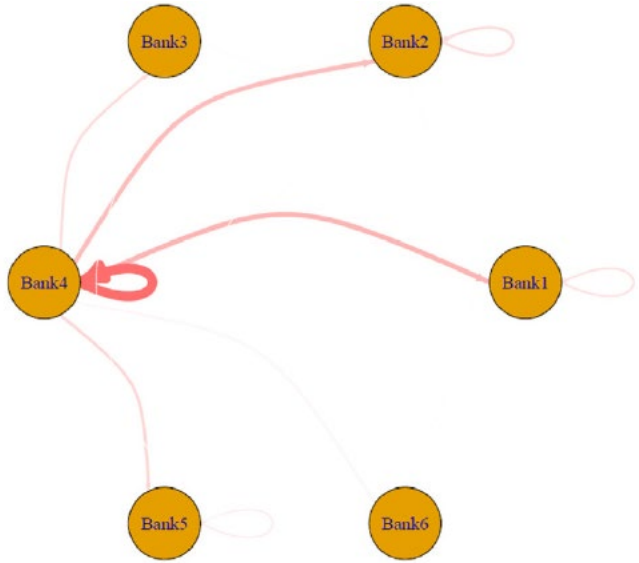
Case study - Canada: real network of exposures

- Granular, monthly, supervisory data on funding sources and the structure of their counterbalancing capacity (retail, corporate, wholesale, repo, and derivative exposures, consistent with the LCR definitions, with monthly maturity ladder).
- The assets' breakdown shows expected inflows, which can be matched with the contractual maturity structure of liabilities.
- Currency breakdown, i.e., CAD, USD, EUR, and GBP
- Haircuts and regulatory run-off rate information.
- Asset encumbrance is available as one of the critical factors of potential liquidity generation

Case study - Canada: results, interpretation, relevance



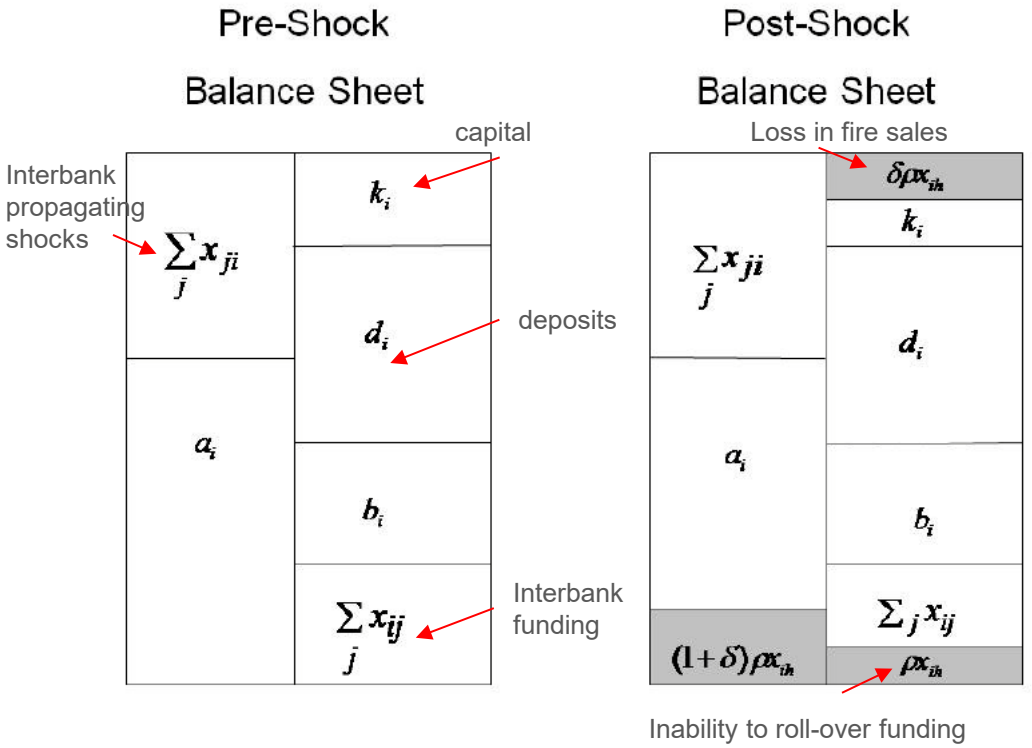
What is a critical shock that impact the system?
What is the impact?



Spillover effects when USD funding outflow hits (edge = impact)

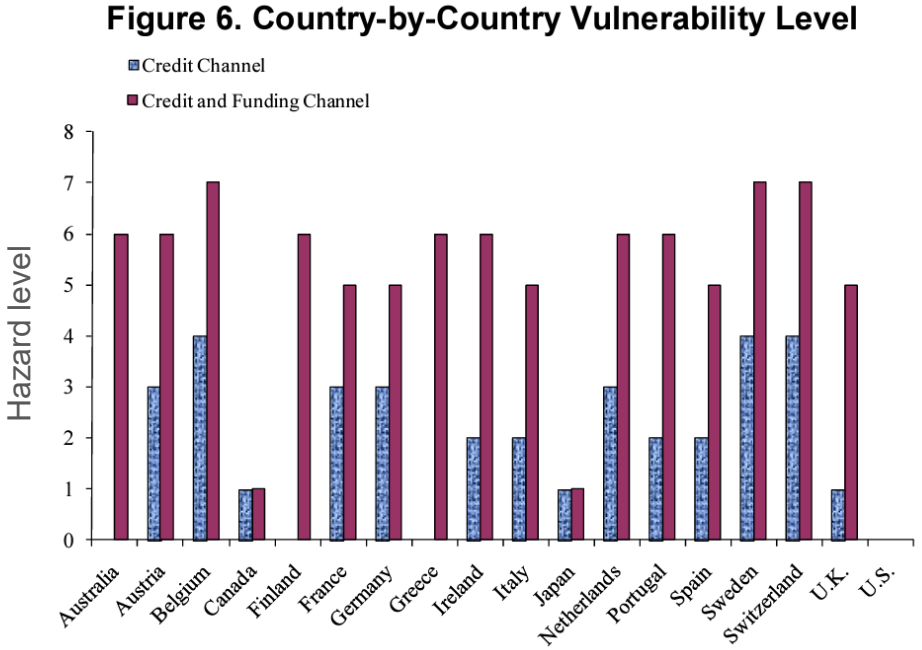
Case study – IMF stress test framework (Espinosa-Vega & Sole)

- Monitoring cross-border contagion channels
- Integrated credit and funding shocks
- The model can be implemented for individual banks' balance sheets or aggregate (country-level) balance sheets of banks



Case study – practical stress indicators based on simulations using IMF framework

- Hazard level, i.e., the number of simulations in which the banking system of the country failed as a result of another country's failure…
- …captures how vulnerable a given banking system is
- Complementary to measures based on:
  capital depletion (impact) or
  # of rounds of contagion (breadth of spreading)



Source: Espinosa-Vega, Sole (2010), IMF WP

Ways forward

Current gaps (or where frontier of research and policy is)…

- Liquidity and solvency interactions (with network channels of price-mediated contagion)
  - Scenario narratives talk about macro-financial conditions that should have very broad implications
  - Stress tests usually analyse one side: either solvency (credit or market losses) or liquidity (funding outflows)
  - Two-way feedback between liquidity and solvency is expected, e.g., in extreme case:

    Capital depletion => Higher funding costs or deposit withdrawals

    Deposit withdrawals => Liquidation of assets to raise cash => Fire-sale losses

- Bank / non-bank interlinkages (and interactions, again through the network of exposures)
  - Funding or hedging is provided between sectors creating channels of shock transmission
  - Typically, given limited mandates and capabilities of regulators, stress testing focused on specific sectors in isolation (e.g., banks, asset managers, CCPs, etc.)

- Dynamic balance sheets, with implication on (network) structure of the system
  - Static balance sheet helps to compare stress impact across banks
  - However, banks would adjust their balance sheets, even business model, esp. in the typical long horizon of stress (1-3 years), potentially altering the magnitude of stress impact and how it reverberates through the financial system

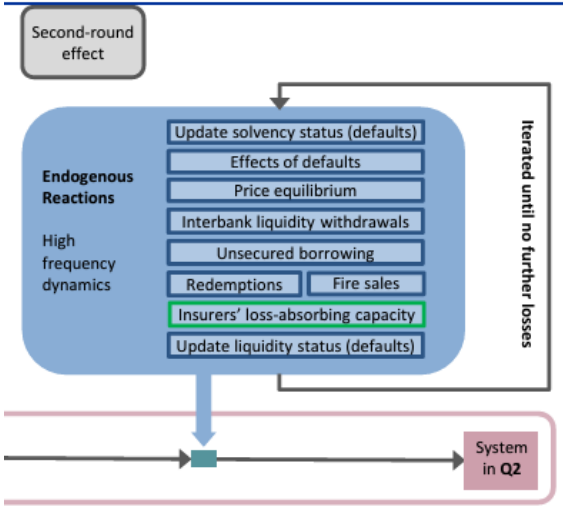
How to draw policy-relevant conclusions?

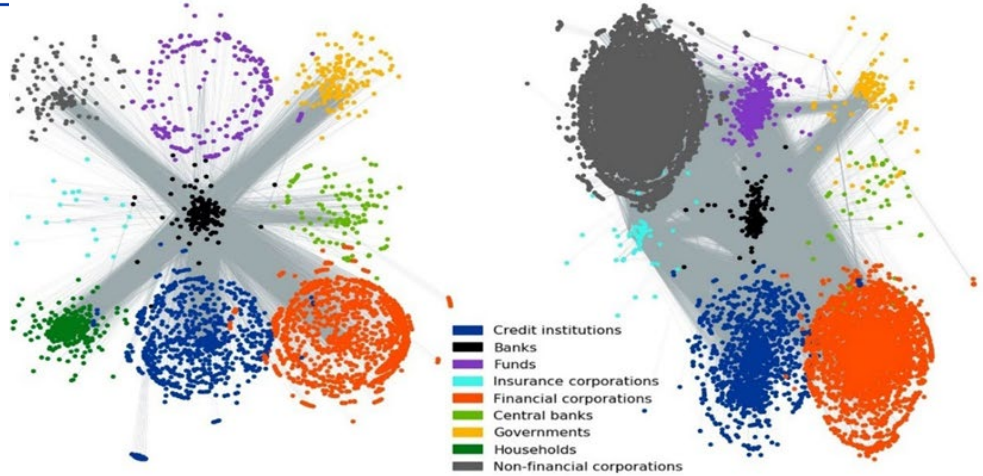
- Visualize (BIS 2020): how to avoid cluttering?
  - Either clever layout or small network, e.g., with a selection of important nodes/ links /layers
- Select adequate measures
  - Tailored to the complexity of the data
- Apply scenario analysis
  - Can be customized to explore specific features of the system that cannot be captured by crude networks statistics

ECB case: data-driven, network-based monitoring…

- Network of loans and securities holdings as part of a system-wide stress test model

  - ➢ A simulation of shocks and their propagation using mechanistic rules and assumptions on management actions, focus on 2nd-round effects





Loans (left-hand panel) and security holdings (right-hand panel)

Dubiel-Teleszynski et al (2022) *Macropru Bulletin*

ECB case: …and less about networks

- Explicit network language not necessary
  - Explore bilateral links between sectors to identify trends in vulnerability build-up
- Examples (source: ECB FSR 2020 and 2024):
  - A link between banks and non-banks, e.g., via increasing funding from NBFIs (Fig 1)
  - Who relies on which derivative markets, e.g., "*strong correlation between the VM payments and the inflows to and outflows from MMFs held by the ICPFs facing these payments*" (see ECB FSR, 2020)
  - Links to real sector, e.g., exuberance in RRE or CRE (Fig 2)

Fig 1. Share of funding from the NBFI sector, by bank business model

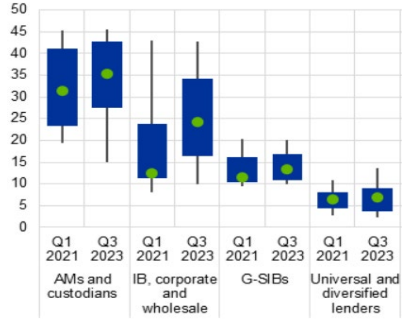
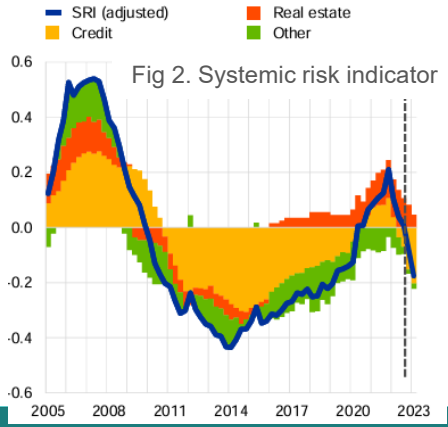


Fig 2. Systemic risk indicator

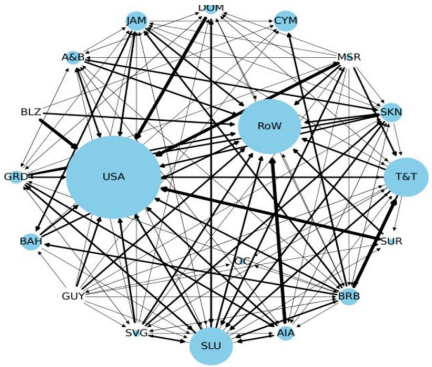


Network analysis useful to monitor systemic risk

- Systemic risk assessment is the name of the game in the interconnected financial system
  - Small-open economies with specific links to the global financial system, e.g., through capital flows and presence of international financial holdings
- Network models help to assess structural vulnerabilities
  - Detect vulnerable banks, or other FIs, and links between them
  - Help to justify and calibrate risk mitigating policies
- Network models complementary to other analytical tools
  - They have their strengths but also limitations, e.g., can identify connected nodes but not always can tell whether is it good or bad
  - Diversification of tools: monitor market trends, design scenarios, measure risks in balance sheets (e.g., credit risk)

Caribbeans highly interconnected with global financial system* – mapping exposures

- Gross cross-border exposures
  - Banking exposures, combining investments, loans and equity
  - Rest of the world considered
- What vulnerabilities depicted
  - A country that a financial institution relies on in terms of capital flows (e.g., of investments) may also rely on foreign countries or banking systems to provide funding
  - What if one fails? Are others affected? How?
- Choice of measures
  - Fragility and reciprocity – immediate feedback in case of a localized shock
- Network representation of the connectivity with the world
  - Conclusions can be drawn just from a visual representation of the system



Caribbean FIs' foreign claims

*) Caribbean Regional Financial Stab Rep, 2025

“And why have you not mentioned AI yet?”

- Research attention already drawn to the topic of risks related to AI, including systemic risk (e.g., Dannielsson & Uthemann, 2024 in finance, more broadly Growiec, 202Xs)…
- …not forgetting about benefits coming with AI for organizations and the society in general (e.g., effectiveness in fraud detection, efficiency of the processes, broader access to financial services, etc.)
- Risks (and opportunities) recognized by regulators (EBA Nov 2024, ECB 202Xs)

Systemic risk: risk that localized shocks spread to a material part of the system

AI: data + automation
(+ autonomy, esp. of a network of agents)

AI, so what are we talking about?

Notably, diverging views on the clarity of the definition of AI systems

- E.g., the AI Act and related guidance: perceived as clear and helpful by some banks, and ambiguous by others
- Some banks with IRB models see Machine Learning techniques as established and well-known technique, with risks well mitigated

Google: *AI is a field of computer science focused on creating smart machines that can perform tasks that typically require human intelligence, like learning, reasoning, and problem-solving.*

IBM: *Artificial intelligence (AI) is technology that enables computers and machines to simulate human learning, comprehension, problem solving, decision making, creativity and autonomy.*

EU: *'AI system' means a machine-based system that is designed to operate with varying levels of autonomy and that may exhibit adaptiveness after deployment… The following AI practices shall be prohibited* [and a long list follows]

Britannica: *On the other hand, some programs have attained the performance levels of human experts and professionals in executing certain specific tasks, so that artificial intelligence in this limited sense is found in applications as diverse as medical diagnosis, computer search engines, voice or handwriting recognition, and chatbots.*

KPMG: *AI is the nexus of this transformation. More than just another technology in the stack, it is becoming the overall operating system for finance—the orchestration layer that unifies data, workflows, and decisions across the enterprise. .*

more philosophy… …more marketing… … and regulatory prudence

EU Commissions' actions – AI Act

- The AI Act defines a general-purpose AI model: "*an AI model, including where such an AI model is trained with a large amount of data using self-supervision at scale, that displays significant generality and is capable of competently performing a wide range of distinct tasks regardless of the way the model is placed on the market and that can be integrated into a variety of downstream systems or applications*" (Article 3(63) AI Act)…

- …and also refers to systemic risks: "*large-scale harm from the most advanced (i.e. state-of-the-art) models at any given point in time, or from other models that have an equivalent impact*" (see Article 3(65) AI Act).

- Critique: with AI-act-like regulation we do not how what we regulate (high- vs low-risk systems) and how (systemic risk too broad of a concept) (Carey, 2025)

Traditional sources of systemic risk… …and how AI connects to them

Systemic risk channels in finance (established framework, Cecchetti et al. 2026):

- Liquidity mismatches: short-term liquid liabilities vs. long-term illiquid assets
- Common exposures: many market participants exposed to the same shock
- Interconnectedness: network linkages facilitating shock propagation
- Lack of substitutability: concentration in critical services or infrastructures
- Leverage & procyclicality: feedback loops amplifying booms and busts

How AI links to these channels:

- AI can accelerate information diffusion, raising run risk in markets or deposits
- AI adoption often relies on shared models/data, increasing common exposures
- AI infrastructure (cloud, smart contracts, APIs) creates new interconnections
- Foundation model providers become critical nodes, raising substitutability concerns
- Automation and speed can increase procyclicality and leverage dynamics

AI features that create or amplify systemic risk

- Monitoring and oversight challenges
  - Complexity limits effectiveness of internal and external supervision; errors hard to detect (**opaque network**)
- Concentration and entry barriers
  - Small number of AI providers (**sparse network**) imply single points of failure, reliance on common infrastructure
- Model uniformity (monoculture)
  - Shared models/data leads correlated errors + herding in markets (**correlation network**)
- Overreliance and excessive trust
  - "Works well in good times", resulting in complacency, unchecked automation, blind adoption (**sentiment network**)
- Speed and automation
  - High-frequency decision loops amplify shocks, reduce intervention time (**dynamic network**)
- Opacity and explainability limits
  - Black-box actions causing panic if failures surface (**phase transition in network**)
- "Hallucinations" and misinformation
  - False signals affecting trading, risk models, news sentiment (**social networks**)
- Malicious use (cyber, fraud, manipulation)
  - AI empowers attackers and insiders with systemic effects via critical infrastructures (**physical network**)
- Legal uncertainty (liability and data)
  - Litigation (e.g., settlement risk) or policy shocks (e.g., frantic regulation, arbitrage) can hit institutions or key providers (**networks of legal systems**)

So, isn't systemic risk of AI the same old story… …but in a new disguise?

- In general, with AI things move faster and with larger volumes of exchanged information…
- …and we, humans, may have trouble to keep pace, eventually, losing control (Harrari, 2026 Davos keynote)

To remind about some established, foundational work in seminal research:

- Dou et al. (2025), Kyle (1985) Trading, auctions, algorithmic trading (emergent collusion and price inefficiency)
- Collin-Dufresne (2012) Insider Trading, Stochastic Liquidity and Equilibrium Prices
- Brunnermeier (2005) Predatory Trading

We do not know where (a fatal?) phase transition may happen and if existential risks lie ahead.

So far, systemic risk did not prove to be deadly and is an opportunity for a very colorful area of research and a headache for policymakers and risk managers

What have we learned?

- **System-wide analysis of systemic risk, esp., stress tests, a very natural place to apply network models**
- **It's not enough to just look into one segment of the economy / financial system to address systemic risk questions; tools, data, models grow to helps analyse linkages between financial institutions beyond banks and catch up covering technological advancements**