BANCA D'ITALIA
EUROSISTEMA

# Questioni di Economia e Finanza

(Occasional Papers)

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by Valentina Michelangeli, Silvia Sacco, Valentino Bado, Valeria De Chiara, Ginette Eramo, Francesco Ficarola, Irene Mavilia, Claudia Miani, Ivan Quaglia, Giuseppe Reale, Francesco Sciarretta, Riccardo Scimone and Laura Sigalotti

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# SYSTEM-WIDE STRESS TESTS: A SURVEY OF EMPIRICAL EVIDENCE, CONCEPTS, AND METHODOLOGIES

by Valentina Michelangeli*, Silvia Sacco*, Valentino Bado*, Valeria De Chiara*, Ginette Eramo*, Francesco Ficarola*, Irene Mavilia*, Claudia Miani*, Ivan Quaglia*, Giuseppe Reale*, Francesco Sciarretta*, Riccardo Scimone* and Laura Sigalotti*

**Abstract**

This paper surveys the rapidly evolving literature on system-wide stress-testing models, with particular emphasis on the interconnections among multiple financial institutions, including both banks and non-bank financial intermediaries. We begin by reviewing the key systemic events that motivate the development of such models. We then describe the network structures that characterize financial interconnections and review the principal modelling approaches, highlighting the most recent methodological advances. We then categorize the types of shocks typically analysed and the mechanisms through which contagion propagates across institutions. Finally, we highlight the main lessons learned and identify the critical gaps that still need to be addressed.

**JEL Classification**: G21, G22, G23, G18.

**Keywords**: banks, insurers, investment funds, system-wide stress test.

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## 1. Introduction[1]

In the aftermath of the global financial crisis and, more recently, in the COVID-19-led market turmoil, system-wide stress testing has emerged as a useful tool for assessing the resilience of the entire financial system to severe but plausible adverse scenarios. Unlike institution-level or sector-level stress tests, system-wide approaches aim to capture the broader dynamics of financial distress, including interconnectedness among institutions (banks and non-bank financial institutions, NBFIs[2]), feedback loops between the financial system and the real economy, and the amplification of shocks through behavioural responses and market dysfunctions.

The growing complexity and integration of financial systems have increased the likelihood that localized shocks can have far-reaching and systemic consequences. This has underscored the need for analytical frameworks that go beyond the direct impact of shocks on individual balance sheets and incorporate contagion mechanisms, such as fire sales, funding withdrawals, and loss of confidence. As such, system-wide stress tests are increasingly used by both supervisory authorities and international financial institutions to identify vulnerabilities, inform macroprudential policy, and support crisis preparedness.

This paper offers a review of the literature on system-wide stress testing, structured around seven key objectives presented in different sections. Section 2 examines several notable episodes of systemic financial distress to illustrate the underlying mechanisms and dynamics that drive system-wide vulnerabilities. Section 3 highlights some aspects related to the network structures that characterize financial interconnections. Section 4 outlines the most common methodological frameworks used in the design and implementation of system-wide stress tests, highlighting their respective strengths and limitations. Section 5 surveys the major types of shocks included in stress test models. Section 6 describes the main channels through which these shocks propagate across the financial system. Section 7 summarises the key insights gained from the literature. Section 8 identifies significant gaps and areas in need of further research.

By synthesizing the current state of knowledge, this review aims to contribute to the ongoing efforts to enhance the design and policy relevance of system-wide stress testing frameworks. It also seeks to provide guidance for future research in addressing the evolving nature of systemic risk in an increasingly interconnected and dynamic financial environment.

## 2. Relevant system-wide stress cases

This section presents an extended, though not exhaustive, series of crisis episodes, each shedding light on distinct features of systemic risk. The number and diversity of cases underscore how deeply interconnected financial systems amplify vulnerabilities. While the focus is primarily on recent

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[2] NBFIs include insurance companies, pension funds, investment funds (e.g., mutual funds, hedge funds, private equity, money market funds), other financial institutions, which include securitization vehicles, investment firms, and those mainly engaged in lending (leasing, factoring and consumer credit firms).

events, we also revisit key developments from the 2008 Global Financial Crisis (GFC) to provide historical context. Further details on each episode are provided in the Appendix.

The Lehman Brothers bankruptcy revealed how opacity, interconnectedness, and reliance on short-term funding can rapidly transform a firm-specific shock into a systemic crisis. The Lehman's collapse triggered a run on money-market funds, beginning with the Reserve Primary Fund, which held Lehman debt and "broke the buck." This led to widespread redemptions, even from funds without direct exposure, as fear spread through information contagion. Uncertainty about counterparty exposures and hidden risks caused banks and investors to hoard liquidity, freezing interbank and repo markets. The resulting disruption in market-based funding forced institutions to engage in fire sales, further depressing asset prices and weakening balance sheets across the system. Liquidity stress quickly spread to otherwise solvent institutions, amplifying the initial shock. Public interventions, including the Treasury's guarantee of money-market funds, were essential to halt the funding run and prevent broader collapse. The episode highlighted how systemic risk can emerge endogenously through feedback loops in funding markets, rather than through direct default chains.

AIG's near-collapse in September 2008 showed how large, non-bank financial institutions can generate systemic risk through opaque, highly leveraged capital markets activities and extensive counterparty exposures. AIG's systemic threat did not arise from its core insurance business—which remained largely solvent—but from its Financial Products division, which had substantial exposure to credit default swaps (CDS) on mortgage-backed securities. As the value of these securities plummeted, AIG faced escalating collateral calls and liquidity shortfalls, which threatened to trigger a cascade of losses across its counterparties and financial markets more broadly. The crisis underscored how non-traditional activities by non-bank financial entities—especially those involving derivatives and leverage—can become key channels of contagion, threatening both domestic and cross-border financial stability. Government intervention was ultimately required to prevent a systemic breakdown.

The March 2020 market turmoil showed how severe exogenous shocks can trigger systemic liquidity crises through rapid asset fire sales, funding stress, and dealer balance sheet constraints. Unlike the 2008 financial crisis, the COVID-19 shock originated outside the financial system, yet it rapidly destabilized core markets through a sequence of systemic amplification mechanisms. The crisis evolved from a flight to safety into a dash for cash, during which investors liquidated even high-quality assets like U.S. Treasuries to meet urgent liquidity needs. This led to sharp dislocations in key markets, including the Treasury and repo markets, as dealer balance sheets—already limited by regulatory constraints—proved unable to absorb the surge in asset sales. Cross-asset contagion intensified through common ownership structures, margin calls, and redemptions from investment funds. The episode revealed deep structural vulnerabilities in market-based finance, particularly the imbalance between the demand for liquidity and the capacity of intermediaries to supply it under stress. System-wide interventions by central banks, including large-scale asset purchases and backstop facilities, were decisive in halting the liquidity spiral and restoring market functioning.

The 2021 failure of Archegos Capital Management showed how extreme leverage, opacity in derivatives markets, and inadequate counterparty risk management can create systemic vulnerabilities through concentrated losses at major global banks. Operating as an unregulated family office, Archegos built large, leveraged positions using total return swaps and other derivatives that obscured its true exposures from its prime brokers. When a sharp decline in the value of its concentrated security holdings triggered margin calls that Archegos could not meet, banks rushed to liquidate collateral, leading to substantial losses—especially for institutions like Credit Suisse and Nomura. The episode highlighted weaknesses in risk controls, the systemic risks posed by non-transparent leverage outside the regulatory perimeter, and the potential for disorderly deleveraging to disrupt financial markets.

The 2022 UK Liability-Driven Investment (LDI) crisis highlighted how concentrated leverage, margin-driven asset sales, and liquidity mismatches in non-bank financial institutions can trigger systemic stress in core sovereign bond markets. Following the UK government's "mini-budget," surging gilt[3] yields forced highly leveraged LDI funds to rapidly liquidate assets to meet margin calls, amplifying volatility in an already thinly traded market. The fire sales overwhelmed market liquidity, creating a self-reinforcing feedback loop between rising yields and collateral demands. This destabilized not only pension-linked LDI strategies but also spilled over into other segments, including money market and real estate funds. The systemic nature of the episode stemmed from the scale of leverage, the concentration of LDI exposures, and the centrality of gilts in the UK financial system. The Bank of England's emergency gilt purchases were critical to halting the spiral and preventing broader contagion across financial markets.

The 2023 banking turmoil underscored how confidence shocks, asset-liability mismatches, and uninsured deposits can rapidly ignite systemic instability through depositor runs and contagion across institutions and borders. The failures of Silicon Valley Bank, Signature Bank, and First Republic Bank revealed how the interest rate tightening cycle revealed fragilities linked to concentrated business models, large unrealized losses on long-duration assets, and high shares of uninsured deposits. Once depositor confidence eroded, even solvent banks faced destabilizing liquidity runs. Digitalisation played a crucial amplifying role in the speed and intensity of these outflows. The widespread adoption of digital banking platforms and mobile applications enabled depositors to move large sums of money almost instantaneously, significantly compressing the time window available for bank management and regulators to respond. Furthermore, social media platforms amplified depositor anxiety and coordinated reactions, allowing real-time dissemination of news, rumors, and calls for withdrawal. The crisis quickly spread beyond the U.S., with Credit Suisse—already weakened by longstanding governance and strategic issues—hit by renewed market scrutiny and outflows. System-wide contagion was transmitted via funding markets and investor sentiment, leading to elevated market volatility, tighter financial conditions, and a sharp repricing of bank equity and credit risk. Authorities intervened forcefully through liquidity support and coordinated rescue packages to prevent further escalation. This episode highlighted the renewed systemic relevance of interest rate risk and the speed with which confidence shocks can propagate in an interconnected banking system.

## 3. Financial network structure

A financial system can be represented as a network by modeling financial institutions (such as banks, insurers, asset managers, and other non-bank financial intermediaries) as nodes, and the financial relationships between them—such as loans, derivatives contracts, securities holdings, or funding dependencies—as edges or links (Barucca et al., 2020). The direction and weight of the links can

[3] UK Government bonds are often called "gilts" because the paper certificates for bonds in the past had a gilded (golden) edge.

further characterize the structure: for example, a directed edge may represent a loan from one bank to another, while a weighted edge captures the size or risk intensity of the exposure. This network-based representation enables the analysis of systemic risk by highlighting the topology of interconnections. The system could be described as a core–periphery structure, where core nodes are connected densely to each other, while peripheral nodes are connected to the core nodes but not to other peripheral nodes (Figure 1, panel A). In an alternative representation, a system could be described as a bipartite network, which is a type of network in which nodes are divided into two distinct sets, and connections only occur between nodes in different sets—never within the same set (Figure 1, panel B; see Caccioli et al., 2018 for a review of network models).

The structure of the financial network plays a significant role in the propagation of contagion (Acemoglu et al. 2015; Co-Pierre, 2013). Allen and Gale (2000) identify two key characteristics – market completeness and interconnectedness – that affect the extent of contagion. In their model, a complete market—where all institutions are equally connected—can actually prevent contagion, as risks are more evenly shared and losses absorbed across the system. However, in incomplete but interconnected markets, where banks have uneven or partial connections, shocks can amplify due to localized vulnerabilities and concentrated exposures. Thus, the relationship between connectivity and stability is non-linear and context-dependent. More recently Elliott et al. (2014) introduced a more nuanced view by distinguishing between integration and diversification.[4] Diversification, defined as the number of counterparties to which an institution is exposed (Figure 2), can both amplify and mitigate contagion. While a more interconnected network creates more channels through which shocks can travel, it also reduces an institution's dependence on any single counterparty, thus enhancing resilience. Higher integration – measured by the size and concentration of bilateral exposures – increases the magnitude of losses when a counterparty fails, thereby raising the likelihood of systemic cascades once a shock occurs. At the same time, greater integration can enhance stability in normal times by distributing risk more broadly, thereby lowering the probability of an initial failure. The non-monotonic effect is presented in Figure 3.

The location of an institution within the network is also crucial in determining the fragility of the system. Mistrulli (2011) and Trapp and Wewel (2013) show that the propagation of a shock can differ significantly depending on the position of the initially affected institution within the network. This finding suggests that systemic risk is not only a function of network density but also the specific vulnerabilities of key nodes. Covi et al. (2021) show that systemic risk is highly sensitive to the network structure and bank-specific characteristics, with tipping points leading to a transition from a less vulnerable to a highly vulnerable state. Therefore, policies aimed at reducing systemic risk should focus on strengthening the resilience of weak nodes and reshaping network structures to limit potential losses.

Network dynamics are time-variant and depend on the state of the financial system at the time of a shock (Castrén and Rancan, 2014). As highlighted by Paltalidis et al. (2015), the same shock can produce different outcomes depending on the structure of the network and the time it occurs. For example, in the post-crisis era, the banking system has become less vulnerable to contagion due to increased capitalization and regulatory reforms.

[4] Integration captures the depth or extent of organizations' cross-holdings and thus it is like the an intensive margin; diversification considers the number of organizations interacting directly with one another, and so it is an extensive margin.

Multiplex networks[5] amplify the propagation of shocks. When institutions are connected through multiple layers—such as funding, derivatives, and securities markets—interactions across these layers can produce nonlinear contagion effects. Multiplex networks can help capture the multidimensional interdependence of financial institutions—showing how risks can propagate through multiple channels simultaneously (e.g., market exposure and funding links). Poledna et al. (2015, Figure 4) and Bargigli et al. (2015) show that these overlapping networks reinforce each other, exacerbating systemic stress beyond what is visible in any single layer. Michelangeli et al. (2026), using a multilayer network, show that consolidation events can generate changes in the structure of the Italian financial system.

A key limitation of network analysis is that it often assumes static relationships and fails to fully capture dynamic behavioral responses, feedback effects, and the evolving nature of interactions among agents over time; this can limit its ability to accurately model complex adaptive systems, such as financial markets, where agents' behaviors change in response to shocks and each other. The strength of network analysis lies in its flexibility regarding the underlying processes that shape network structures. Network analysis helps reveal hidden patterns, identify influential actors, assess vulnerabilities, and understand how complex systems behave collectively, especially in areas like systemic risk in financial systems, where the failure of one node can impact many others.

## 4. Methodologies

Different and complementary approaches have been put in place to assess the overall resilience of the financial system.

Indicators play an important role in assessing the resilience of the financial system by quantifying exposures, monitoring the build-up of systemic risks, and providing measurable signals of emerging vulnerabilities based on historical data. By capturing developments in areas such as leverage, liquidity, interconnectedness, and market sentiment, well-designed indicators contribute to early warning efforts and inform macroprudential policy responses aimed at maintaining financial stability. However, because of delays in data availability and the unpredictable nature of financial markets, only a limited number of indicators are appropriate for real-time surveillance, and certain emerging or unforeseen risks may remain undetected until they materialize.

Among the recent contributions, the ESRB report (2025) outlines a surveillance framework for systemic liquidity risks accounting for: i) an extended range of markets and entities; ii) different transmission channels and potential amplifiers of liquidity shocks. The analysis considers both funding and market liquidity, and the feedback mechanisms between them. The entities identified as key to systemic liquidity are banks, investment funds, insurance corporations, pension funds, open-ended funds and money market funds, while key markets are selected based on their role in liquidity provision for the financial system. Funding liquidity risks are captured by a set of indicators that considers the risks associated with the refinancing of debt (rollover risk), liquidity outflows (redemption risk) and changes in collateral valuation in secured funding or derivative transactions (haircut or margin risk). For market liquidity risks, the framework includes indicators of tightness (the cost of transactions), immediacy (the pace of execution), depth and breadth (the size and scope

[5] A multiplex network is a type of complex network in which the same set of nodes are connected by multiple types of relationships or interactions, each represented as a separate layer or "dimension" of the network.

of possible transactions). Furthermore, there is also a composite index of contagion and amplification risks. The proposed surveillance indicators are a good starting point for the assessment of systemic liquidity risks. It could be used to design stress test scenarios and could itself be refined based on the outcome of systemic liquidity stress tests. However, sound expert judgement must be used when interpreting the results: the relatively short time series for some input variables and the z-score methodology mean that the framework is more suitable for assessing the dynamics (e.g. increase vs decline) rather than the absolute level of systemic liquidity risks. Moreover, given the relatively long reporting lags for some of its elements, only a subset of the indicators included in the framework is suitable for real-time monitoring of liquidity stress.

Bottom-up stress tests are essential tools for assessing financial system resilience, as they rely on data reported by individual institutions that simulate how each would respond to adverse macro-financial scenarios based on their specific balance sheets, exposures, and internal risk models. This granular approach allows authorities to identify vulnerabilities within specific segments of the financial sector, assess the potential for loss absorption, and evaluate the transmission of shocks through the system. By aggregating these institution-level outcomes, bottom-up stress tests provide valuable insights into system-wide fragilities and inform targeted supervisory and policy actions.

Focusing on recent works on bottom-up system wide stress test, it is worth mentioning the 2024 Bank of England System Wide Exploratory Exercise (SWES); this exercise, conducted by the Bank of England in collaboration with the UK's Financial Conduct Authority (FCA) and The Pensions Regulator (TPR), examines how the UK financial system would respond to a market shock. Its objective is to deepen the understanding of the behaviours of banks and NBFIs active in the UK's core markets under stressed conditions and to investigate how these behaviours, along with market dynamics, can amplify shocks. Compared to traditional firm-focused stress tests, the SWES takes a system-wide perspective, incorporating complex firm behaviours and interactions through the active engagement of around 50 different financial firms (banks, insurers, central counterparties, and different types of funds such as hedge funds, LDI funds, money-market funds, and asset managers). Participants were actively involved through two rounds of the exercise itself. In the first round, participants were asked to submit quantitative templates providing detailed information on how the scenario would impact their business and what actions they would take in response. In the second round, the Bank of England provided firms with an updated scenario based on the collective actions of firms in the first round. By analysing responses across participating firms and supplementing them with qualitative information, different aspects have been explored, i.e. sectoral behaviours, cross-sectoral interactions and interconnections between different firms, and the combined impact on financial markets. The SWES is thus a collaborative exercise conducted over multiple rounds of engagement, allowing to explore feedback and amplification effects and to assess the resilience of the entire financial system (not of individual entities). The scenario comprises a sudden and severe shock to global financial markets (a 10-day market shock and other features of the scenario like a hedge fund default). The SWES scenario comprised a rapid and significant shock to rates and credit spreads triggering significant losses and margin calls, with margin flowing from NBFIs to banks and CCPs. The large and rapid market shock generated a significant liquidity need for many NBFIs in the form of margin calls and redemption requests (Figure 5). This liquidity impact combined with leverage and risk constraints, as well as investment strategies and other commercial drivers of behaviour, leading to some NBFIs having to recapitalise and/or deleverage rapidly. Many firms in the SWES rely on repo to manage liquidity or monetise assets and thus repo markets are core to supporting firms' ability to absorb the liquidity shock. Banks were not acutely impacted by the stress;

however, the uncertainty in the scenario and their risk management means they were often reluctant to extend new financing or warehouse risk in core markets to the extent demanded by SWES participants. Through derisking and deleveraging, the financial system acted to distribute and amplify the impact of the shock and some core UK markets came under pressure. The exercise also highlighted mismatches in firms' expectations of how others would act in a stress scenario.
It is important to keep in mind that results from bottom-up stress test are highly dependent on the shock considered, on the starting point of the financial institutions and on the ability of institutions to provide accurate answers.

Top-down stress test models and network models are structural and theory-based tools that assess financial system resilience by explicitly modelling the underlying economic mechanisms, institutional interlinkages, and behavioural responses that shape the propagation of shocks. Unlike purely statistical approaches, structural models allow policymakers to conduct counterfactual analysis and explore the effects of specific policies or structural changes. This makes them particularly valuable for stress testing and scenario analysis, as they can simulate how shocks transmit through complex networks and feedback loops, helping to identify vulnerabilities and inform macroprudential policy design.

The top-down approaches differ in scope, complexity, and underlying assumptions, aiming to capture interconnections and vulnerabilities beyond the banking sector.
Among the recent contributions, Cetorelli's framework at the Federal Reserve Bank of New York adopts a very simplified spreadsheet-based approach to simulate shock propagation (Cetorelli, et al., 2023). This model focuses on fire-sale dynamics and liquidity spirals, incorporating a broad set of NBFIs. Its simplicity makes it easy to implement and interpret, particularly for preliminary assessments of systemic vulnerabilities. However, the lack of granular data, dynamic feedback mechanisms and behavioural responses limits its ability to capture second-round effects and complex contagion patterns.
Agent-based models (ABMs) represent a more sophisticated class of methodologies. These models simulate heterogeneous behaviours and endogenous reactions, allowing for feedback loops and non-linear amplification. However, these models require high computational capacity as well as many behaviuoral parameters (e.g., rules for banks) that are hard to calibrate and may rely on stylized assumptions. The Bank of Canada has pioneered ABMs for system-wide stress testing, particularly in the context of climate transition shocks (Bruneau, et al., 2025). Similarly, the Bank of Japan and the Bank of Spain have employed ABMs to explore interconnections between domestic banks and foreign investment funds, highlighting vulnerabilities in cross-border exposures and liquidity mismatches (Konaka, et al., 2025) and (Borsos, et al., 2025).
Academic research has contributed network-based models such as DebtRank (Battiston, et al., 2016), which measures systemic importance and shock propagation through interconnected exposures. The ECB's Interconnected System-wide stress test Analytics (ISA) model (Sydow et al., 2021 and 2024) is a dynamic microstructural framework designed for system-wide stress testing covering multiple segments of the financial sector. Its primary goal is to offer a comprehensive representation of systemic dynamics by incorporating both initial shocks and their subsequent amplification through interconnected channels of contagion. These channels reflect distinct risk categories – credit, liquidity, and market risk – whose interactions are explicitly modelled. Key features of the framework include the interplay between liquidity shortages and solvency distress, endogenously evolving balance sheets, a detailed incorporation of regulatory requirements, and the endogenous

determination of market prices (Figure 6). Recently the Bank of France is adapting the ISA model to the specificities of its own country.

While effective for analysing contagion and second-round effects, network-based models require detailed bilateral exposure data and do not fully incorporate behavioural dynamics or liquidity constraints.

In sum, these approaches for to-down system-wide stress test differ significantly in complexity and applicability. Spreadsheet-based models offer simplicity and transparency but fail to capture dynamic contagion. Agent-based models provide granular insights into behavioural dynamics but are computationally intensive and data-demanding. Network-based models provide valuable insights into systemic importance and network contagion but are limited by data availability and the absence of behavioural dynamics. Since the GFC of 2008–2009, the availability of granular data on the financial sector has improved significantly, enabling substantial progress in the modelling and quantification of financial contagion channels. However, these models remain highly sensitive to underlying assumptions, and certain key parameters – such as the market liquidity of specific asset classes – are difficult to calibrate accurately. As a result, point estimates should be interpreted with caution. Their greatest value in a policy context lies not in precise prediction, but in offering a structured framework for exploring how systemic stress might propagate under different conditions.

## 5. Types of shocks

In the context of system-wide stress testing, the classification of shocks is fundamental to accurately assessing vulnerabilities and potential amplification mechanisms within the financial system. Shocks are typically distinguished in two categories: (a) those that are purely exogenous, and (b) those that can be either exogenous in origin or are primarily driven by endogenous responses within the financial sector. Purely exogenous shocks originate outside the financial system—such as natural disasters, geopolitical events, or abrupt policy shifts—and serve as external inputs into stress testing frameworks. These shocks are treated as given, with no initial dependence on the behaviour of financial institutions or market dynamics.

However, many real-world scenarios involve exogenous shocks that interact with the internal dynamics of the financial system, leading to feedback loops and nonlinear amplification effects. For instance, a macroeconomic downturn or a commodity price shock may initially be external but can quickly result in deteriorating asset quality, fire sales, tightening funding conditions, and behavioral responses that amplify the initial stress. These endogenous reactions are particularly relevant in a system-wide perspective, as they reflect the interconnectedness among banks and NBFIs, the role of market infrastructure, and the transmission of stress across sectors and borders.

The following two subsections present the most relevant shocks identified within the system-wide stress testing framework, categorized by shock type. For each category, we illustrate the shock with historical episodes to contextualize its potential systemic impact.

### 5.1 Purely exogenous shocks

Macroeconomic shocks refer to large, economy-wide disturbances that significantly alter key aggregate indicators such as GDP growth, inflation, unemployment, or interest rates. (Alfaro and

Drehmann, 2009; Jobst et al., 2013; Henry and Kok, 2013; ESRB, 2015; Cont et al., 2020; Apicella et al., 2022; Fay and Ghiselli, 2023; ESRB, 2022, among others)**.** These shocks can originate from a range of sources – domestic or global, demand- or supply-driven – and often have pervasive effects across sectors. Although their primary impact is on the real economy, they can propagate into the financial system through deteriorating asset quality, increased credit risk, heightened market volatility, and shifts in investor expectations or policy responses.
Historical examples include the global recession following the 2008 financial crisis, the energy price shocks in the aftermath of the Russian invasion of the Ukraine (and earlier in the 1970s), and the inflationary surge of 2021–2022 that led central banks across advanced economies to raise interest rates sharply, with knock-on effects on debt servicing capacity, asset valuations, and financial stability.

Sovereign risk shocks refer to sudden and significant increases in the likelihood that a government may default on its debt obligations or encounter serious difficulties in refinancing its liabilities (Furfine and Remolona, 2002; Gennaioli et al., 2014; Paltalidis et al., 2015, among others). These shocks can be triggered by a variety of factors, including deteriorating fiscal conditions, or political instability, or adverse macroeconomic developments and can trigger widespread disruptions across financial markets, particularly in jurisdictions where banks or institutional investors are heavily exposed to domestic sovereign debt. Key features of a sovereign risk shock include sharp increases in government bond yields and credit default swap (CDS) spreads, credit rating downgrades, and a generalized reassessment of sovereign creditworthiness.
The consequences can be systemic. Banks with concentrated sovereign exposures may face large mark-to-market losses, funding strains (with subsequent credit tightening; Albertazzi et al., 2014), or collateral shortages. In extreme scenarios, these shocks can reduce trust among financial institutions, potentially freezing interbank lending and forcing asset fire sales to meet liquidity demands—thereby amplifying market volatility and financial stress. NBFIs are also significantly exposed. Declining sovereign bond prices can erode the value of their portfolios, impairing their capacity to meet liabilities and, in some cases, forcing asset liquidations. These sales can further destabilize markets, creating a negative feedback loop that intensifies systemic risk.
Historical examples include the Russian default in 1998 on domestic ruble-denominated debt also had global repercussions, severely affecting emerging markets and contributing to the near collapse of the hedge fund Long-Term Capital Management. The Argentina's repeated defaults – in 2001 and again between 2018 and 2020 – produced deep financial and economic dislocations. At European level the euro area sovereign debt crisis (2010–2012), where fiscal distress in Greece, Portugal, and Ireland triggered a sharp repricing of risk and laid bare the vulnerabilities of the European banking sector.

Real estate or asset price shocks[6] can serve as powerful triggers of systemic financial crises, particularly in are highly leveraged markets (Deng et al. 2019; Koetter and Poghosyan, 2010; Huang et al, 2013). A sharp decline in residential or commercial property prices can significantly impair the balance sheets of financial institutions with direct exposures to these assets or indirect exposures through real estate-backed lending. As property values fall, banks experience a deterioration in the value of collateral, a rise in mortgage delinquency and default rates, and a decline in the market value of their real estate loan portfolios. These effects reduce profitability and may undermine capital adequacy, especially in institutions with concentrated exposures. NBFIs can also be affected, as

[6] Real estate or asset price shocks are typically considered a subset of macroeconomic shocks; however, given their relevance, they are discussed separately as a distinct category of shock.

declining property values reduce the value of their investment portfolios and may impair their ability to meet long-term liabilities. Large-scale corrections in real estate markets may also trigger fire sales, further depress asset prices, and amplify losses through feedback loops. The risk of systemic disruption is exacerbated when real estate markets are tightly interconnected with broader credit conditions or when price declines coincide with economic downturns.
Historical examples include housing market collapses, such as during the U.S. subprime mortgage crisis (2007–2008), as well as sharp declines in commercial real estate valuations that have threatened financial stability in both advanced and emerging economies, especially in periods of raising interest rates.

Natural catastrophic, climate or environmental shocks are an increasingly relevant source of systemic financial risk, encompassing both physical and transition risks associated with climate change (Battiston et al., 2017; Acharya et al., 2023; ESRB, 2023; Labini et al., 2024). Physical risks refer to the economic and financial impacts of acute climate-change related events – such as hurricanes, floods, wildfires, and droughts – or longer-term changes in climate patterns. Moreover, physical risks related to natural disasters not directly affected by climate change – such as earthquakes, windstorms, severe connective storms and subsidence – could also be a source of systemic risk. These events can result in substantial asset write-downs, particularly in sectors with high exposure to physical infrastructure or property, and can impose significant losses on banks, insurers, lenders, and investors. Transition risks arise from the process of adjusting to a low-carbon economy. These may stem from abrupt regulatory changes, such as the introduction of carbon taxes or emissions caps, shifts in market preferences, technological disruptions, or changes in investor sentiment regarding environmental, social, and governance (ESG) factors. Such developments can lead to a sharp repricing of assets in carbon-intensive sectors (e.g., energy, utilities, transportation, heavy industry), generate stranded assets, and impair credit quality for exposed firms and financial institutions.
The systemic nature of climate and cat nat shocks lies in their potential to affect large segments of the economy and financial system simultaneously, through multiple transmission channels. For instance, a major natural disaster can lead to sudden insurance payouts, a decline in real estate valuations, and higher credit losses. Similarly, an unanticipated tightening of environmental regulation may trigger market corrections, reduce profitability in polluting industries, and create spillovers through supply chains and financial portfolios.

Political or geopolitical shocks encompass a broad range of events such as political instability, armed conflict, trade disputes, international sanctions, or abrupt changes in government policy. These shocks can have significant implications for financial stability, directly affecting asset prices and macroeconomic conditions, and indirectly influencing investor confidence, capital flows, and global supply chains. Banks may face increased credit, market, and liquidity risks due to sudden shifts in asset valuations, cross-border exposures, or a deterioration in borrower creditworthiness, particularly in politically exposed sectors or regions. NBFIs may also be impacted through valuation losses, increased redemption pressures, or rising uncertainty around sovereign and corporate risk. In both cases, heightened volatility and risk aversion can amplify financial stress and contribute to broader market instability.
Examples include the economic and financial repercussions of the Russian invasion of Ukraine, which not only disrupted global energy and food markets but also led to asset freezes, forced divestments, and market exits by financial institutions. Similarly, the U.S.–China trade tensions in 2018–2019 created market volatility, altered cross-border investment patterns, and contributed to uncertainty in global manufacturing and financial markets. More recently (April 2, 2025), the

imposition of new trade tariffs by the United States has contributed to heightened market volatility by increasing uncertainty around global trade dynamics, raising input costs for some firms, and prompting retaliatory measures from some trading partners.
Because geopolitical events are often sudden, difficult to predict, and highly nonlinear in their effects, they present particular challenges for risk assessment and stress testing. Yet their growing frequency and severity underline the need for financial institutions and regulators to incorporate geopolitical scenarios into their systemic risk frameworks.

### 5.2 Shocks as exogenous events or endogenous reactions

Credit risk shocks refer to sudden and substantial deterioration in the creditworthiness of borrowers – households, firms, or sovereigns –which lead to elevated default rates, sharp declines in the value of credit portfolios (such as loans and bonds) held by banks and investors, a tightening of lending standards (as financial institutions become more risk-averse), and a broad repricing of credit risk, typically reflected in a rapid widening of credit spreads (Caccioli et al., 2015; Aikman et al., 2023; Sydow et al., 2024, among others). After occurring, such shocks rarely remain isolated. In the banking sector, a rise in credit risk typically manifests through an increase in non-performing loans, capital erosion, and subsequent deleveraging. These effects can constrain the supply of credit to the real economy, reinforcing a classic adverse feedback loop between financial distress and economic activity. However, the growing role of NBFIs has introduced additional channels for the transmission and amplification of credit shocks. NBFIs are exposed to credit risk through various mechanisms: direct holdings of corporate bonds, structured credit instruments, and leveraged loans; insurers' and pension funds' exposure to corporate and sovereign credit within long-duration portfolios; open-ended investment funds facing redemption pressures during episodes of credit market stress—often resulting in forced asset sales; and procyclical investment behaviour, particularly by leveraged credit funds engaging in activities such as credit default swap (CDS) selling.
Prominent examples include the subprime mortgage crisis (2007–2008), which originated from a widespread deterioration in U.S. household credit quality, and the euro area sovereign debt crisis (2010–2012), during which sovereign credit stress in peripheral countries led to severe losses for banks with concentrated exposures.

Market risk shocks refer to abrupt and substantial changes in financial market conditions that adversely affect the value of financial assets (ESRB, 2015; Apicella et al., 2022; Fay and Ghiselli, 2023; Schilte et al., 2022; Sydow et al. 2024; Bank of England, 2024, among others). While credit default shocks may take time to impact credit exposures, market shocks have an immediate effect on the fair value of market exposures. Market shocks typically result from unexpected economic developments, abrupt shifts in investor sentiment, or geopolitical events, and they impact key market variables such as interest rates, exchange rates, equity prices, commodity prices, and credit spreads[7]. While the initial shock could be exogenous, the amplification mechanisms are largely endogenous, driven by interconnected financial institutions and their behavioural responses. These abrupt price movements can also elevate market volatility and contribute to broader financial instability by triggering margin calls, portfolio rebalancing, or fire sales. In this context, NBFIs play a particularly relevant role, given their central position in capital markets and their structural characteristics, such

[7] Insurers in some cases act procyclically in market downturns and can amplify actual shocks. Insurance companies typically hold assets until maturity and tend to buy assets when market prices fall. However, insurers – especially those that are less capitalised – may act pro-cyclically in certain market segments during stress episodes.

as leverage, liquidity mismatches, and mark-to-market accounting. For example, asset managers managing bond funds may be exposed to liquidity mismatches (liquid liabilities, illiquid assets).
Examples of such shocks include sharp increases in interest rates following unexpected monetary policy decisions, sudden equity market crashes, rapid depreciations in exchange rates that raise debt-servicing costs for foreign-currency borrowers, or geopolitical disruptions that trigger extreme volatility in oil or commodity markets.

Market liquidity shocks refer to a sudden and severe decline in the ability to buy/sell financial assets rapidly and at prices close to their fundamental values (FSB, 2020; Adrian and Shin, 2010; Allen et al., 2009). During such episodes, market functioning deteriorates markedly, characterized by sharp increases in bid-ask spreads, a collapse in trading volumes, heightened price volatility, and significant deviations of asset prices from underlying fundamentals. These conditions make it difficult or prohibitively costly for market participants to unwind positions without incurring in substantial losses. What begins as an external shock can be amplified through endogenous dynamics, particularly in markets dominated by NBFIs. These institutions can intensify liquidity stress due to their reliance on short-term funding and their tendency to engage in procyclical behaviour. In periods of market stress, NBFIs may respond to investor redemptions or mark-to-market losses by liquidating assets simultaneously, contributing to fire-sale dynamics and further eroding liquidity across asset classes.
Common drivers of market liquidity shocks include panic selling or herding behaviour, a withdrawal of market-making activity due to capital constraints or heightened risk aversion, increased uncertainty or loss of confidence among market participants, and disruptions related to regulatory or technical factors.
A notable example occurred in March 2020 during the onset of the COVID-19 crisis, when even U.S. Treasury markets – typically among the most liquid assets in the world – experienced severe liquidity stress, with dislocated pricing, elevated bid-ask spreads, and intense selling pressure.

Redemption shocks occur when there is a sudden and substantial increase in investor withdrawals from financial products or institutions, such as investment funds, money market funds, or other collective investment schemes (FSB, 2020). These shocks are often initiated by factors such as heightened market volatility, persistent underperformance, reputational damage, or broader macro-financial disruptions that undermine investor confidence. While the initial trigger may be external, the amplification of redemption pressures often arises through endogenous mechanisms, especially within NBFI sector. As highlighted by the FSB, collective investment vehicles with liquidity mismatches are particularly vulnerable, as they may be forced to sell less liquid assets in stressed market conditions to meet redemptions. This dynamic can lead to a downward spiral in asset prices, further investor panic, and broader market dislocations.
A prominent example occurred during the market turmoil of March 2020, when a broad-based flight to cash led to severe redemption pressures in corporate bond funds. In response, some funds were forced to suspend redemptions or liquidate assets at distressed prices, thereby amplifying market dislocations and contributing to broader financial instability. An example of an attempt to mitigate potential impacts from future redemption shocks is given by the Central Bank of Ireland, which enforced financial stability measures on property funds according to the provisions of Article 25 of AIFMD.[8]

[8] https://www.centralbank.ie/financial-system/financial-stability/macro-prudential-policy/nbfi/property-funds

Funding shocks refer to a sudden disruption or tightening in the availability or cost of financing for financial institutions, corporations, or sovereigns, typically arising during periods of heightened market stress or a loss of confidence (Brunnermeier and Pedersen, 2009; FSB, 2020; ECB, 2023; Bank of England, 2021). Exogenous triggers for such shocks may include abrupt changes in monetary policy, sovereign credit events, or geopolitical crises that undermine investor trust or risk appetite. Once triggered, funding shocks can rapidly propagate through the financial system via endogenous amplification channels. Institutions reliant on short-term wholesale funding or foreign currency financing are particularly vulnerable, as they may face refinancing difficulties or sharply increased funding costs. NBFIs, such as investment funds, finance companies, and securities dealers, are increasingly exposed to funding shocks due to their dependence on market-based funding sources, including repos, commercial paper, and margin-based leverage.
Notable examples include the 2008 global financial crisis, during which interbank lending markets froze amid fears of counterparty defaults, and during the March 2020 liquidity crisis, several NBFIs encountered severe funding pressures as repo markets became impaired and counterparties raised haircuts or withdrew liquidity altogether. These disruptions contributed to forced asset sales, further market volatility, and a tightening of financial conditions.

Surrender shocks refer to a sudden and unexpected increase in policy surrenders[9] by holders of insurance contracts (EIOPA, 2020; IMF, 2020). A surrender shock can be triggered by various factors, such as a sharp rise in interest rates, making alternative investments more attractive, loss of confidence in the insurer (e.g., due to rumours of financial distress), economic hardship prompting liquidity needs among policyholders. During the financial crisis or in times of economic instability, insurers might face higher-than-expected surrenders, stressing their liquidity needs and their Asset-Liability Management framework with potential impact on their profitability and future business sustainability. The systemic risk arises when surrender shocks spill over into broader asset markets or affect financial stability through interconnected exposures. Incorporating surrender risk into stress testing frameworks is therefore essential.

## 6. Transmission channels

In this section, we present an overview of various contagion channels through which shocks can propagate within the financial system, affecting both banks and NBFIs. The academic literature broadly distinguishes between two principal types of contagion mechanisms: *direct* and *indirect* linkages. Direct linkages arise through contractual exposures, such as interbank lending or counterparty relationships, where financial distress can be transmitted from borrower to lender or vice-versa. Direct exposures can be analysed, for instance, using an accounting representation of the balance sheet of the financial system. Indirect linkages, by contrast, operate through common exposures to similar or correlated assets or, more generally, through the common good of public confidence in financial institutions. In such cases, distress in one institution can lead to asset sales, price declines, and valuation losses for other institutions holding the same or similar assets, potentially triggering further rounds of deleveraging and amplifying systemic risk.

[9] In the insurance sector, “surrender" refers to the voluntary termination of a life insurance policy by the policyholder prior to its maturity or before the event it insures against has occurred. In return for surrendering the policy, the policyholder receives the surrender value from the insurance company, if any. The surrender value is usually a portion of the premiums that have been paid towards the policy, minus any charges (including the penalty option, if any).

The direct credit exposure channel or direct contagion via the solvency channel operate through contractual credit exposures between financial institutions (Jobst et al., 2013; Bardoscia et al., 2019; Cont et al., 2020; Sydow et al., 2024). When one institution lends to another, it becomes exposed to the borrower's credit risk. In the event of default or financial distress, the lender may incur losses that, net of provisions and income buffers, can erode its capital base, impair its balance sheet, and generate liquidity pressures or solvency concerns. In severe cases, such losses may be large enough to trigger the lender's own default, particularly if it is unable to meet obligations to other counterparties. A financial institution is deemed insolvent when the capital falls below a certain threshold, which can be zero or a regulatory one. Financial institutions typically are prompted to act after a shock because they want to restore their initial target regulatory or internal levels. This dynamic may set off a cascade of failures throughout the more vulnerable financial institutions. As recent data suggest, the interconnection between banks and NBFIs through such direct exposures are increasingly over time (Acharya et al., 2024).

The funding liquidity channel captures the dynamics through which financial institutions lose access to short-term funding or face sharply increased funding costs during periods of stress (Angelini et al., 1996; Brunnermeier and Pedersen, 2009; Gai et al. 2011; Georgescu, 2015; Paltalidis et al., 2015; Glasserman and Young, 2016; Cont et al. 2020; FSB, 2020; Franceschi et al., 2023; BoE, 2024). Disruptions can stem from interbank market stress, management of interbank payments, margin calls[10], repo[11] runs or precautionary hoarding by funding providers; insurers also hold shares in the markets for long-term bank debt, acting as an important source of funding. A contraction in interbank lending can propagate distress through the network, triggering a broader funding run. The process could be non-linear: modest shocks could result in manageable increases in funding costs, while more severe shocks – especially those leading to the default of one or more institutions – could trigger sharp jumps in funding costs and liquidity withdrawal across the system. As access to liquidity dries up, institutions may be forced to scale back their balance sheets, either by selling assets or by curtailing lending. The liquidation of assets by other institutions can amplify funding pressures by causing adverse price movements that undermine collateral values (Figure 7).

In the case of NBFIs, funding liquidity stress can materialize through investor flows. Negative returns due to an exogenous shock may prompt redemptions from investment funds, which must then liquidate assets to meet withdrawals. These sales can depress market prices further, causing additional losses and redemptions in a self-reinforcing dynamic. This mechanism closely parallels traditional funding runs and can have system-wide implications when large or highly interconnected funds are involved.

Concentration risk is another potential concern. If, for instance, a small number of large banks rely heavily on repo funding provided by NBFIs, these banks occupy a critical position in the market, effectively acting as the primary recipients of repo liquidity from the broader NBFI sector. In the event that one or more of these banks were to experience distress, the repercussions could be significant, potentially impairing the ability of large segments of the NBFI sector to manage their own liquidity and market risks.

[10] Margins increase as prices drop, as they are a function of asset price volatility. Arbitrageurs must finance the haircut on their investments with their own capital and they will be forced to sell assets in order to satisfy margin calls, depressing prices even further. This leads to higher margins and tougher funding constraints.

[11] Financial institutions can raise liquidity by entering a repurchase agreement (repo) with a market counterparty. This requires the provision of liquid marketable (unencumbered) collateral and thus the volume of liquidity that can be raised through this channel is capped by the size of the firm's pool of unencumbered marketable assets, discounted by the corresponding haircut parameter.

As a final remark, a firm may experience illiquidity without being insolvent, just as it may be insolvent while still remaining liquid (Figure 8).

The asset liquidation and fire-sale channel arises when distressed institutions, facing financial strain, are forced to sell assets quickly, which in turn depresses market prices (Cifuentes et al., 2005; Leitner, 2005; Shleifer and Vishny, 2011; Greenwood et al., 2015; Cecchetti et al., 2016; Cont and Schaanning, 2017; Coen et al., 2019; Chernenko and Sunderam, 2020; Duarte and Eisenbach, 2021; Falato et al., 2021; Aikman et al., 2023; Sydow et al., 2024a and 2024b). These fire sales exacerbate market instability by causing mark-to-market losses for other institutions holding similar or correlated assets. The pressure to sell can occur when institutions need to maintain leverage targets, when leverage surpasses a critical threshold, in response to liquidity and solvency constraints, or as a consequence of reputational and confidence spillovers.
Two key conditions must be met for fire-sale contagion to unfold. First, mark-to-market accounting must be in place, meaning that assets are valued at current market prices. Second, the market must have limited capacity to absorb the asset sales without causing significant price declines. This can happen if buyers are constrained or if assets are sold to less specialized investors, who may not fully appreciate the intrinsic value of the assets. The amplification of losses via this channel is more pronounced when institutions are highly leveraged and face liquidity mismatches, especially when there are large cross-holdings of similar assets across the financial system.
The fire-sale process is typically described by three components: (1) the initial trigger causing the need for asset liquidation, (2) the strategy employed in deciding which assets to sell, and (3) the price impact resulting from the sales. The liquidation strategy can vary depending on the institution's situation. For example, some institutions may adopt the "waterfall" approach prioritizing the sale of the most liquid assets first and following a specific hierarchy: cash, investment-grade sovereign bonds, investment-grade corporate bonds, high-yield sovereign bonds, equities, and finally high-yield corporate bonds. In contrast, the "slicing" approach implies that assets are sold proportionally across the portfolio to maintain its structure, typically by asset class. Under an optimal deleveraging strategy, most losses occur in the most liquid asset classes; in contrast, with proportional deleveraging, banks no longer prioritize the retention of illiquid assets, resulting in a more even distribution of losses across asset types (Figure 9). The market impact and losses from fire sales are also influenced by the type of assets involved, their liquidity, and the broader market conditions. The price impact of selling assets increases with the amount sold.
This fire-sale dynamic contributes to the broader contagion process by cascading losses through the financial system, particularly when large or systemically important institutions are involved.

The collateral (margin) channel refers to the mechanism by which sudden increases in margin requirements or collateral demands force financial institutions to rapidly raise liquidity, often by selling assets, which can amplify market stress and trigger broader contagion across the financial system (Gai et al., 2011; Paddrik et al., 2020; Luu et al., 2021; Ghamami et al., 2022; Aikman et al., 2023). As an illustrative example, Figure 10 shows the composition of a bank balance sheet, where collateral assets are those assets that can be used as collateral in repo transactions. When asset prices fall, institutions may be required to post additional collateral or face liquidation, intensifying the pressure on their balance sheets. Changes in collateral values or margin requirements can directly trigger contagion. For instance, shifts in haircuts within secured funding markets can lead to a funding squeeze for borrowing institutions. These institutions may then be forced to dip into their cash buffers, seek additional funding, or sell assets, which can have cascading effects on other financial intermediaries.

Additionally, collateral held in illiquid assets can create a channel for indirect contagion. When an institution defaults, its counterparties may seize and liquidate the collateral. While this could benefit a bank if the failure of another institution frees up collateral, the sale of such collateral may depress market prices. This decline in prices can lower the value of collateral held by other institutions, potentially triggering further margin calls and reinforcing the contagion effect through asset sales and fire sales.
The practice of collateral rehypothecation, where collateral is reused by the lender to secure additional transactions, introduces another layer of contagion risk. Although rehypothecation increases funding liquidity by allowing multiple institutions to rely on the same set of collateral, it also magnifies the risk of distress propagation as failures can reverberate across institutions due to the interconnectedness created by this practice.
In the case of NBFIs, the increased use of collateral following the 2008 crisis was aimed at reducing counterparty credit risk. This typically involves two types of collateral: initial margins (or haircuts) and variation margins. Initial margins involve overpayment by one counterparty to account for potential market fluctuations, while variation margins reflect collateral flows between counterparties due to price changes in either the collateral or the underlying derivative contract. Failure to meet margin calls is typically treated as a default event. While the use of collateral reduces counterparty credit risk and mitigates solvency contagion, it introduces funding liquidity risks, as institutions may need to raise funds to meet margin calls. After a default event, market liquidity risks emerge as counterparties attempt to sell collateral to recoup losses.

During systemic crises, information contagion or loss of confidence channel can lead to a broad withdrawal of funding or market panic, affecting even institutions that have not defaulted or shown signs of insolvency (Battiston et al., 2012; Anand et al., 2012). When external creditors lack clear information about an institution's financial health or ability to repay debt, any perceived deterioration in its creditworthiness can trigger a revaluation of the institution's risk profile. This uncertainty can spread to other institutions, affecting the value of creditors' assets and subsequently increasing their own probability of default. As a result, distress can propagate through the financial system even before an actual default occurs. Financial institutions could respond to negative information by withdrawing funding to minimize potential losses, with the rate of information flow and the maturity structure of debt contracts playing key roles in shaping the intensity of contagion.
In this way, the loss of confidence can set off a chain reaction of funding withdrawals and asset value reductions, even in the absence of a direct default, demonstrating the profound influence that information contagion can have on the stability of the financial system.

The common exposure or overlapping portfolios channel refers to the systemic risk that arises when multiple institutions hold similar or correlated assets (Caballero et al. 2013; Cont and Schaanning, 2019; Roncoroni et al., 2021; Aldasoro et al., 2022; Acharya et al., 2024). As financial institutions are linked by common assets, the losses are not confined to a single institution but simultaneously affect the balance sheets of many institutions that share exposure to the same asset class. Thus, price shocks can lead to cascading effects, where one institution's distress creates further stress for others. This interdependency can result in a network effect that heightens the overall vulnerability of the financial system to systemic risk. This form of contagion can be particularly acute in periods of market stress, where price movements are often amplified across financial institutions due to shared asset holdings. In essence, the common exposure / overlapping portfolios channel underscores the dangers of concentrated asset holdings across institutions and sectors. When institutions share significant exposure to the same assets, even a seemingly localized price shock can trigger widespread financial instability. This form of contagion can be especially problematic in sectors where assets are highly liquid, widely held, or highly correlated, making the financial system vulnerable to the amplification of shocks through shared risks.

The cross-border transmission of systemic financial shocks refers to the propagation of financial distress from one country's or jurisdiction's financial system to another, often through banking linkages, capital flows, or common exposures (Paltalidis et al., 2015; Daly et al., 2019; Ahnert and Bertsch, 2022). The mechanisms at play are similar to those previously described and applied to financial institutions and markets that are interconnected across national boundaries.

The magnitude and intensity of cross-border transmission depend critically on the size of foreign financial systems and the degree of exposure that domestic banks have to them. In particular, the more heavily domestic banks are exposed – whether through direct lending, interbank funding, derivative positions, or holdings of foreign securities – to foreign financial institutions or sovereigns, the more susceptible they are to spillover effects when those foreign systems experience stress. Financial contagion across borders is particularly likely when domestic banks have substantial claims on foreign financial institutions, or when they rely heavily on foreign sources of funding. In such cases, a shock originating abroad – such as a sovereign default, a banking crisis, or a collapse in asset prices – can transmit rapidly to domestic financial institutions, undermining their capital positions, constraining their access to liquidity, and eroding investor confidence.

Cross-border contagion can also operate through more indirect channels, including global investor behaviour, exchange rate movements, and correlated risk perceptions. When a crisis emerges in one country, global investors may reassess risk across entire regions or asset classes, leading to capital outflows and a tightening of financial conditions even in countries not directly affected by the original shock. This phenomenon, sometimes described as "wake-up calls" or "guilt by association", reflects the interconnectedness of risk perceptions and investment strategies in global financial markets.

Moreover, multinational banking groups can act as transmission vectors of shocks between countries. If a banking group experiences losses in one jurisdiction, it may respond by deleveraging, liquidating assets, or curtailing lending across multiple markets, including those where conditions remain stable. This behaviour can transmit stress from one part of the group's operations to another, and from one jurisdiction to many others, especially when host-country subsidiaries are dependent on parent funding.

The structure of the international financial network also affects the likelihood and speed of cross-border contagion. When financial linkages are concentrated among a small number of globally systemically important banks (G-SIBs), the failure or distress of one such institution can have outsized effects across multiple countries. Conversely, if exposures are more dispersed or if buffers (such as capital and liquidity reserves) are strong, the international transmission of shocks can be more contained.

It is essential to acknowledge that shocks rarely occur in isolation. As shown by the review of systemic distress episodes in recent years (see section 2), multiple shocks can strike simultaneously or in rapid succession, and the interaction of contagion channels often leads to powerful amplification effects within the financial system (Cont et al., 2020; Glasserman and Young, 2016, among others). As highlighted in Covi et al. (2021), Aldasoro et al. (2022), and Caccioli et al. (2015), the interplay between different mechanisms of contagion – such as funding liquidity stress, asset fire sales, and credit risk – can significantly exacerbate systemic vulnerabilities. Among empirical studies, Pierret (2015) shows that firms with increased solvency risk are more susceptible to liquidity problems and that the availability of short-term funding decreases with solvency risk; Schmitz et al. (2019) provide evidence on the link between bank solvency and funding costs, demonstrating that neglecting the solvency-funding cost nexus results in a substantial underestimation of the effects of shocks on banks' capital ratios (Figure 11, panel A). Caccioli et al. (2024) show that not accounting for common asset holdings across multiple sectors (banks and NBFIs) can severely underestimate the fire sale losses in the financial system (Figure 11, panel B).

Traditional life insurance activities are widely regarded as posing lower systemic risk than those associated with the banking sector, due to their predominantly liability-driven investment strategies, high degree of substitutability, and a low likelihood of runs (IAIS, 2012; ESRB, 2013; EIOPA, 2023). The low risk is largely due to policyholder protection schemes and the idiosyncratic nature of past insolvencies (Geneva Association, 2010b; Klein, 2012; Cummins and Weiss, 2014). Even in the case of large insurer failures, such as Equitable Life, policyholders typically face only partial losses (Radice, 2010). Moreover, the resolution of life insurers is typically a slow and orderly process, which avoids sudden defaults, fire sales, or liquidity pressures (Geneva Association, 2010a, 2010b; Kessler, 2014). More recently, some authors are arguing that insurers increasingly resemble shadow banks as they expand into non-traditional, market-based activities—such as credit intermediation, securitization, and alternative asset investments—thereby raising concerns about their systemic relevance and regulatory perimeter gaps (Fringuellotti and Santos, 2021; Foley-Fisher et al., 2023). Ellul et al. (2022) emphasize that as insurers increasingly operate as asset managers—allocating large portions of their portfolios to illiquid and riskier assets—they may amplify procyclicality and market stress, with important implications for systemic risk and the design of prudential regulation. Most systemic concerns arise when insurers deviate from core practices: writing complex guarantees (e.g. variable annuities), using derivatives aggressively, investing in illiquid assets, or becoming deeply integrated with banks or private equity. In particular, large and diversified multiline insurers, or those with significant exposure to market volatility, highly interconnected portfolios, or involvement in non-traditional, market-facing activities, can become key nodes in systemic risk transmission—especially during periods of financial stress (Bonaccolto et al., 2025; Paulson and Rosen, 2016; Billio et al., 2012; Eling and Pankoke, 2016). Growing financial linkages between banks and insurers can amplify systemic risk, particularly through common asset exposures, cross-holdings, and liquidity spillovers during periods of market stress.

## 7. Lesson learned

We identify a few major insights from the literature.

Amplification mechanisms are central to systemic risk. While systemic crises are often triggered by relatively small initial shocks, the ensuing instability typically arises from amplification mechanisms, such as fire sales, leverage-induced feedback loops, and overlapping exposures. Studies by Sydow et al. (2024a) and Falato et al. (2021) illustrate how modest asset repricing can cascade through the financial system, leading to widespread distress. This indicates that a comprehensive assessment of total losses in the financial system requires a shift in focus from isolated vulnerabilities to the analysis of second-round effects and feedback dynamics that serve to amplify initial shocks.

Non-bank financial institutions are critical vectors of contagion. NBFIs play an increasingly important role in shock transmission. The risk of contagion within the financial system is strongly influenced by the balance sheet structure of NBFIs and the interconnections between institutions (Acharya et al., 2024). Their contribution to liquidity risk, particularly through margin calls, redemptions, and leverage, has been well documented by ESMA (2019) and the ECB (2024). Some of these institutions also exhibit a long and often opaque chain of intermediation (Trapanese, 2021), exacerbating systemic fragility. It should be noted that the perimeter of NBFIs encompasses multiple activities and entities with different level of maturity/complexity of the sectorial micro- and macroprudential regulation where in place. In particular, European insurers operate under a well-established and robust micro-prudential capital regime that includes also macroprudential measures enhanced by the review of the Solvency II framework and the new regime on recovery and resolution (IRRD)[12]. Moreover, the traditional business model of insurers based on the inverted production cycle is not characterised by an extensive use of leverage (EIOPA, 2024a).

Liquidity and solvency risks are interdependent and mutually reinforcing. Liquidity stress and solvency deterioration are deeply interconnected, especially during systemic events. Institutions experiencing funding shortfalls may be forced to sell assets at depressed prices, further impairing their balance sheets and those of others. Cont et al. (2020) and Georgescu (2015) demonstrate how Liquidity-at-Risk frameworks can reveal vulnerabilities that are invisible to traditional, siloed stress tests. This highlights the need for integrated, dynamic models that jointly account for solvency and liquidity risks under stress conditions.

Systemic risk propagates across borders and sectors. Systemic shocks often have a pronounced cross-border and cross-sector dimension, particularly in globally integrated markets. Empirical evidence from Jotikasthira et al. (2012) and the Bank of England (2024) shows that international asset exposures and liquidity spillovers can transmit stress to institutions in seemingly unrelated jurisdictions. Similarly, Dubiel-Teleszynski et al. (2022) show that transition risks from climate policy can reverberate through global corporate credit markets. These findings reinforce the importance of system-wide approaches that incorporate both geographic and sectoral interconnectedness.

Shared constraints and common behaviours amplify systemic risk. Systemic fragility often stems not just from interlinkages, but from synchronized responses to market conditions or regulatory rules. Common constraints (such as capital or liquidity ratios), similar portfolio structures, and herding behaviour can induce correlated reactions under stress. Girardi et al. (2021) and Franch et al. (2024) show that such synchronization, even in the absence of shocks, can create instability through crowded trades and temporal network effects. This may suggest a need for policies that discourage excessive homogeneity in risk-taking and promote structural diversification at the system level. It also underscores the importance of modelling shifts in market sentiment and risk aversion, which can act as powerful amplifiers of systemic dynamics.

Stress test design shapes risk perception and detection. Traditional microprudential stress tests often fail to capture the non-linear and networked nature of systemic risk. More recent work by Falato et al. (2021) and Sydow et al. (2024a) demonstrates that agent-based and network-oriented models offer a more realistic description of how risks propagate through markets and institutions. These models highlight that system-wide vulnerabilities emerge not merely from individual balance sheets but from their interactions. Therefore, stress testing frameworks should evolve toward dynamic, granular approaches that integrate behavioural feedbacks, institutional interdependencies, and endogenous market responses.

[12] Adopted by the Council on November 5, 2024.

## 8. What is missing

Despite the progress made in system-wide stress testing, several critical areas remain underdeveloped or underexplored, limiting the full potential of these frameworks to capture and address systemic risks effectively. The following gaps have been identified.

Behavioural dynamics. Many stress testing models still treat financial institutions as passive entities that follow simple, rule-based behaviours. These models often overlook the complex, adaptive responses of institutions when faced with stress. While some agent-based models are beginning to be explored, they are not yet widely implemented. These models have the potential to capture heterogeneous responses to shocks, revealing how institutions' decisions evolve over time and how they may amplify or mitigate systemic risks.

Global interconnectedness. While much attention has been paid to domestic financial networks, truly international linkages remain underexplored. Only a few studies attempt to model cross-border contagion and the impact of global interconnectedness. As financial institutions and markets are increasingly interconnected across borders, it is crucial to understand how international linkages can amplify shocks and lead to systemic risks. More comprehensive models could capture global financial interconnections, incorporating the effects of cross-border capital flows, foreign exchange exposures, and international regulatory divergences to better assess how global networks contribute to systemic risk.

Intra-group positions. Intra-group positions refer to the ownership and financial linkages that exist within banking or insurance groups or within financial conglomerates—such as non-bank financial institutions (NBFIs) that are part of banking groups, or such as banks and other financial institutions (OFIs) that are part of insurance groups. These internal relationships pose distinct risk profiles compared to exposures between independent entities. However, current stress testing frameworks typically do not differentiate financial conglomerates from standalone institutions. Failing to account for the interdependencies among banks, insurers, and asset managers within the same group may lead to an underestimation or mischaracterization of systemic vulnerabilities in cross-sectoral stress tests.

Cross-border implications. From a cross-border perspective, investment funds could be domiciled in a country other than that of their asset management company, resulting in a transfer of risk from the financial system of one country to another.

Insurance specificities. Despite recent advancements and efforts in stress testing frameworks (EIOPA, 2024b), many models still struggle to accurately capture the complex, non-linear behavior of insurance liabilities and the dynamic nature of associated hedging strategies. As a result, the impact of shocks on insurers—particularly regarding their capital and solvency positions—may be overstated. This can lead to a distorted assessment of sectoral vulnerabilities and an artificial amplification of spillover effects across the broader financial system.

Liquidity in derivatives and collateral markets. Liquidity in derivatives and collateral markets remains an underexplored area in stress testing, despite its importance during periods of market distress. The European Central Bank (ECB) acknowledged this gap in its 2020 report, but most stress testing frameworks have yet to systematically integrate liquidity risks in derivatives markets.. Derivatives, especially in over-the-counter (OTC) markets, and collateralized lending arrangements can behave as key transmission channels during financial stress, with the potential to trigger widespread liquidity shortages.

Non-linear effects of network structure. The relationship between network structure and financial fragility is non-linear. Both highly interconnected and sparsely connected networks can increase vulnerability to contagion, but in different ways. While well-diversified networks may reduce the potential for systemic risk under smaller shocks, they can also facilitate rapid transmission of larger shocks. Understanding how different network configurations affect the propagation of systemic risk is essential for improving stress testing frameworks.

Operationalization for policy. Currently, system-wide stress tests are largely descriptive, providing insights into the potential impact of shocks but offering limited guidance for policymakers in terms of actionable policy responses. While some models provide useful information on the financial system's vulnerabilities, they lack integration with policy decision rules, making it difficult to translate test results into concrete policy actions.

## REFERENCES


Acharya, V. V., Berner, R., Engle, R., Jung, H., Stroebel, J., Zeng, X., & Zhao, Y. (2023). Climate stress testing. Annual Review of Financial Economics, 15(1), 291–326.

Acharya, V. V., Cetorelli, N., & Tuckman, B. (2024). Where Do Banks End and NBFIs Begin?. National Bureau of Economic Research, No. w32316.

Acemoglu, D., Ozdaglar, A., & Tahbaz-Salehi, A. (2015). Systemic risk and stability in financial networks. American Economic Review, 105(2), 564–608.

Adrian, T., & Shin, H. S. (2010). Liquidity and leverage. Journal of Financial Intermediation, 19(3), 418–437.

Ahnert, T., & Bertsch, C. (2022). A wake-up call theory of contagion. Review of Finance, 26(4), 829–854.

Aikman, D., Beale, D., Brinley-Codd, A., Covi, G., Hüser, A.-C., & Lepore, C. (2023). Macro-Prudential Stress Test Models: A Survey. IMF Working Paper No. 2023/173.

Albertazzi, U., Ropele, T., Sene, G., & Signoretti, F. M. (2014). The impact of the sovereign debt crisis on the activity of Italian banks. Journal of Banking & Finance, 46, 387–402.

Aldasoro, I., Hüser, A.-C., & Kok, C. (2022). Contagion accounting in stress-testing. Journal of Economic Dynamics and Control, 137:104354.

Alfaro, R. A., & Drehmann, M. (2009). Macro stress tests and crises: what can we learn?. BIS Quarterly Review December.

Allen, F. & Gale, D. (2000). Financial contagion. Journal of Political Economy, 108, 1–33.

Allen, F., Carletti, E., & Gale, D. (2009). Interbank market liquidity and central bank intervention. Journal of Monetary Economics 56, 639–652.

Anand, K., Gai, P., & Marsili, M. (2012). Rollover risk, network structure and systemic financial crises. Journal of Economic Dynamics and Control, 36(8), 1088–1100.

Angelini, P., Maresca, G., & Russo, D. (1996). Systemic risk in the netting system. Journal of Banking & Finance, 20(5), 853–868.

Apicella, F., Gallo, R., & Guazzarotti, G. (2022). Insurers' investments before and after the Covid-19 outbreak. Bank of Italy Temi di Discussione (Working Paper), 1363.

Bank of England (2021). Solvency and liquidity stress testing for non-bank financial institutions: A conceptual framework.

Bank of England (2024). The Bank of England's system-wide exploratory scenario exercise final report, November.

Bardoscia, M., Barucca, P., Codd, A. B., & Hill, J. (2019). Forward-looking solvency contagion. Journal of Economic Dynamics and Control, 108:103755.

Barucca, P., Bardoscia, M., Caccioli, F., D'Errico, M., Visentin, G., Caldarelli, G., & Battiston, S. (2020). Network valuation in financial systems. Mathematical Finance, 30(4), 1181–1204.

Bargigli, L., Di Iasio, G., Infante, L., Lillo, F., & Pierobon, F. (2015). The multiplex structure of interbank networks. Quantitative Finance, 15(4), 673–691.

Battiston, S., Gatti, D.D., Gallegati, M., Greenwald, B., & Stiglitz, J.E. (2012). Liaisons dangereuses: increasing connectivity, risk sharing, and systemic risk. Journal of Economic Dynamics & Control 36, 1121–1141.

Battiston, S., D'Errico, M. & Gurciullo, S. (2016). DebtRank and the Network of Leverage. The Journal of Private Equity, 20(1), 58–71.

Battiston, S., Mandel, A., Monasterolo, I., Schütze, F., & Visentin, G. (2017). A climate stress-test of the financial system. Nature Climate Change, 7(4), 283–288.

BCBS (2023). Report on the 2023 banking turmoil, October.

Billio, M., Getmansky, M., Lo, W., & Pelizzon, L. (2012). Econometric measures of connectedness, and systemic risk in the finance and insurance sectors. Journal of Financial Economics, 104, 535–559.

Bonaccolto, G., Borri, N., Consiglio, A., & Di Giorgio, G. (2025). Systemic Risk in the European Insurance Sector. arXiv preprint arXiv:2505.02635

Borsos, A., Carro, A., Glielmo, A., Hinterschweiger, M., Kaszowska-Mojsa, J., & Uluc, A. (2025). Agent-Based modelling at central banks: recent developments and new challenges. Bank of England Staff Working Paper, Issue 1122.

Branzoli, N., Miglietta, A., Nucera, F. C., Panzarino, O., & Porello, C. (2021). Lessons learned from the collapse of Archegos: policy and financial stability implications. Banca d'Italia, Notes on Financial Stability and Supervision, 26.

Bruneau, G., Ojea-Ferreiro, J., Plummer, A., Tremblay, M.C. & Witts, A. (2025). The interdependencies of Canadian financial institutions: An application to climate transition shocks. Latin American Journal of Central Banking, 6(3).

Brunnermeier, M.K., & Pedersen, L.H. (2009). Market Liquidity and Funding Liquidity, The Review of Financial Studies, 22(6), 2201–2238.

Caballero, R. J., & Simsek, A. (2013). Fire sales in a model of complexity. The Journal of Finance, 68(6), 2549–2587.

Caccioli, F., Farmer, J. D., Foti, N., & Rockmore, D. (2015). Overlapping portfolios, contagion, and financial stability. Journal of Economic Dynamics and Control, 51, 50–63.

Caccioli, F., Barucca, P., & Kobayashi, T. (2018). Network models of financial systemic risk: a review. Journal of Computational Social Science, 1, 81–114.

Castrén, O., & Rancan, M. (2014). Macro networks: an application to Euro area financial accounts. Journal of Banking & Finance, 46, 43–58.

Cecchetti, S., Rocco, M. & Sigalotti, L. (2016). Contagion and fire sales in banking networks. Bank of Italy Working Paper (Temi di discussione), 1050.

Cetorelli, N., Landoni, M. & Lu, L. (2023). Non-Bank Financial Institutions and Banks' Fire-Sale Vulnerabilities. FRB of Boston Supervisory Research & Analysis Unit Working Paper, Issue SRA 23-01.

Chernenko, Sergey, & Adi Sunderam (2020). Do fire sales create externalities?. Journal of Financial Economics, 135(3), 602–628.

Cifuentes, R., Ferrucci, G. & Shin, H.S. (2005). Liquidity Risk and Contagion. Bank of England Working Paper, 264.

Coen, J., Lepore, C., & Schaanning, E. (2019). Taking regulation seriously: fire sales under solvency and liquidity constraints. Bank of England Working Paper, 793.

Cont, R., & Schaanning, E. (2017). Fire sales, indirect contagion and systemic stress testing. Norges Bank.

Cont, R., & Schaanning, E. (2019). Monitoring indirect contagion. Journal of Banking & Finance, 104, 85–102.

Cont, R., Kotlicki, A., & Valderrama, L. (2020). Liquidity at risk: Joint stress testing of solvency and liquidity, Journal of Banking & Finance, 118.

Co-Pierre, G. (2013). The effect of the interbank network structure on contagion and common shocks. Journal of Banking & Finance, 37, 2216–2228.

Covi, G., Gorpe, M. Z., & Kok, C. (2021). CoMap: Mapping contagion in the euro area banking sector. Journal of Financial Stability, 53.

Cummins, J. D., and M. A. Weiss, (2014). Systemic Risk and the U.S. Insurance Sector, Journal of Risk and Insurance, 81(3), 489–527.

Daly, K., Batten, J. A., Mishra, A. V., & Choudhury, T. (2019). Contagion risk in global banking sector. Journal of International Financial Markets, Institutions and Money, 63(C), 101–136.

Deng, Y., Zeng, Y., & Li, Z. (2019). Real estate prices and systemic banking crises. Economic Modelling, 80, 111–120.

Duarte, F., & Eisenbach, T. M. (2021). Fire-sale spillovers and systemic risk. The Journal of Finance, 76(3), 1251–1294.

Dubiel-Teleszynski, T., Franch, F., Fukker, G., Miccio, D., Pellegrino, M. & Sydow, M. (2022). A system-wide amplification of climate risks, ECB Macroprudential Bulletin No 17.

ECB (2024). Financial Stability Report. Containing risks from leverage in the NBFI sector – insights from recent policy initiatives, May.

EIOPA (2020). Methodological Principles of Insurance Stress Testing.

EIOPA (2023). Assessing Systemic Risk of the European Insurance Industry, update.

EIOPA (2024a). EIOPA feedback to EU COM Consultation Paper on Assessing the adequacy of macroprudential policies for Non-Bank Financial Intermediation (NBFI).

EIOPA (2024b). Insurance stress test 2024.

Eling, M., & Pankoke, D. A. (2016). Systemic risk in the insurance sector: A review and directions for future research. Risk Management and Insurance Review, 19(2), 249–284.

ESMA (2019). ESMA Report on Trends, Risks and Vulnerabilities.

ESRB (2015). Report on systemic risks in the EU insurance sector.

ESRB (2013). Recommendation on intermediate objectives and instruments of macro-prudential policy.

ESRB (2023). Climate-related scenarios for the one-off Fit- for-55 scenario analysis exercise.

ESRB (2025). Systemic liquidity risk: a monitoring framework.

Elliott, M., Golub, B., & Jackson, M. O. (2014). Financial networks and contagion. American Economic Review, 104(10), 3115–53.

Ellul, A., Jotikasthira, C., Kartasheva, A., Lundblad, C. T., & Wagner, W. (2022). Insurers as asset managers and systemic risk. The Review of Financial Studies, 35(12), 5483–5534.

Falato, A., Goldstein, I., & Hortaçsu, A. (2021). Financial fragility in the COVID-19 crisis: The case of investment funds in corporate bond markets. Journal of Monetary Economics, 123, 35–52.

Fay, C., & Ghiselli, A. (2023). Insurers' investment behaviour and the coronavirus (COVID-19) pandemic. ESRB Occasional Paper Series, 22.

Foley-Fisher, N., Heinrich, N., & Verani, S. (2023). Are US life insurers the new shadow banks?. Available at SSRN 3534847.

FSB (2020). Holistic Review of the March Market Turmoil, November.

FSB (2024). Depositor Behaviour and Interest Rate and Liquidity Risks in the Financial System. Lessons from the March 2023 banking turmoil, October.

Franceschi, E., Grodzicki, M., Kagerer, B., Kaufmann, C., Lenoci, F., Mingarelli, L., Pancaro C., & Senner, R. (2023). Key linkages between banks and the non-bank financial sector. Financial Stability Review, 1.

Franch, F., Nocciola, L., & Vouldis, A. (2024). Temporal networks and financial contagion. Journal of Financial Stability, 71.

Fringuellotti, F., & Santos, J. A. (2021). Insurance companies and the growth of corporate loans' securitization. FRB of New York Staff Report, 975, Rev. July 2025.

Furfine, C., & Remolona, E. (2002). What's behind the liquidity spread? On-the-run and off-the-run US Treasuries in autumn 1998. BIS Quarterly Review, 6, 51–58.

Gai, P., Haldane, A., & Kapadia, S. (2011). Complexity, concentration, and contagion. Journal of Monetary Economics, 58, 453–470.

Georgescu, O.A. (2015). Contagion in the interbank market: Funding versus regulatory constraints, Journal of Financial Stability, 18, Pages 1–18.

Geneva Association (2010a). Systemic Risk in Insurance – An Analysis of Insurance and Financial Stability, March.

Geneva Association (2010b). Key Financial Stability Issues in Insurance – An Account of the Geneva Association's Ongoing Dialogue on Systemic Risk with Regulators and Policy-Makers, July.

Gennaioli, N., Martin, A., & Rossi, S. (2014). Sovereign default, domestic banks, and financial institutions. The Journal of Finance, 69(2), 819–866.

Ghamami, S., Glasserman, P., & Young, H. P. (2022). Collateralized networks. Management Science, 68(3), 2202–2225.

Girardi, G., Hanley, K.W., Nikolova, S., Pelizzon, L., & Sherman, M.G. (2021). Portfolio similarity and asset liquidation in the insurance industry. Journal of Financial Economics, 142(1), 69–96.

Glasserman, P., & Young, H. P. (2016). Contagion in Financial Networks. Journal of Economic Literature 54(3), 779–831.

Greenwood, R., Landier, A., & Thesmar, D. (2015). Vulnerable banks. Journal of Financial Economics, 115(3), 471–485.

Hearnshaw, E.J.S., & Wilson, M.M.J. (2013). A complex network approach to supply chain network theory. International Journal of Operations & Production Management, 33(4), 442–469.

Henry, J., & Kok, C. (2013). A macro stress testing framework for assessing systemic risks in the banking sector. ECB Occasional Paper, No. 152.

Huang, X., Vodenska, I., Havlin, S., & Stanley, H. E. (2013). Cascading failures in bi-partite graphs: model for systemic risk propagation. Scientific reports, 3(1).

Hüser, A.-C., Halaj, G., Kok, C., Perales, C., & van der Kraaij, A. (2018). The systemic implications of bail-in: a multi-layered network approach. Journal of Financial Stability, 38, 81–97.

IMF (2020). Solvency Stress Testing of the Insurance Sector. Technical Note, Financial Sector Assessment Program.

International Association of Insurance Supervisors (2012). Global Systemically Important Insurers: Proposed Assessment Methodology, May.

IMF (2023). Lessons from the United Kingdom's Liability-Driven Investment (LDI) Crisis.

Jotikasthira, C., Lundblad, C., & Tarun Ramadorai, T. (2012). Asset Fire Sales and Purchases and the International Transmission of Funding Shocks. Journal of Finance, 67(6), 2015−2050.

Jobst, M. A. A., Ong, M. L. L., & Schmieder, M. C. (2013). A framework for macroprudential bank solvency stress testing: Application to S-25 and other G-20 country FSAPs. International Monetary Fund.

J.P. Morgan (2021). The Failure of Archegos Capital Management: Estimating Potential Spillovers to ASEAN+3 Financial Systems. Testimony to U.S. Congress, April 14.

Kapadia, S., Drehmann, M., Elliott, J., & Sterne, G. (2012). Liquidity risk, cash-flow constraints and systemic feedbacks. Bank of England, No. 456.

Kessler, D. (2014). Why Re(insurance) Is Not Systemic, Journal of Risk and Insurance, 81(3), 477–488.

Klein, R. W. (2012). Principles for Insurance Regulation: An Evaluation of Current Practices and Potential Reforms, Geneva Papers on Risk and Insurance – Issues and Practice, 37(1), 175–199.

Koetter, M., & Poghosyan, T. (2010). Real estate prices and bank stability. Journal of Banking & Finance, 34(6), 1129–1138.

Konaka, Y., Maruyama, T. & Nakamura, F. (2025). Exploratory Scenario Analysis Considering the Growing Presence of Domestic and Foreign Investment Funds. Bank of Japan, Working Paper Series, Issue 25-E-11.

Labini, S. S., D'Apolito, E., & Nyenno, I. (2024). Systemic Risk and the Insurance Sector: A Network Perspective. In Systemic Risk and Complex Networks in Modern Financial Systems. Cham: Springer Nature Switzerland, 211–228.

Leitner, Y. (2005). Financial networks: contagion, commitment, and private sector bailouts. Journal of Finance, 60, 2925–2953.

Luu, D. T., Napoletano, M., Barucca, P., & Battiston, S. (2021). Collateral unchained: Rehypothecation networks, concentration and systemic effects. Journal of Financial Stability, 52:100811.

Michelangeli, V., Sacco, S., Bado, V., de Chiara, V., Eramo, G., Ficarola, F., Mavilia, I., Miani, C., Quaglia, I., Reale, G., Sciarretta, F, Scimone, R., Sigalotti, L. (2026). Interconnections in the Italian Financial System: A Multilayer Network Analysis, Bank of Italy, *mimeo*.

Mistrulli, P.E. (2011). Assessing financial contagion in the interbank market: Maximum Entropy versus observed interbank lending patterns. Journal of Banking & Finance, 35(5), 1114–1127.

Paddrik, M., Rajan, S., & Young, H. P. (2020). Contagion in derivatives markets. Management Science, 66(8).

Paltalidis, N., Gounopoulos, D., Kizys, R., & Koutelidakis, Y. (2015). Transmission channels of systemic risk and contagion in the European financial network. Journal of Banking & Finance, 61(S1), 36–52.

Paulson, A., & Rosen, R. (2016). The life insurance industry and systemic risk: A bond market perspective. Annual Review of Financial Economics, 8(1), 155–174.

Pierret, D. (2015). Systemic risk and the solvency-Liquidity nexus of banks. International Journal of Central Banking 11(3), 193–227.

Poledna, S., Molina-Borboa, J. L., Martínez-Jaramillo, S., Van Der Leij, M., & Thurner, S. (2015). The multi-layer network nature of systemic risk and its implications for the costs of financial crises. Journal of Financial Stability, 20, 70–81.

Radice, M. P. (2010). Systemische Risiken im Versicherungssektor? Working Paper, FINMA.

Roncoroni, A., Battiston, S., D'Errico, M., Halaj, G., & Kok, C. (2021). Interconnected banks and systemically important exposures. Journal of Economic Dynamics and Control, Elsevier, 133(C).

Schmitz, S. W., Sigmund, M., & Valderrama, L. (2019). The interaction between bank solvency and funding costs: A crucial effect in stress tests. Economic Notes: Review of Banking, Finance and Monetary Economics, 48(2), e12130.

Shleifer, A., & Vishny, R. (2011). Fire sales in finance and macroeconomics. Journal of Economic Perspectives, 25(1):29–48.

Schilte, A., Sydow, M., Fukker, G.,& Piquard, T. (2022). System-wide stress tests: a deep dive into the financial system. Eco Notepad, Financial Stability, Post 249, Banque de France. https://www.banque-france.fr/en/publications-and-statistics/publications/system-wide-stress-tests-deep-dive-financial-system

Sydow, M., A. Schilte, G. Covi, M. Deipenbrock, L. Del Vecchio, P. Fiedor, G. Fukker, M. Gehrend, R. Gourdel, A. Grassi, B. Hilberg, M. Kaijser, G. Kaoudis, L. Mingarelli, M. Montagna, T. Piquard, D. Salakhova, & N. Tente (2024a). "Shock amplification in an interconnected financial system of banks and investment funds". Journal of Financial Stability, 71.

Sydow, M., G. Fukker, T. Dubiel-Teleszynski, F. Franch, S. Gallet, H. Grund, S. Kotronis, D. Miccio, M. Pellegrino, S. Schlutter, & M. Sottocornola (2024b). Banks and non-banks stressed: liquidity shocks and the mitigating role of insurance companies, *mimeo*.

Trapanese, M. (2021). The economics of non-bank financial intermediation: why do we need to fill the regulation gap?. Bank of Italy Occasional Paper, 625.

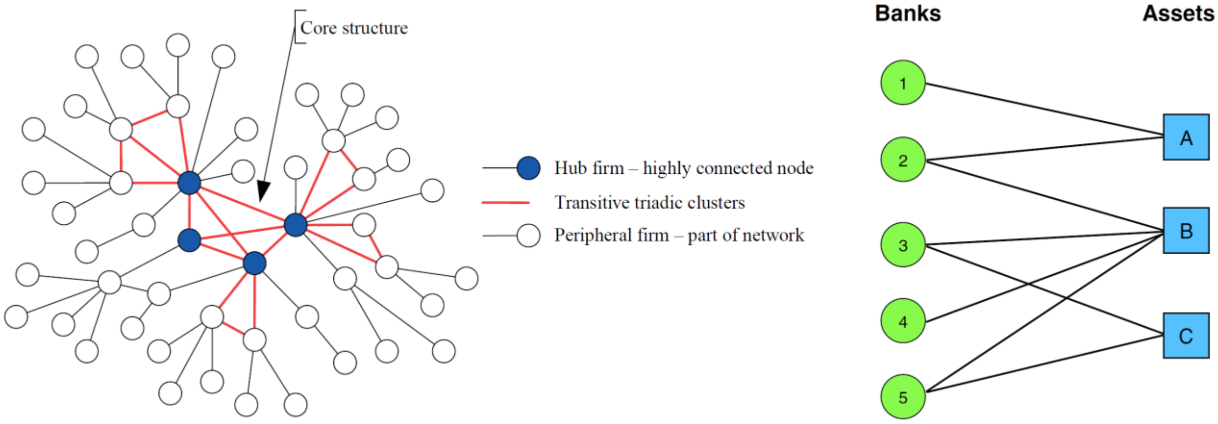
Trapp, M., & Wewel, C. (2013). Transatlantic systemic risk. Journal of Banking & Finance, 37(11), 4241−4255.

## Figures

Figure 1: Examples of network models

Panel A. Core –Periphery network

Panel B. Bipartite network



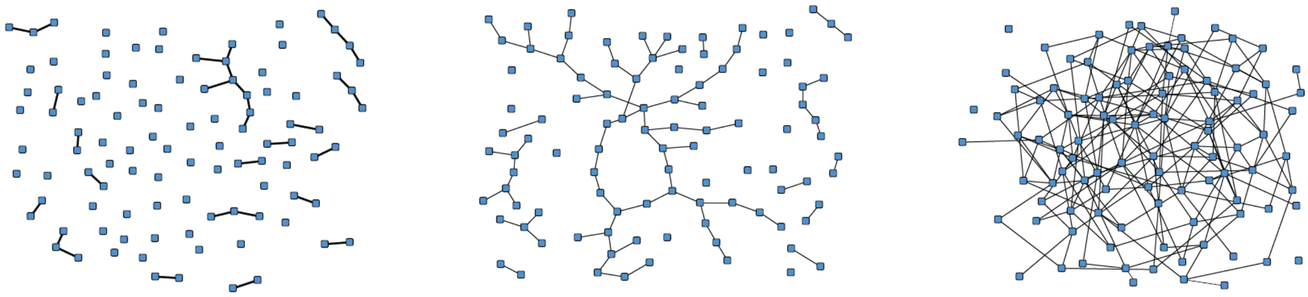

Source: Panel A) Hearnshaw et al. (2013). Panel B) Caccioli et al. (2018). Pictorial representation of a bipartite network of overlapping portfolios.

Figure 2: Example Random Networks for Different Levels of Diversification

Panel A. Low diversification

Panel B. Medium diversification

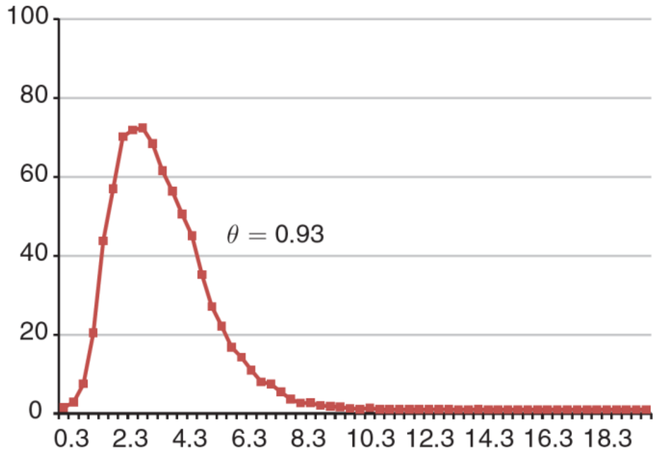
Panel C. High diversification



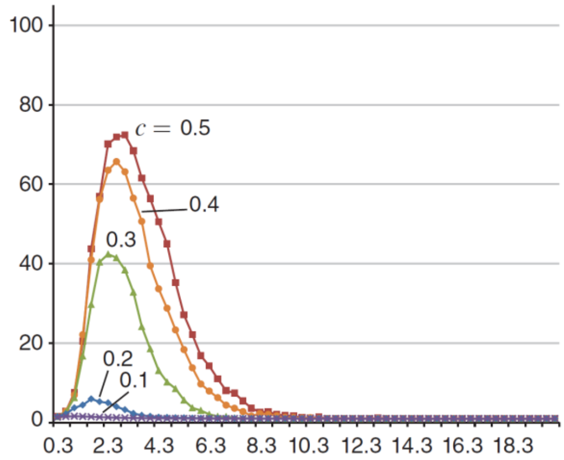
Source: Elliott et al. (2014).

Figure 3: Diversification and Integration

Panel A. Effects of diversification: the percentage of organizations failing

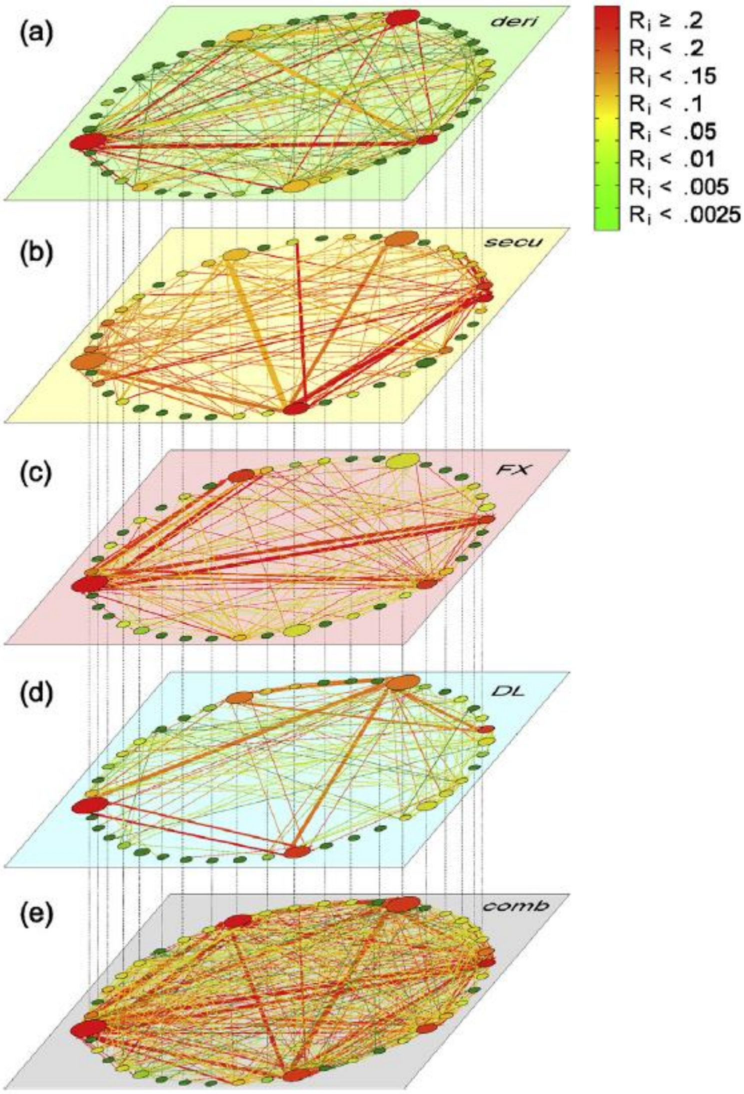



Panel B. Five levels of integration ($c$) and the percentage of organizations failing



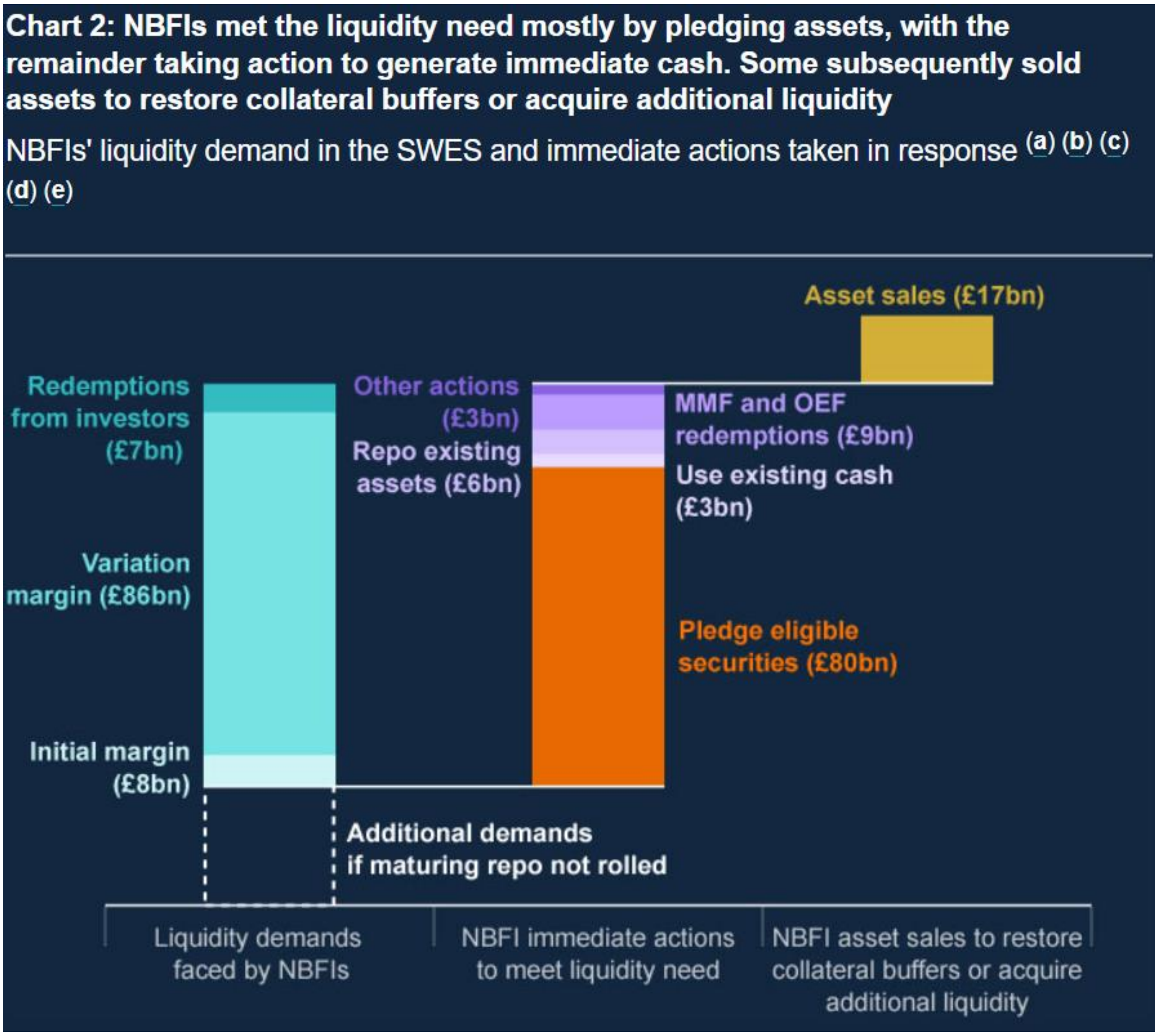

Source: Elliott et al. (2014). The x-axis corresponds to diversification in terms of the expected degree in the random network of cross-holdings. Panel A. When diversification is low, contagion remains limited due to few network connections. As institutions become moderately diversified, systemic cascades emerge, affecting large portions of the network. However, with high diversification, contagion risk declines again, as organizations' portfolios are sufficiently diversified so that they become insensitive to any particular organization's failure. Panel B. If there is no integration, then there cannot be any contagion. As integration increased, the exposure of organizations to each other increases and there are increased cascades. For high levels, the integration level may help avoid first failures, because each organization is less exposed to the failure of its own proprietary asset.

Figure 4: Banking multi-layer network




Source: Poledna et al. (2015). a) Network of exposures from derivatives, (b) security cross-holdings, (c) foreign exchange expo-sures, (d) deposits & loans and (e) combined banking network. Nodes (banks) are coloured according to their systemic impact in the respective layer: from systemically important banks (red) to systemically safe (green). Node size represents banks' total assets. Link width is the exposure size between banks, linkcolor is taken from the counterparty.

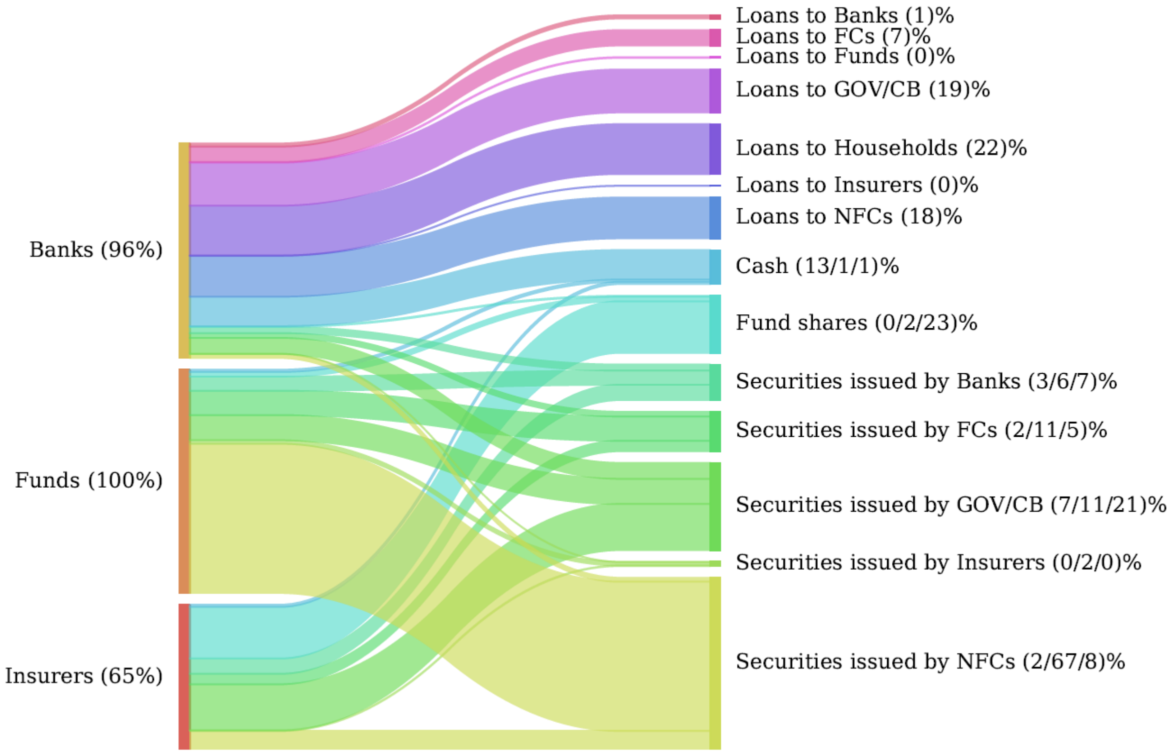
Figure 5: Bank of England SWES



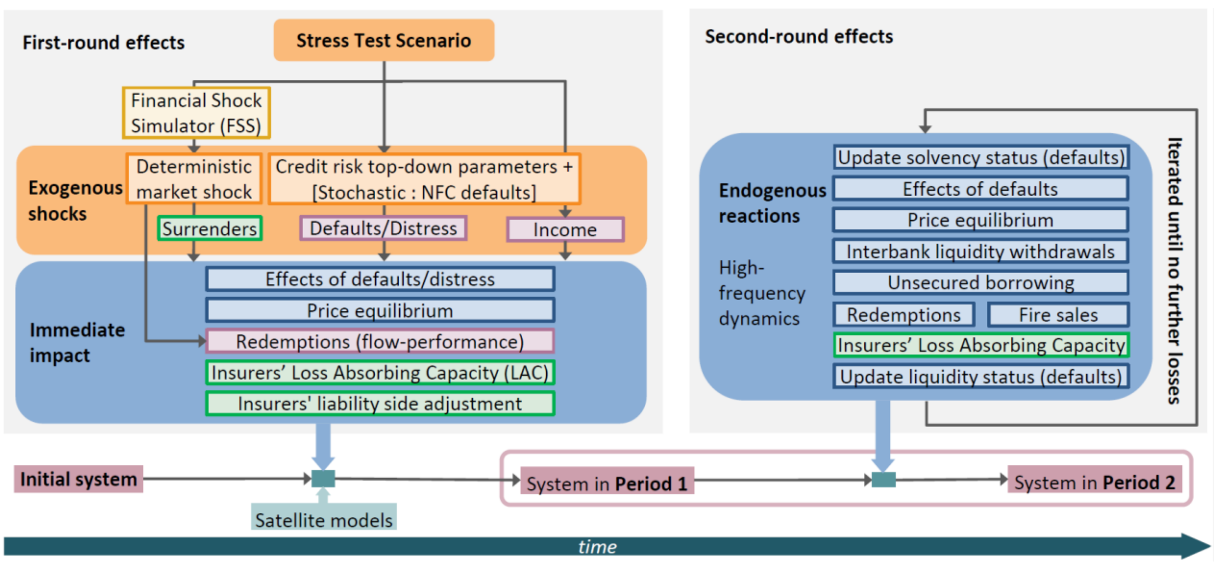

Source: Bank of England (2024).

Figure 6: ECB's Interconnected System-wide stress test Analytics (ISA) model

A. Sankey chart of exposures covered in the model

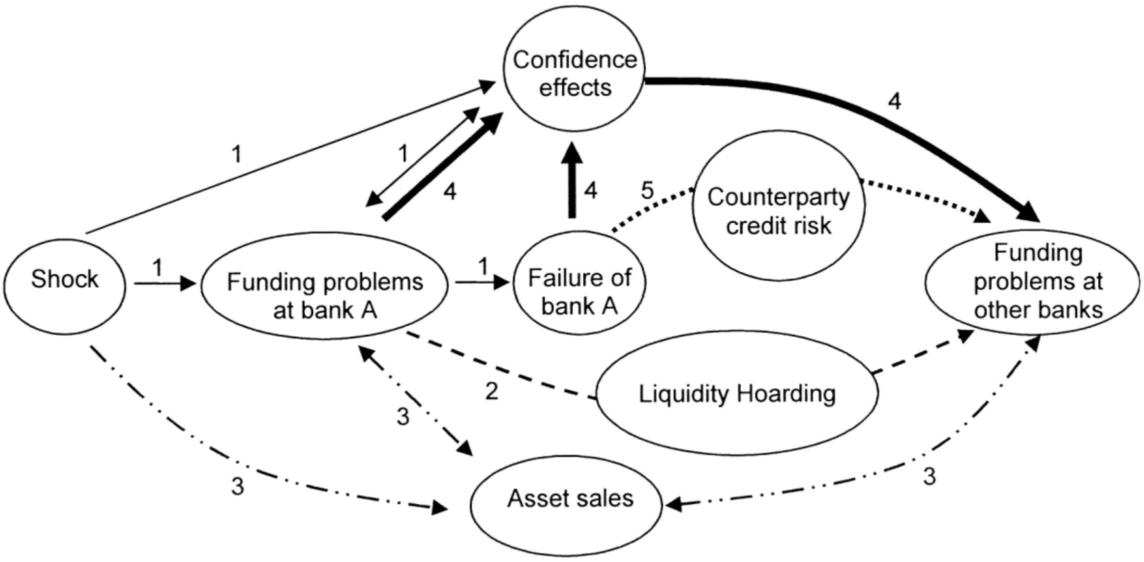



B. Summary of model dynamics



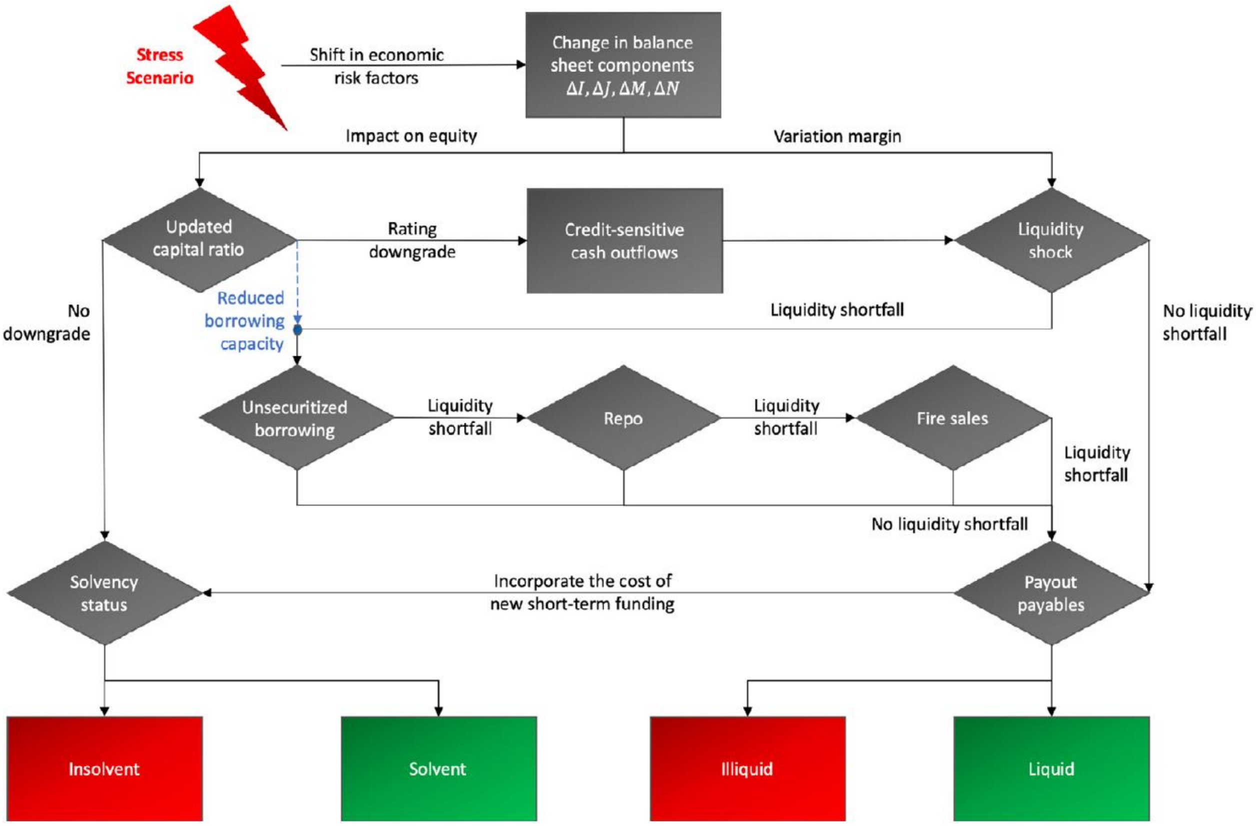

Source: Sydow et at. (2024).

Figure 7. Funding liquidity channel




Source: Kapadia et al. (2012).

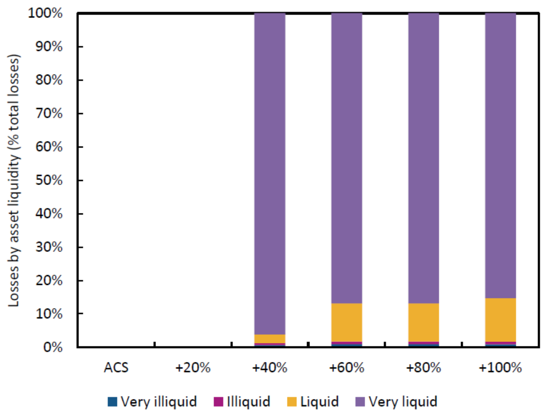
Figure 8: Joint stress test of solvency and liquidity.



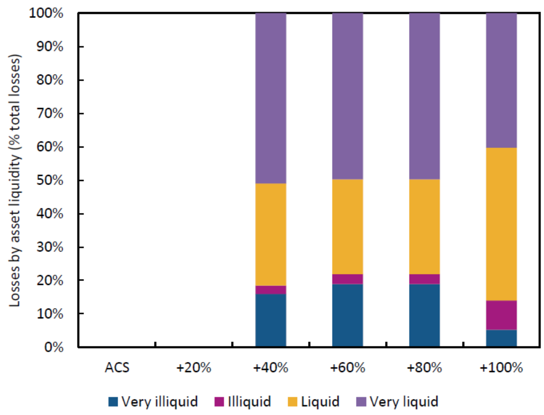

Source: Dynamics of balance sheet components under stress, Cont et al. (2020); where I is illiquid/encumbered assets subject to margin requirements, J illiquid/encumbered assets not subject to margin requirements, M marketable unencumbered assets subject to margin requirements, N marketable unencumbered assets not subject to margin requirements.

Figure 9: Loss by quartile of asset liquidity for optimal and proportional asset sales following solvency shocks

Panel A. Optimal asset sales

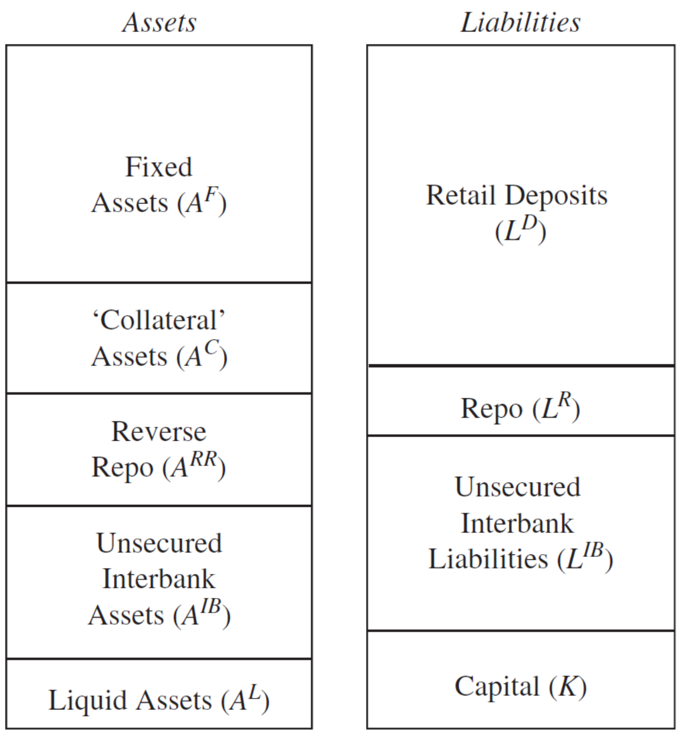



Panel B. Proportional asset sales




Source: Coen et al. (2019).

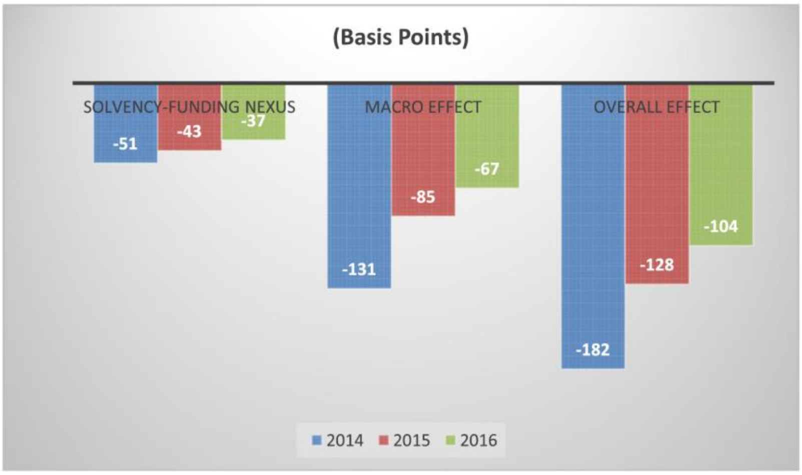
Figure 10: Stylised balance sheet highlighting collateral channel



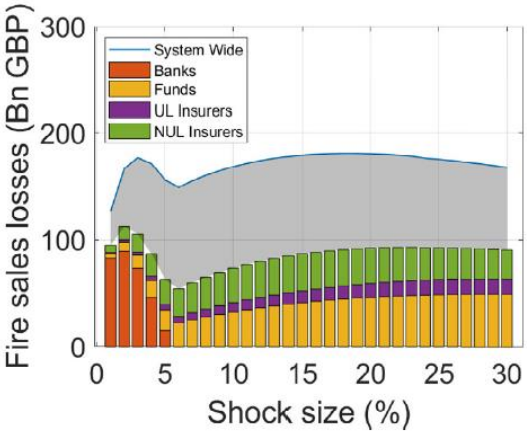

Source: Gai et al. (2011).

Figure 11: Amplification effects

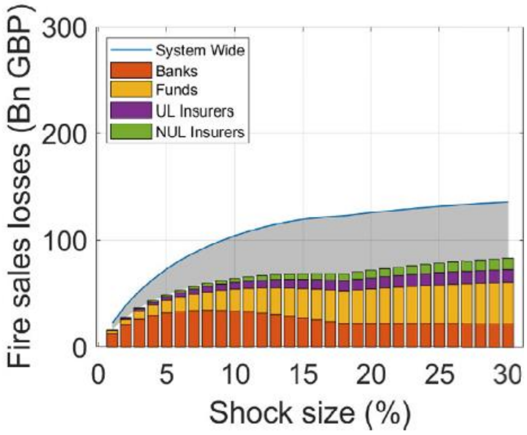
A. Decomposition of the cumulative impact on aggregate CET1



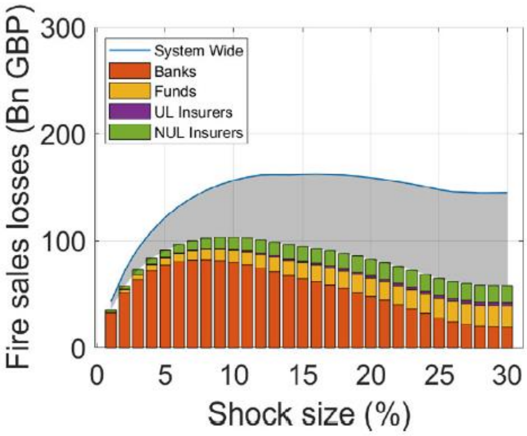

B. Fire sale losses



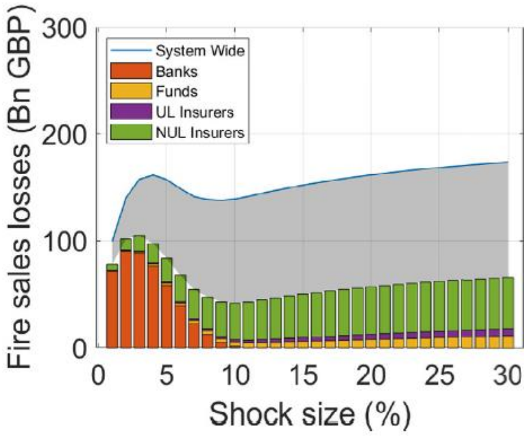

(a) Shock on all assets.




(b) Shock on all equities.




(c) Shock on all corporate bonds.




(d) Shock on all goverment bonds.

Source: Panel A) Schmitz et al. (2019); Panel B) Caccioli et al. (2024).

## Appendix

**September 2008 Lehman Brothers Bankruptcy**. In September 2008, the bankruptcy of Lehman Brothers, a major U.S. investment bank, marked a pivotal moment in the global financial crisis. The most immediate direct impact of Lehman's collapse was the forced liquidation of the Reserve Primary Fund, a money-market fund that held Lehman's debt. This event triggered widespread withdrawals from money-market funds, including those without direct exposure to Lehman, disrupting a key channel of short-term funding for both financial and non-financial firms. As the system, already heavily dependent on short-term financing, faced mounting strain, credit providers grew increasingly anxious about borrower solvency and began hoarding liquidity as a precaution to shield themselves from further turmoil. The interbank market was frozen, with banks unwilling to lend to each other, leading to a severe liquidity crisis. In essence, the days following Lehman's failure resembled a funding run rather than a chain reaction of defaults.

By the end of that week, the U.S. Treasury intervened by guaranteeing money-market fund assets in an effort to stabilize short-term lending markets. Without this intervention, funds would likely have been forced to sell illiquid assets to meet redemption demands, triggering fire sales that would have depressed asset prices across the financial system.

The Lehman episode thus exemplifies multiple contagion channels: direct losses suffered by the Reserve Primary Fund, information contagion that spread fear across money-market funds, a funding run driven by creditor panic, and the looming threat of fire sales. Moreover, the opaque nature of financial networks deepened uncertainty in the period leading up to Lehman's bankruptcy (Glasserman and Young, 2016).

**September 2008 American International Group's near-collapse.** The case of the American International Group (AIG) during the 2008 financial crisis is widely recognized as a key example of how insurance groups can pose systemic risk, though not through traditional insurance activities. AIG's systemic relevance stemmed primarily from its non-insurance operations – especially its Financial Products division – which had substantial exposure to credit default swaps (CDS) and other derivatives tied to mortgage-backed securities. These activities created large, opaque counterparty exposures across the global financial system. When the value of these securities collapsed, AIG faced massive collateral calls and liquidity shortfalls, which threatened to trigger a cascade of losses across its counterparties and financial markets more broadly. What made AIG's case systemic was not the potential failure of its insurance subsidiaries, which were largely solvent and subject to state regulation, but the risk of disorderly default in its interconnected financial operations. This distinction is critical: AIG's near-collapse and the resulting U.S. government bailout were driven by capital markets activities typically outside the core insurance business. Some non-traditional non-insurance activities may also use repo markets for leverage, exposing them to the risk of run-type withdrawals of funding. The AIG's near-collapse highlighted multiple contagion channels: cross-sector contagion, cross-border transmission, counterparty risks, involvement in non-traditional and non-insurance activities (ESRB, 2015).

**March 2020 Market Turmoil.** The COVID-19 pandemic triggered one of the most severe episodes of financial stress in recent years (FSB, 2020). Unlike the 2008 GFC, this shock originated outside the financial sector, as the pandemic and subsequent government lockdowns caused a rapid and profound contraction in real economic activity, placing acute pressure on the financial system.

The stress unfolded in three phases: an initial "flight to safety" (late February–early March), where investors shed riskier assets for safer and more liquid ones; a "dash for cash" (mid-March), marked by mass liquidations across asset classes, even the safest, to meet urgent liquidity needs; and a subsequent easing phase (late March), following rapid and large-scale interventions by authorities that helped restore market stability.

As with past crises, the shock triggered a major repricing of risk and a surge in the demand for safe assets. However, this episode also exposed deep and persistent imbalances in the demand for, and the supply of, liquidity, which is critical to financial intermediation.[13]

Initially, secured funding markets like repo markets continued to function relatively smoothly, allowing participants to turn assets into cash. But as stress mounted, surging asset sales overwhelmed dealers' constrained balance sheets. Higher perceived risks made dealers increasingly reluctant to absorb liquidity imbalances, leading to soaring repo rates and severe dislocations in short-term funding markets. Market dysfunction was aggravated by large sales of US Treasuries by leveraged investors and foreign holders, further straining dealer capacity and fuelling a self-reinforcing liquidity spiral.

In response, central banks implemented unprecedented policy measures – massive asset purchases, expanded liquidity operations (including dollar liquidity provision), and the establishment of backstop facilities targeting key financial institutions like MMFs and primary dealers. These interventions, particularly their announcement effects, were crucial in restoring confidence and stabilizing markets.

The March 2020 Market Turmoil episode thus exemplifies multiple contagion channels: liquidity contagion, asset fire sales, cross-asset contagion partly due to common holders, portfolio rebalancing and investor behaviour, leverage and margin calls, redemption pressures in investment funds.

**2021 Failure of Archegos Capital Management.** Archegos Capital Management (ACM) was reportedly engaged in highly leveraged long-short investment strategies, utilizing complex derivative instruments that effectively concealed its actual market exposures from its lending partners. ACM was classified as "family office" and thus it was not subject to registration of and/or disclosure and reporting duties to U.S. regulatory authorities (Branzoli et al., 2021).

Trouble began when a series of adverse developments caused sharp declines in the value of several stocks within ACM's investment portfolio (J.P. Morgan, 2021). The firm had taken concentrated long positions in media companies and U.S.-listed Chinese technology firms, both of which experienced significant losses in the days leading up to ACM's collapse. As these stock prices fell, ACM was unable to meet the resulting margin calls requested by the banks on which it relied.

The default of this private investment firm in March 2021 reverberated across global financial markets. The ACM episode involved some of the world's largest banks, with potential spillover implications, and has hit at least two of them particularly hard (Nomura and Credit Suisse). The Archegos failure underscored the risks posed by the combination of extreme leverage and the use of opaque, complex financial instruments. It also revealed vulnerabilities in the broader financial system. The incident serves as a stark reminder of how the build-up of concentrated derivative positions combined with a lack of transparency on these positions can impose significant counterparty losses on systemically important banks.

[13] On the demand side, non-financial corporations rushed to secure funding by tapping short-term money markets and issuing commercial paper; meanwhile, the corporate bond market seized up, with issuance costs soaring. Foreign borrowers scrambled for US dollar liquidity, with the appreciating dollar potentially triggering margin calls on hedged positions, further intensifying demand. Money market funds (particularly non-government MMFs) and some open-ended funds experienced heavy redemptions, which could have contributed to price dislocations and fire sales. On the supply side, risk aversion, regulatory constraints, and operational disruptions impaired dealers' ability to intermediate, especially in core funding markets.

**2022 UK Liability-Driven Investment crisis.** Liability-Driven Investment (LDI) funds were at the heart of the turmoil that gripped the UK gilt market following the announcement of the UK government's September 2022 "mini-budget". This crisis, coming shortly after the "dash for cash" in 2020 and the Archegos collapse in 2021, exposed deeper structural vulnerabilities within the broad and complex non-bank financial institution sector (IMF, 2023).

Since the late 1990s, regulatory shifts and demographic trends have prompted many UK defined benefit (DB) pension schemes to close to new entrants and pivot away from equities in favour of fixed-income assets. To address funding shortfalls – which could have broader implications for corporate finances – these pension schemes increasingly adopted LDI strategies offered by asset managers. These strategies aim to align the present value of pension assets with that of their liabilities, through exposure to long term fixed rate instruments. However, the LDI market is highly concentrated, with the top three asset managers controlling roughly 70 per cent of the space.

The "mini-budget" announcement in September 2022 rattled investor confidence, triggering a sharp spike in gilt yields. As a result, the value of LDI portfolios plummeted, compelling funds to quickly raise liquidity to meet margin calls and post additional collateral for leveraged positions. Given the concentrated exposures in pooled LDI strategies, this led to abrupt and significant asset sales, especially in long-duration and inflation-linked gilts, overwhelming a market that was already facing liquidity constraints. This wave of selling intensified the rise in yields, further exacerbating collateral demands.

The sell-off spread to other assets as well, with money market funds (MMFs) and open-ended investment funds also seeing liquidations. While MMFs met redemptions without disruption, certain real estate funds were forced to halt withdrawals due to liquidity pressures. Conditions in the gilt market became increasingly chaotic, raising the risk of broader contagion across financial markets.

To prevent systemic fallout, the Bank of England (BoE) intervened with a temporary and targeted program to purchase long-dated gilts. This financial stability measure, combined with the government's subsequent fiscal policy reversals, helped stabilize the market and provided LDI funds with crucial breathing room to bolster their resilience.

The LDI crisis revealed multiple contagion channels: leverage and margin calls, asset fire sales, cross-institutional contagion, reputational and confidence spillovers.

**2023 Banking Turmoil.** The banking turmoil that erupted in March 2023 marked one of the most significant episodes of system-wide banking stress since the GFC, both in terms of its breadth and intensity (BCBS, 2023).

Over a span of just 11 days – from 8 to 19 March 2023 – four banks, representing around $900 billion in total assets, were closed, placed into receivership, or rescued.

Silicon Valley Bank Financial Group (SVB) provided financial services predominantly to companies in the technology and life sciences sectors. During the tech boom of 2019–2021 and a period of exceptionally low interest rates, SVB grew rapidly, tripling its balance sheet as deposits surged – most of which were uninsured. These deposits were invested heavily in long-duration securities, exposing the bank to significant interest rate risk. As rates rose in 2022, SVB faced growing deposit outflows and rising unrealized losses. Efforts to restructure its balance sheet, announced on 8 March 2023, failed to reassure investors, triggering a classic bank run the next day. SVB collapsed on March 10, leading ultimately to the bankruptcy of its holding company. Digitalisation played a crucial amplifying role in the speed and intensity of these outflows. At SVB, for instance, more than $40 billion in deposits were withdrawn in a single day—a speed and scale facilitated by digital banking channels and unprecedented in historical bank runs. The startup community involved in the SVB deposit run was highly connected through social media before the run and used social media to exchange information about the bank during the runs (FSB, 2024), suggesting a role for social media in influencing the deposit run.

Signature Bank New York (SBNY) followed shortly after, failing on 12 March 2023. Like SVB, it had seen rapid growth driven by uninsured deposits, and it was particularly vulnerable to contagion after the liquidation of Silvergate Bank and the collapse of SVB. Although the immediate cause of SBNY's failure was illiquidity following deposit flight, the root cause of SBNY's failure was poor management.

In Europe, Credit Suisse (CS) came under intense market scrutiny in mid-March 2023, following a technical delay in the publication of its 2022 annual report due to concerns about internal financial controls. Despite limited direct exposure to the failing U.S. banks, CS was already viewed as vulnerable due to prolonged strategic and operational weaknesses. Amid surging CDS spreads and plummeting share prices, a renewed wave of liquidity outflows hit the bank. Swift and extraordinary measures by Swiss authorities over the weekend of March 19 successfully stabilized CS and broader market conditions.

First Republic Bank (FRC) also succumbed to the cascading effects of the March turmoil. Sharing characteristics with SVB – particularly uninsured deposits and significant gaps between loan book values and market valuations – FRC experienced rapid outflows and severe liquidity distress following SVB and SBNY's failures. Despite efforts to stabilize the situation, FRC was closed on 1 May 2023, and the FDIC arranged its sale to JPMorgan Chase under a loss-sharing agreement. Several authorities then intervened with wide-ranging public support measures to contain the fallout.

The turmoil also spilled over into the broader financial system, with volatility reaching its highest levels since the GFC, funding conditions tightening, and investors dramatically reassessing prospects for economic growth and monetary policy. Access to capital markets was impaired. Although the underlying vulnerabilities of each failed institution differed, their collapse triggered widespread contagion across the banking sector, visible in sharp declines in bank equity prices and surging costs of insuring against bank defaults.

The 2023 banking turmoil highlighted several contagion mechanisms: confidence and depositor runs, asset-liability mismatches and interest rate risk, contagion via funding markets, cross-border spillovers.