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A Framework for Systemwide Liquidity Analysis

Xiaodan Ding, Dimitrios Laliotis and Priscilla Toffano

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WORKING PAPER

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Monetary and Capital Markets Department

A Framework for Systemwide Liquidity Analysis**Prepared by Xiaodan Ding, Dimitrios Laliotis and Priscilla Toffano***

Authorized for distribution by Hiroko Oura

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ABSTRACT: We developed a novel Systemwide Liquidity (SWL) framework to identify liquidity stress in the system that goes beyond banks and to assess the role played by non-bank financial institutions (NBFIs) in episodes of liquidity stress. The framework, which complements standard liquidity and interconnectedness analyses, traces the flow of liquidity among various agents in the economy and explores possible transmission channels and amplification mechanisms of correlated liquidity shocks. The framework uses unique balance sheet and asset encumbrance data to demonstrate the importance of assessing liquidity at the system level by allowing for (i) analyses of each agent's contribution to liquidity stress, (ii) analyses of the impact of different behavioral assumptions (e.g., pecking order of collateral utilization, negative externalities of fire-sales and margin positions), and (iii) policy simulations. Since this framework covers a comprehensive set of financial instruments and transactions, it paves the way for harmonization of systemwide liquidity analysis across countries. We applied this general framework to Mexico in the context of the FSAP. Results for Mexico show that commercial banks safeguard the resiliency of the financial system by backstopping the liquidity needs of other agents. Moreover, certain sectors appear more vulnerable when binding regulatory liquidity constraints trigger risk-averse behavioral responses.

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Author's E-Mail Address:	xding@imf.org , dlaliotis@imf.org , ctoffano@imf.org

WORKING PAPERS

A Framework for Systemwide Liquidity Analysis

Prepared by Xiaodan Ding, Dimitrios Laliotis, and Priscilla Toffano¹

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Glossary

BOE	Bank of England
CB	Central Bank
DB	Development Bank
ELA	Emergency Lending Assistance
FDI	Foreign Direct Investment
FC	Financial Corporation
FSAP	Financial Sector Assessment Program
GOV	General Government
HH	Household
IF	Investment Fund
LCR	Liquidity Coverage Ratio
NFC	Nonfinancial Corporation
NFBI	Non-bank Financial Institution
PD	Probability of Default
PF	Pension Fund
ROW	Rest of World
SWL	Systemwide Liquidity
VAR	Vector-Auto Regression

I. Executive Summary

Systemwide liquidity analysis has gained momentum in recent years due to growing linkages between financial institutions, often a key symptom of the buildup of systemic risk. The global dash-for-cash in 2020, for instance, triggered investors to sell sovereign and corporate securities rapidly, pushing up yields and slashing asset prices. In turn, corporates tapped into their credit lines and redeemed shares in fears of impending cash shortages, exerting pressure on the balance sheets of commercial banks and investment funds. Reputational risks and business models' vulnerabilities, such as those that exposed SVB and Credit Swiss to rapid deposit outflows, could easily translate to loss of confidence in the wider financial market, stoke fears of further bank runs and trigger systemic instability. These increasing uncertainties and severity of liquidity shocks and their system wide implications have sown seed in the international financial community in searching for adequate toolkits to monitor and strengthen system wide liquidity resilience. Several important endeavors – such as the December 2022 and 2023 FSB report on Non-Bank Financial Intermediation as well as the ongoing BOE system-wide exploratory scenario (SWES) exercise – speak to the increasing demand in understanding the interaction between banks and NBFIs in transmitting and potentially amplifying liquidity shocks within the system, giving rise to financial stability concerns.

However, data limitation and the lack of a standardized approach have so far impeded in-depth systemwide analysis. These studies often require highly granular data within agent and between agents, such as full balance sheets and bilateral claims among banks, non-bank financial institutions, non-financial private sectors including households and corporates, and foreign investors. The transmission of shocks, if assessed appropriately, also involves the triggering of margin calls, which requires data on the level of asset encumbrances of each market agent for repo transactions as well as margin positions if the agents engage in other types of derivative transactions (e.g., futures, swaps, options, etc.). Moreover, systemwide stress test approaches are often country specific and feature tailored scenarios, which can be difficult to harmonize across countries.

To overcome these challenges, we developed a novel Systemwide Liquidity (SWL) framework using Mexico as a case study to identify potential liquidity stress in the system beyond commercial banks.

The development of this framework, which complements standard liquidity and interconnectedness analyses, stemmed from the understanding that it is not sufficient to ensure the resilience of an individual sector or institution to protect the stability of the entire system. Specifically, the framework allows us to:

- Go beyond banks and assess **transmission and amplification** of liquidity stress within the financial system.
- Apply the analysis at **aggregate agent level** (banks, investment funds, pension funds, Insurance companies etc.) or at the level of **individual entities**.
- Use data on **asset encumbrance and collateralized exposures** (repo, etc.) to properly capture agent's liquidity buffers, quantify the effect of **margin calls for existing positions**, and **trace the flow of collateral** underlying each position under stress.
- Adapt the analysis to **any jurisdiction regardless of depth and complexity** of its financial system with **tailored shock** narratives.

- Apply **distribution of shocks** with pre-defined correlation, instead of single point estimates, to **tackle scenario uncertainty** and identify the possible **tipping points** that lead to liquidity shortfalls.
- Measure the **relative contribution** of each agent to the system-wide liquidity stress.
- Incorporate **behavioral elements**, such as **order of asset liquidation or fire-sales**, and their implication on other agents or system-wide liquidity.
- Allows **policy simulation** to assess the capacity and willingness of agents to intermediate when facing **regulatory constraints**.

For Mexico, results show that:

- **Commercial banks ensure the liquidity of the financial system by backstopping liquidity needs of all other agents.** Commercial banks act as a shock absorber by providing liquidity to other agents through repo transactions. They show only marginal liquidity shortfalls even under the most severe narratives.
- **Development banks are more vulnerable when liquidity constraints are binding.** When the Liquidity Coverage Ratio (LCR) is mandatory for commercial banks or minimum liquidity buffers are mandatory for investment funds, larger liquidity shortfalls can materialize in the system for certain agents. For instance, under binding liquidity constraints, commercial banks with liquidity surplus are less willing to roll-over existing fundings and therefore amplify stress on development banks' funding conditions. In a similar vein, policy analysis also suggests that expanding access of investment funds to the repo market could reinforce systemwide resiliency and liquidity conditions.
- **Important amplification mechanisms emerge when considering the systemwide effect of fire-sales of certain market agent(s) on asset prices.** For instance, fire-sales of investment funds trigger additional broad-based mark-to-market asset devaluations which worsen the liquidity position of the entire system. A comparison of distributions of net liquidity positions pre- and post- shock reveals higher market discounts across all types of tradable securities as well as higher tail liquidity risks, with post fire-sale distributions having longer and fatter left tails for all market agents, in line with historical evidence.

Finally, the framework could play a pivotal role in the calibration of macro-prudential and crisis management policies. Through a comprehensive assessment of liquidity buffers, direct and indirect balance sheet exposures between sectors, decision-makers can identify critical areas of concern and devise appropriate policies to mitigate liquidity risks from a systemwide perspective. The outcome of the analysis could also inform both micro- and macroprudential liquidity measures, such as limiting certain asset and funding exposure or build more liquidity buffers, which could contribute to the overall resilience of the financial system. Furthermore, during times of crisis, the analysis could empower policymakers to swiftly identify the institutions and markets most susceptible to liquidity strains and quantify their liquidity needs, while preemptively assess the need to adjust (e.g., tighten and loosen certain limit or buffers, or allow broader eligible collateral under the ELA framework or market access for certain agents) existing calibrations under stress.

II. Introduction

Systemwide liquidity analysis has gained momentum in recent years due to growing linkages between financial institutions, often a key symptom of the buildup of systemic risk. The economic scars left by the COVID-19 pandemic and the Russia-Ukraine war are stark wake-up calls of how crucial the financial network is in transmitting, amplifying, and transforming idiosyncratic shocks into systemic shocks. The global dash-for-cash in 2020, for instance, triggered investors to sell sovereign and corporate securities rapidly, pushing up yields and slashing asset prices. In turn, corporates tapped into their credit lines and redeemed shares in fears of impending cash shortages, exerting pressure on the balance sheets of commercial banks and investment funds. Reputational risks and business models' vulnerabilities of certain banks, such as those that exposed SVB and Credit Swiss to rapid wholesale deposit outflows, could easily translate to loss of confidence in the wider financial market, stoke fears of further bank runs and trigger systemic instability. Many levered market participants, such as hedge funds and property funds, were forced to sell securities to meet margin calls, which lead to liquidity spirals. Risk perceptions also shaped adverse behavioral responses of certain sectors, as banks became increasingly reluctant to act as market makers, such as in the repo markets. The COVID-19 pandemic and Russia-Ukraine war led to rising commodity and energy prices, with an impact on costs of production and inflation. As a result, companies experiencing lower profitability and losses ate into their solvency and liquidity buffers, and those without sufficient buffers were compelled to liquidate short term assets, with distress cascading throughout their counterparts and the entire financial system. These increasing uncertainties and severity of liquidity shocks and their system wide implications have sown seed in the international financial community in searching for adequate toolkits to monitor and strengthen system wide liquidity resilience. Several important endeavors – such as the December 2022 and 2023 FSB report on Non-Bank Financial Intermediation as well as the ongoing BOE system-wide exploratory scenario (SWES) exercise – speak to the increasing demand in understanding the interaction between banks and NBFIs in transmitting and potentially amplifying liquidity shocks within the system, giving rise to financial stability concerns.

However, data limitation and the lack of a standardized approach has so far fettered in-depth systemwide analysis. These studies often require highly granular data within agent and between agents, such as full balance sheets and bilateral claims among banks, non-bank financial institutions, non-financial private sectors including households and corporates, and foreign investors. The transmission of shocks, if assessed appropriately, also involves the triggering of margin calls, which requires data on the level of asset encumbrances of each institution for repo transactions as well as margin positions if they engage in other types of derivative transactions (e.g., futures, swaps, options, etc.). Moreover, systemwide stress test approaches are often country specific and feature tailored scenarios, which can be difficult to harmonize across countries.

To overcome these challenges, we developed a novel Systemwide Liquidity (SWL) framework using Mexico as a case study to identify potential liquidity stress in the system beyond commercial banks. The development of this framework, which complements standard liquidity and interconnectedness analyses, stemmed from the understanding that it is not sufficient to ensure the resilience of an individual sector or institution to protect the stability of the entire system. It also aims at filling the gap in the literature by proposing a standardized framework to analyze correlated liquidity shocks which, often identified as a common pattern under stress, can be applied to different jurisdictions. The framework proposed in this study allowed to map liquidity linkages among various agents in the economy and understand the transmission channels and amplification mechanisms of liquidity shocks. It also allows to evaluate the liquidity capacity of the system and conduct some policy counterfactual experiments.

The benefit of this framework is that it requires less granular data while still be able to preserve complex financial market characteristics. Since the framework only requires aggregated sectoral level data, it can be applied to both advanced economies and emerging markets as these data is being increasingly collected by central banks and made available to the public. In the meantime, it covers a comprehensive set of financial instruments and transactions well beyond the direct exposure between sectors, such as repo and derivative exposures, and trace the flow of collateral between sectors to match repo transactions (e.g., the return of collateral to the borrower following the expiration of the repo contract) as well as calls on existing margin positions and encumbered collateral as a response to market valuation shocks. These features allow the framework to be tailored to financial markets with varying levels of depth and complexity, thus rendering more robust country specific outcomes.

Finally, this framework could play a pivotal role in the calibration of macro-prudential and crisis management policies. Through a comprehensive assessment of liquidity buffers, direct and indirect balance sheet exposures between sectors, decision-makers can identify critical areas of concern and devise appropriate policies to mitigate liquidity risks from a systemwide perspective. The outcome of the analysis could also inform both micro- and macroprudential liquidity measures, such as limiting certain asset and funding exposure or build more liquidity buffers, which could contribute to the overall resilience of the financial system. Furthermore, during times of crisis, the analysis could empower policymakers to swiftly identify the institutions and markets most susceptible to liquidity strains and quantify their liquidity needs, while preemptively assess the need to adjust (e.g., tighten and loosen certain limit or buffers, or widen the perimeter of eligible collateral under the ELA framework or allow broader market access for certain agents) existing calibrations under stress.

The rest of the paper is organized as follows: Section III presents a literature review and discusses how the systemwide liquidity analysis can add value to the existing literature. Section IV explains the key features of the framework. Section V offers a case study on Mexico which gives a more granular view of the methodology and summarizes main results and findings. Section VI performs policy experiments by assessing the impact of agents' behavioral response to regulatory constraints on systemwide liquidity. Section VII considers second-round effects of fire-sales on funding and market liquidity and asset price disruptions. Section VIII concludes.

III. Literature Review

Systemwide liquidity analysis is inspired by a growing literature that examines resilience of various sectors of the economy to both domestic and foreign shocks while identifying important transmission and amplification mechanisms post-shock. Most recently, Oura (2022) spearheaded the systemwide liquidity stress test by developing a user-friendly Excel-based tool to assess the high-level impact on multiple financial sectors of aggregate liquidity stresses - in particular those associated with foreign currency outflows - to help calibrate macroprudential measures and related liquidity supports. The tool was subsequently applied to the Türkiye and Iceland Financial Sector Assessment Programs (FSAP) to assess the capacity of the financial system to withstand large FX liquidity shocks. Sydow et al. (2021) developed a model for the joint stress testing of banks and investment funds which enabled a dual channel of solvency and liquidity risks in the assessment of capital losses and revealed that the inclusion of additional sectors such as investment funds into the traditional single sector stress testing framework would amplify losses via fire sales and depletion of banks' capital ratios by around one percentage point. Relatedly, Fukker et al. (2022) gauged systemic risk within the

euro area financial system of banks and investment funds by considering contagion between institutions via market price impact on common portfolios holdings induced by fire sales. The 2020 U.S. FSAP assessed the transmission of the risks from NFC debt across the financial system – composed of banks, insurers, mutual funds, money market funds - focusing on an instant market shock lasting for a month and leading to immediate asset liquidation. The study found significant exposure of NBFIs to the corporate debt market, and any stress on the NBFIs, especially mutual funds, could spill over to other segments through both direct balance sheet and indirect channels, such as further valuation losses to commonly exposed corporate bond market. Farmer et al. (2020) implemented a systemwide stress test for the European financial system with heterogeneous institutions covering commercial banks, investment funds and hedge funds. They considered both direct exposures through interbank claims as well as indirect linkages through collateral margin calls through repo transactions or common holdings of tradable securities. Their findings confirmed that 1) the stability of the financial system hinges on the shock amplifying mechanism under stress; 2) the behavioral response of the banks, such as their willingness to use buffers to absorb losses, is of great consequence to systemic resilience, and 3) capital buffers can be potentially underestimated when a systemwide view is absent. Recently, the Bank of England has also launched its first system-wide exploratory scenario (SWES) exercise which invites a group of large banks, insurers, central counterparties (CCPs), and a variety of funds to participate in order to 1) enhance understanding of the risks to and from NBFIs, and the behavior of NBFIs and banks in stress, including what drives those behaviors; and 2) investigate how these behaviors and market dynamics can amplify shocks in markets and potentially pose risks to UK financial stability. The exercise is anticipated to be completed in 2024 with a published bank report.

A growing body of literature also offers insights on liquidity risks originated from NBFIs. Lô and Carpentier (2023) presented a liquidity stress testing framework for investment funds characterized by 1) a time to liquidation approach, whereby a dynamic dimension is integrated in the assessment of the fund portfolio liquidity, 2) a dual impact shock on both redemption on liabilities and haircut on liquid assets and 3) a macroprudential perspective with both a contagion (via the price impact of first-round sales) and an amplification (via second-round effects of redemptions) channel. They found that high-yield bond funds are more vulnerable in case of larger shocks. Similarly, Gourdel and Sydow (2023) developed a framework to assess impact of climate risks on investment funds sector via market risk and shock propagation through funds' crossholdings and overlapping exposures. They found that network amplification induced by transition risks is less likely, but the second-round effects induced by physical risks are less efficiently absorbed by investment funds. Fricke and Wilke (2020) used granular data for the German fund sector to identify that cross-fund investments (a) are becoming increasingly important over time, (b) were heavily liquidated during March 2020, and (c) display measurable contagion effects. Overall, cross-fund investments can elevate structural fund sector vulnerabilities.

In a similar vein, various studies have looked into the potential trigger of liquidity shocks on the financial system. For instance, Drechsler et al. (2023) modeled the impact of interest rates on liquidity risk of the banks and indicated that bank run risks increase as interest rate rises. They found positive relationship between outflow risks with the value of a bank's deposit franchise, and an increase in interest rate could increase the value of deposit franchise, thus making a run, especially on uninsured deposits, more likely. Similar studies such as Jiang et al. (2023) investigated factors leading to a bank run following the SVB incident and concluded that banks with a low initial capital ratio, high uninsured customer deposits and high mark-to-market losses to increase in interest rates could amplify banks' fragility to uninsured deposit runs. They identified similar incentives for the U.S. banks and estimated that even if only half of uninsured depositors decide to withdraw, almost 190 banks with assets of \$300 billion are at a potential risk of impairment, meaning

that the mark-to-market value of their remaining assets after these withdrawals will be insufficient to repay all insured deposits. Finally, ESRB (2020) conducted a top-down analysis to gauge the liquidity impact of a corporate bond downgrade on the broader financial system. Such downgrade is expected to be accompanied by severe yield shocks of corporate bonds. The study shows how sizable losses could be triggered by the initial yield shock and compounded by subsequent behavioral response such as fire sales. It also finds considerable overlap of the corporate portfolio holdings by investment funds and insurers.

Relatedly, several studies further tap into risk drivers of capital flows, one of the important factors contributing to systemwide liquidity risks for the emerging market. For instance, Alba et al. (2021) estimated a vector autoregression model (VAR) to quantify the determinants of debt flows over time and found that the contribution of global risk aversion to the evolution of debt flows increased during the March 2020 episode, but its importance has gradually subsided since. Tellez-Leon and Ibarra (2019) conducted similar study to quantify the impact on investment flows and concluded that an increase in the foreign interest rate leads to lower portfolio investments, particularly in public sector securities, and that foreign investors are more sensitive to foreign interest rate and liquidity shocks compared to domestic investors. Bush and Canon (2021) leveraged security level data for global mutual funds to explore the drivers of fund holdings of emerging market economy (EME) bonds. Vega (2021) attempted to analyze the effect of high uncertainty on portfolios flows to Mexico and found that high uncertainty leads to a marked depreciation of the nominal exchange rate, a contraction in economic activity and a fall in the stock index. Vega (2019) also explored the impact of foreign direct investment and portfolio flows on house price and found that that increase of both flows contributes to higher house price, although mortgage credit trumps these flow variables in terms of overall contribution to price dynamics. Finally, associated with capital flows, Bush (2019) found that hedging demand is an important factor in the FX forward market.

Traditional interconnectedness analyses also shed light on transmission channels within the financial network. These studies mostly focused on capital losses via the credit channel of the interbank, intersectoral and cross-border networks, albeit with limited scope and depth in assessing systemwide liquidity implications. For instance, in an interbank context, Boss et al. (2004), Inaoka et al. (2004), Iyer and Peydro (2011), Hale (2012), Minoiu and Reyes (2013), Alter, Craig, and Raupach (2015), Minoiu et al. (2015), Cingano, Manaresi, Sette (2016), Hale, Kapan, Minoiu (2016), Cai and others (2018) and Aldasoro and Ehlers (2019) all strived to analyze financial contagion in the interbank markets using either public or confidential supervisory data. Some of them focused on country specific vulnerabilities while others extended to the global network to uncover, for instance, hidden concentration risks. Roncoroni et al. (2021) also studied the interplay between direct (via interbank loans) and indirect (via exposures to common asset classes) interconnectedness and identified non-linear relationships between diversification of exposures, shock size, and losses due to interbank contagion, and offered policy insights on the impact of the diversification of portfolios on the propagation of shocks. From an intersectoral perspective, Alonso and Stupariu (2019) for Spain showed significant cross-border interconnectedness, a growing presence of the non-bank sector and significant similarities between certain sectors' portfolios. As part of the ECB financial stability review, Cera et al. (2020) demonstrated that stress in non-banks can affect other parts of the financial system, for example through forced asset sales and reduced short-term funding. Aldasoro et al. (2020) used recent enhancements to the Bank for International Settlements (BIS) cross-border statistics and found that cross-border bank claims on NBFIs, such as investment funds and central counterparties (CCPs), have grown significantly in the last five years, mainly denominated in US dollars, and concentrated in financial centers and large advanced economies, but also in emerging market economies.

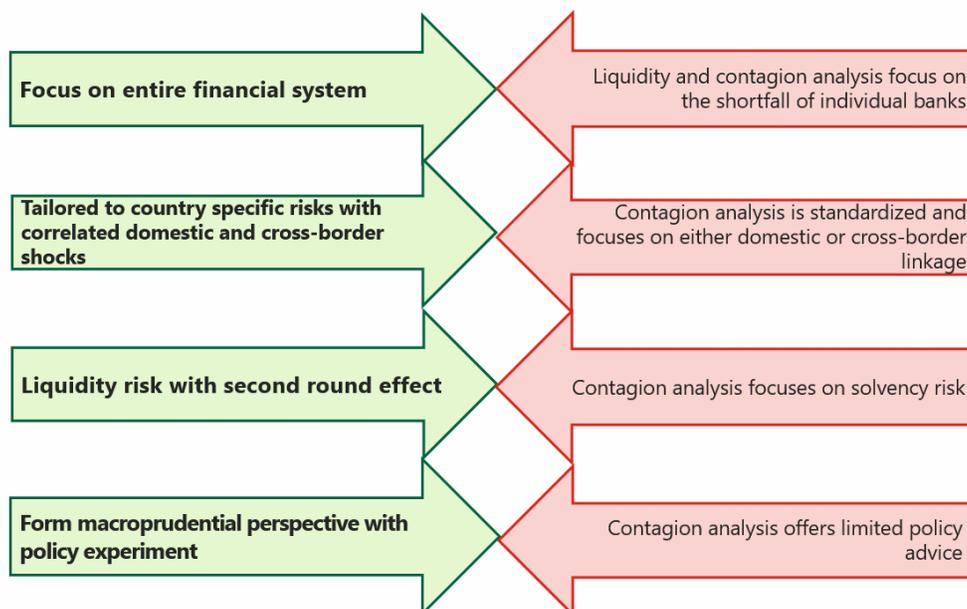
A rich set of methodologies were developed and widely used in various studies on financial interconnectedness. For instance, several publications on interconnectedness analysis, such as those under the IMF Financial Sector Assessment Program (FSAP), applied the Espinosa-Vega and Sole (2010) approach to examine domestic and cross-border interbank contagion by considering the solvency impact of both credit and funding shocks. Similarly, Covi, Gorpe, and Kok (2019) used ECB supervisory data to stress the interlinkages of euro area banks' large exposures within the global banking system. Xu (2012) and Beirne and Bricco (2014) also analyzed the international transmission of credit shocks using the Global VAR approach pioneered by Dees et al. (2007). In addition, Cortes et al. (2018) developed the Systemic Risk and Interconnectedness (SyRIN) tool to gauge risk amplification impact stemming from interbank and bank-NBFI network. Finally, Hamilton, Hughes, and Malone (2015) devised the Systemic Risk Monitor tool to combine network analysis with the Moody's CreditEdge platform, which quantifies contagion among financial entities, to offer early warning signals of systemic risk in the financial system.

Renowned research leveraged market-based indicators to study the systemwide importance of a financial institution, which this study also attempts to uncover from a liquidity perspective. The Conditional Value-at-Risk (CoVaR) indicator by Adrian and Brunnermeier (2008) estimates the value at risk of the financial system conditional on institutions being under stress, an indicator of systemic risk contribution, using market and balance sheet data. The SRISK framework developed by Acharya, Engle, and Richardson (2012) captures the expected capital shortfalls of a firm using debt, equity, and Marginal Expected Shortfall (MES) information, where MES is the expected loss of an equity investor if the overall market declines substantially. Jobst and Gray (2013) presented a forward-looking systemic contingent claims framework to measure systemic solvency risk, computed as joint default risk of multiple institutions, to help mitigate risks from systemwide linkages.

The systemwide liquidity analysis adds value to existing literature in several ways.¹ First, it brings together the liquidity and interconnectedness approaches by not only looking at a single market agent (e.g., commercial banks or investment funds), but also at the interaction between agents within the entire system, tracing the flow of money from one agent to another – including also those underlying the exchanges of collaterals or margin positions - and assessing liquidity resilience in a holistic way. Second, the flexibility and adaptability of the framework could allow tailored shock narratives to any jurisdictions based on country specific vulnerabilities, as well as simultaneous realization of various domestic and external shocks with high correlation under stress (e.g., domestic deposits' outflows and foreign investors' selling of sovereign bonds) to jointly determine the counterbalancing capacity of the system and preventing any potential underestimation of the impact of liquidity shocks. Furthermore, the analysis complements traditional contagion analysis – which focuses solely on solvency risks - by targeting also the liquidity narrative of the network, while taking into account second-round effects induced by behavioral responses such as liquidation of assets. Finally, the analysis brings to the fore the macroprudential perspective by looking at economy-wide liquidity risks and the significance of each agent contributing to such risks, rather than risks associated to individual institutions or a single sector, while enabling multiple sensitivity and counterfactual analyses, such as imposing or relaxing regulatory binding constraints on liquidity, to assess the willingness to intermediate of certain agents in the market and to inform ongoing policy decisions.

¹ The published 2021 FSB progress report on enhancing the resilience of non-bank financial intermediation and the IMF paper on the new Institutional View (IV) on capital flow measures (IMF 2022a) underscored the importance to assess liquidity risks in the NBFI sectors via liquidity imbalances both on- and off-balance sheets (e.g., margin calls), as well as risks stemming from capital flows linking to financial stability considerations.

Figure 1: Systemwide Liquidity Analysis — A Comparison with Existing Methodologies



Source: IMF staff.

IV. Key Features of the Framework

The systemwide liquidity analysis was performed in three distinct steps: narrative design, shock generation and Monte Carlo simulation to generate each agent’s net liquidity position (Figure 1). The first step formulates several country specific narratives, each simulating a liquidity stress event facing the specific financial system. The second step generates a series of liquidity shocks impacting the agents’ balance sheets according to each narrative. The third step carries out the Monte Carlo simulation using the generated shocks and quantifies the net liquidity position for each market agent after each simulation. These liquidity shocks are expected to hit each agent’s balance sheet and propagate through the entire system via both direct channels of funding and market stress, as well as second-round revaluation effects (calls on encumbered collateral for existing funding or margin positions).

The narrative design could promote a deep understanding of the financial system. This may include key players in the market, their interconnectedness, and potential strength and vulnerabilities associated with their liquidity conditions. It needs to be tailored to country specific circumstances rather than following a “one-size-fits-all” approach across countries. For instance, for a small open economy which faces larger risks of capital flows but does not have a deep financial market, the narrative could target a capital flow shock which could drain liquidity outside of the system, exerting pressure on corporates funding and the price of liquidity assets such as sovereign and corporate securities that are commonly held by various market agents. For advanced economies with deep financial markets such as a well-developed repo and derivative market, the narrative

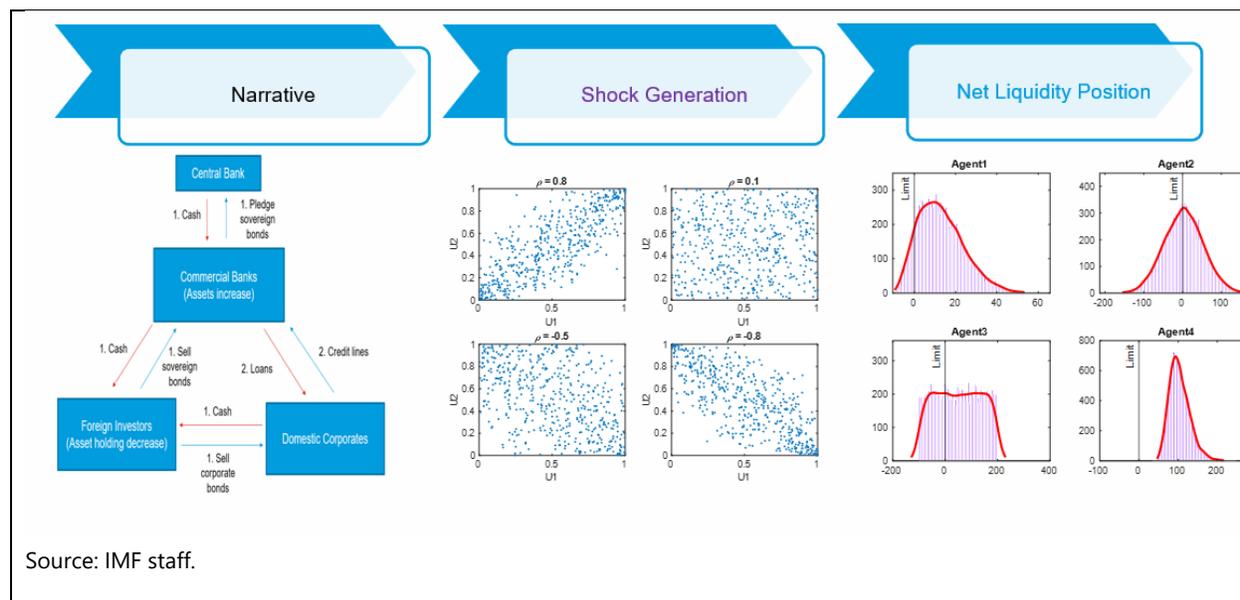
could explore margin calls on existing derivative exposure of market agents, as well as on encumbered assets underlying a repo transaction. That being said, both type of economies can also be subject to a common set of liquidity risks, such as deposit runs on banks from domestic households and corporates.²

The shock generation step aligns with narratives while addressing risks associated with scenario uncertainties. In the second step, a set of shock parameters need to be chosen in accordance with the triggering points identified in the narrative(s). For instance, wholesale and retail deposit outflow rates are needed to simulate bank runs from households and corporates. Similarly, selloff rates on foreigner's holding of sovereign securities and share redemption rates are required to capture shocks related to capital outflows and redemptions on investment funds. As a result, the lower market demand on sovereign securities could also lead to higher yields and lower market price, thus reducing the value of liquid asset holdings of market agents. A novel contribution of this analysis is to use correlated distributions for the generation of shocks to deal with scenario uncertainty. Each shock is drawn from a distribution specified by a copula – a multivariate distribution function with pre-defined correlation factors between shocks –as well as the shape and boundary of each marginal distribution characterizing the shock (Appendix I). The correlation factor can be flexibly adjusted to tailor country-specific realizations of historical liquidity stress, or to better capture the desired level of correlation between each pair of liquidity shocks. For example, if the framework generates one thousand observations of wholesale deposit outflows rates from a pre-defined distribution, they can have higher correlation with the one thousand observations of triggering rates of corporates' credit lines from another pre-defined distribution, and less so with the one thousand observations of the selloff rate on foreigner's holdings of domestic sovereign securities, even though both relationships can be stronger under a systemic liquidity stress. When there are no sufficiently long time series or pre-existing stress episodes to estimate such correlations, a sensitivity analysis experimenting on a range of correlation parameters can be beneficial.

The third step carries out the Monte Carlo simulation which generates distribution of net liquidity position for each agent post-shock. The simulation feeds the generated liquidity shocks under each simulation into the balance sheets of each agent, allows shocks to transmit between agents through their bilateral exposures, recomputes after each simulation the net liquidity outflows and available liquid assets of each agent and deduct the former from the latter to arrive at net liquidity position. As a result, a one-thousand simulation generates one-thousand net liquidity positions, which collectively form a new distribution post shock. From the new distribution, one can easily identify, if any, the maximum size of liquidity shortfalls on the most left tail of the distribution, as well as the tipping point where a simulation would lead to a full depletion of liquidity assets (e.g., net liquidity position equals 0).

Figure 2. Workflow of Systemwide Liquidity Analysis

² The rising debt cost associated, for example, with US monetary policy tightening – although mainly implying an impacting solvency over time – can also be captured in the framework as a form of interest payment outflows, should it be considered as relevant for a given country.



Another key feature of the analysis is that it allows a fully-fledged market clearing mechanisms to guide the flow of liquidity in the system. For instance, an agent may prefer to use more liquid assets (such as cash, sovereign securities or short-term reverse repo) over less liquid assets to meet funding obligations. A change to such preference may alter net liquidity position under the same liquidity shocks. The mechanism also makes possible the exchange of collateral underlying secured funding transactions, or reversal of such transactions. For instance, if an agent decides not to roll over existing repo funding to another agent, it will simply withdraw cash liquidity and simultaneously return the collateral which was pledged by its counterparty agent during the initial transaction. Both cash and collateral flows are captured by the market clearing mechanisms.

Importantly, the framework can also be used to inform liquidity relevant policy decisions. For example, the framework can simulate the impact on systemwide liquidity of a policy change such as allowing greater access of investment funds to the repo market, which could enhance their liquidity positions and positively contribute to the resiliency of the system. This is because they can play an important role in relieving supply pressures in the sovereign bond market while fully utilizing access to the repo markets, without incurring heavy losses due to the inability to quickly liquidate their assets when facing severe funding shocks. Moreover, the framework can simulate the impacts on liquidity of imposing or relaxing regulatory binding constraint (e.g., LCR constraints), taking into account behavioral responses. Finally, liquidity surpluses or shortfalls identified in the analysis can facilitate the design of supportive policy measures under stress, such as the calibration of central bank's emergency liquidity assistance (ELA) or the expansion in the perimeter of eligible collateral or eligible counterparts.

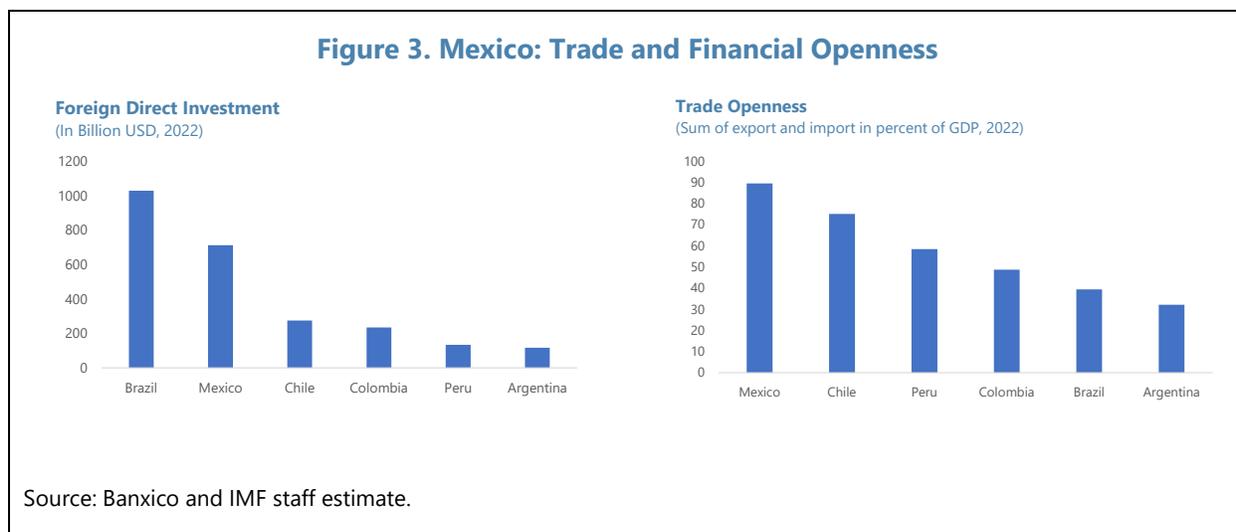
V. A Case Study on Mexico

The systemwide liquidity framework was applied to Mexico. While the design of the framework was motivated by the need to develop a generic, scalable, and adaptable framework to support the FSAP risk and

vulnerability analysis as part of the core stress testing machinery, the 2022 Mexico FSAP was used as a pilot to illustrate how the framework can be implemented in practice. Specifically, this section first provides some background and motivation to conduct a systemwide liquidity analysis for Mexico, and then dive into the core elements of the analysis such as selection of market agents, data collection, narrative design, shock generation and the fully-fledged simulation using generated shocks and their transmission between agents. Several behavioral elements, such as the pecking order of market clearing, are also explained in detail, and followed by a presentation of the results and ex-post analysis to measure the relative contribution of each agent to the system wide liquidity stress.

A. Background

Mexico’s integration in global trade and financial networks may expose it to substantial systemwide liquidity risks. Mexico is one of the Latin American countries most open to trade and foreign direct investments (FDIs), with total flows of export and import ranking top at around 90 percent of GDP and stock of FDIs at around 700 billion US dollar as of 2022, second only to Brazil (Figure 3). The United States is its largest trading partner and source of FDIs, accounting for nearly 80 percent of its exports and 50 percent of FDIs. The Mexican peso is the third most actively traded currency in the Americas (after the United States dollar and the Canadian dollar), and the most actively traded currency in Latin America. The deep integration into the global trade and financial networks offers ample opportunities for growth and diversification but also brings risks to systemwide liquidity when episodes of large and rapid liquidity outflows materialize, triggered by changes in global financial conditions or by shifts in investors’ risk appetite.



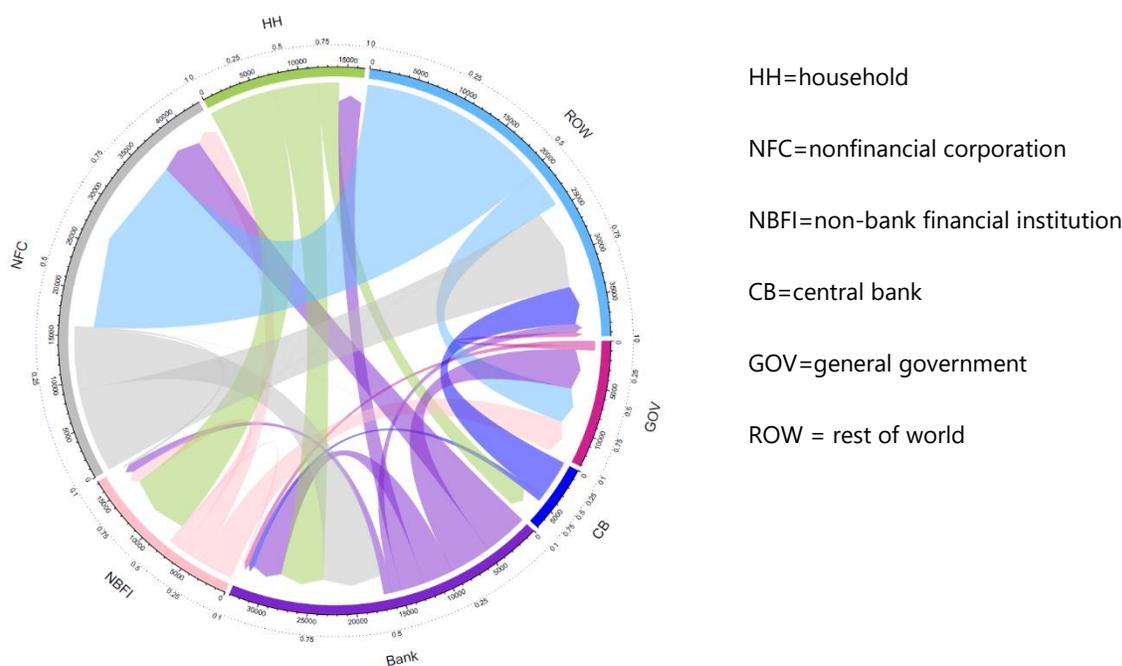
Domestically, the Mexican financial sector is composed of market agents that are also highly interconnected, while exposed to a common set of domestic and external liquidity risks. As shown in Figure 4, several market agents contribute to the systemwide liquidity network, with each acting either as a funding provider or receiver via direct lending, repo transactions and other forms of short-term and long-term financing instruments, such as the issuance of debt securities or secured and unsecured interbank transactions. In addition to direct exposures, they are also subject to indirect exposures through holdings of common assets, mostly sovereign and corporate debt securities, that are exposed to potential market repricing associated with fluctuations in both risk-free rates and sovereign and corporate spreads. Finally, the offshore

market also plays an important role in trading Mexican peso while providing liquidity to the domestic financial system, mostly through the buying and holding of domestic sovereign bonds and corporate stocks.

Figure 4 Mexico: Cross-sectoral Interlinkage

(In billions of Mexican pesos, 2022, asset claims)

Mexico's financial intermediaries are exposed to common assets (i.e., sovereign debt securities) and counterparty risk via direct lending and repo operations, and NFCs are exposed to off-shore refinancing risks

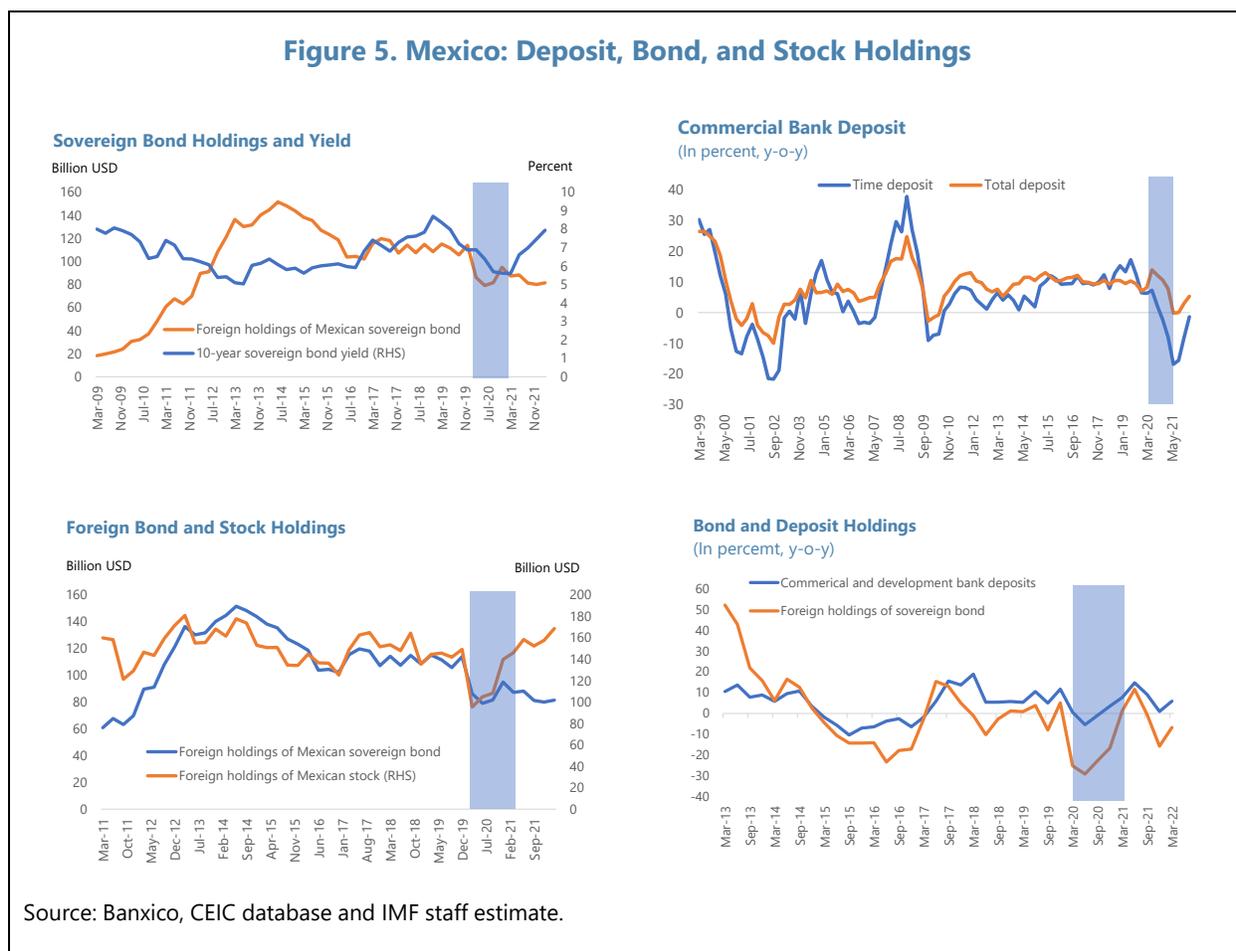


Sources: IMF Balance Sheet Approach Matrix; and IMF staff.

Note: The direction of an arrow shows exposures from a fund provider to a receiver. Non-bank financial institution includes development banks.

Historical evidence suggests that liquidity shocks can be strongly correlated under stress. This may amplify material downside risks compounded by concurrent liquidity shocks in the financial system. For example, sales of Mexican sovereign securities by foreign investors, when taking place in a large scale, may lead to rising sovereign yields and rapid adjustment of market prices, which in turn may diminish the value of existing liquid assets held by market agents to fend off large liquidity outflows. Such liquidity strains can be exacerbated when they materialize in parallel with deposit outflows and triggering of credit lines by both corporates and households, potentially leading to liquidity shortfall of individual agents spilling over to the entire financial system. The correlation between different channels of liquidity shocks can be more pronounced under stress, as evidenced by the March 2020 episode, when there were strong co-movements among sovereign securities sell-off, commercial bank deposit outflows, and liquidation by foreign investors of Mexican corporate stocks (Figure 5). Such synchronized episodes were also evident during the global financial crisis and contributed to the buildup of tail risks of liquidity shortage for the entire system.

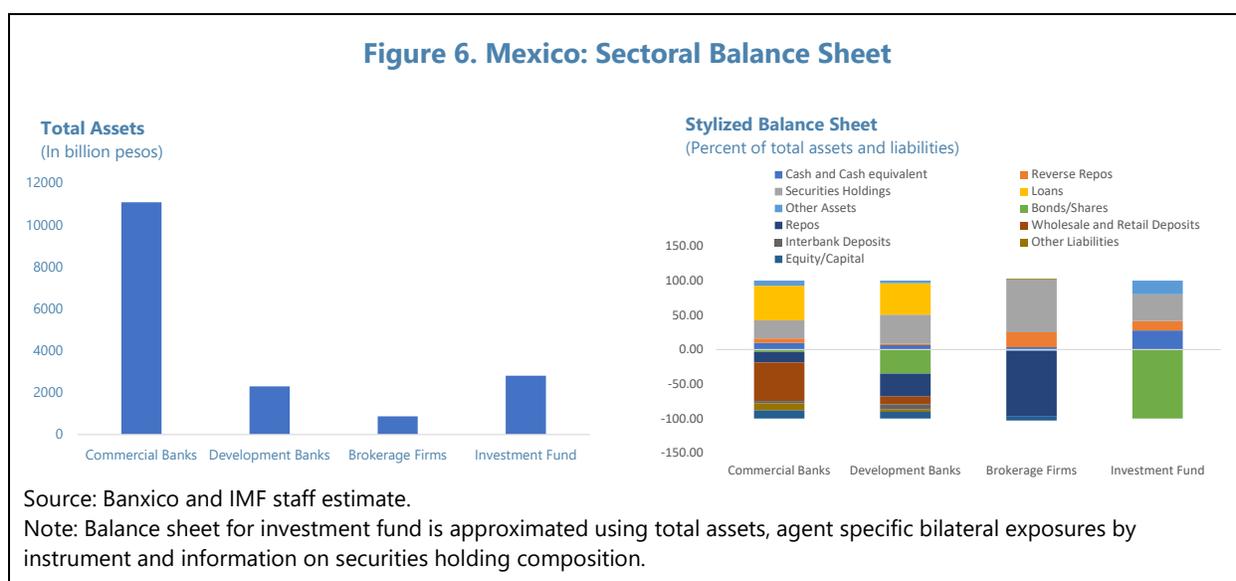
Figure 5. Mexico: Deposit, Bond, and Stock Holdings



Against this backdrop, we use the novel analytical approach previously discussed to assess resilience and vulnerabilities of systemwide liquidity in Mexico. The objective of the systemwide liquidity analysis is manifold. First, it aims at understanding the extent of the interconnectedness among agents and have a systemwide view of liquidity conditions because the resilience of an individual sector or institution cannot itself assure the stability of the entire system, since they may be transferring liquidity risks to other sectors in the system. Second, it aims at quantifying the contribution of each agent to systemwide liquidity stress to improve the understanding of the transmission channels of liquidity shocks, as well as any amplification mechanism associated with the willingness and capacity of each agent to intermediate in the market. Third, it focuses on assessing the financial system's resilience against various adverse liquidity scenarios tailored to country specific vulnerabilities. Finally, the framework can also be used as a diagnostic tool to inform policy discussions, aiming at ensuring sufficient liquidity buffers in the system, with measurable and quantifiable data. Although the analysis was at this stage tailored to address Mexico's specific risks and vulnerabilities, it can be extended to other economies with different macroeconomic and financial structures.

B. An Overview of the Agents Contributing to SWL

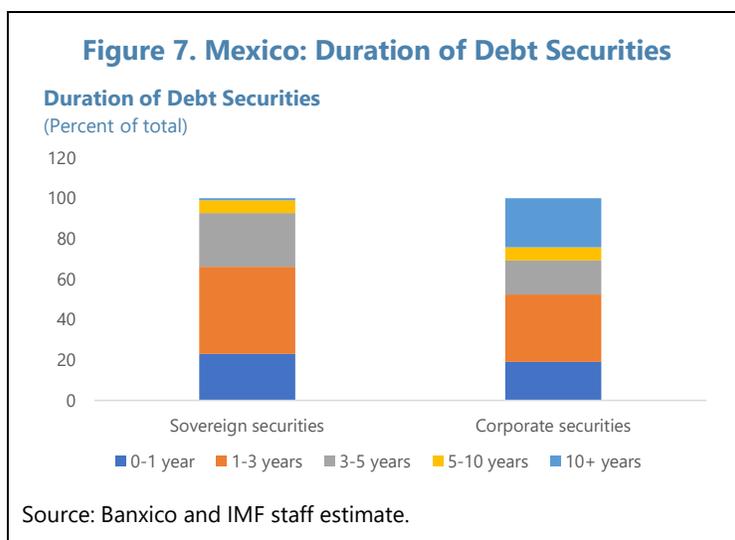
Stylized balance sheets data across agents highlight features of their business models and interlinkages. In Mexico, commercial and development banks have a similar business model, as both conduct maturity transformation by leveraging short-term funding to finance longer-term holdings of sovereign securities and loan portfolios. However, their funding profiles are quite different. Commercial banks rely mostly on retail and wholesale deposits, whereas development banks obtain wholesale funding from investment funds and nonfinancial corporations (NFCs) via short-term repo transactions and short-term bond issuance, with minimal exposure to direct deposits from the public. Investment funds finance themselves almost exclusively via issuance of shares and invest mostly in sovereign securities while providing financing to other financial agents with reverse repos and holding large amount of cash and other assets (e.g., equity investments) on their balance sheet. As a result, investment funds are more liquid than commercial and development banks. Finally, brokerage firms, which typically act as a market maker or agent in securities trading and offer investment advice, are small in size and have much simpler balance sheets, and therefore were excluded in the analysis (Figure 6).



Bilateral exposures between agents are concentrated in certain sectors and instruments. For example, commercial banks hold most claims against corporates, households, and the government in the form of loans and sovereign securities. They accept wholesale and retail deposits mainly from corporates and households and have little financial obligations to other agents in the economy. In contrast, development banks obtain wholesale funding mostly from investment funds and corporates via repos or issuance of securities, both of which are short-term, thus introducing higher funding risks. They use this funding to extend loans to SMEs or invest in sovereign securities.

Large holdings of sovereign securities may expose agents to sudden increases in sovereign yields and associated market revaluation risks. While development banks and investment funds hold a higher share of sovereign securities than commercial banks, all agents are exposed to sovereign securities, making them susceptible to rising sovereign risk premia, declines in market value of unencumbered collaterals, and triggering of margin calls on encumbered collateral. The levels of encumbrance are elevated for sovereign

securities, at 58 percent for commercial banks and 84 for development banks, which may considerably limit their capacity to utilize available liquid assets to absorb large and rapid liquidity outflows in periods of stress. The sensitivity of market repricing to rising sovereign yields is moderate, as the duration of the bulk of sovereign securities is between one to five years, with only a small share having maturity beyond ten years (Figure 7). Corporate securities, although having a notable share at maturity beyond 10 years, are not expected to prompt systemwide market losses and liquidity stress due to the significant lower amount of market holdings.



Contingent credit lines can be a source of vulnerability for systemwide liquidity. At around 3 trillion pesos including both revocable and irrevocable credit and liquidity lines, the off-balance sheet exposure extended by commercial banks to corporates and other private sectors can be an important source of liquidity risk in the system, especially when the sudden outflows associated with the triggering of credit lines are displaced outside of the system due to heightened risk aversion or tightened global financial conditions.

C. Methodology

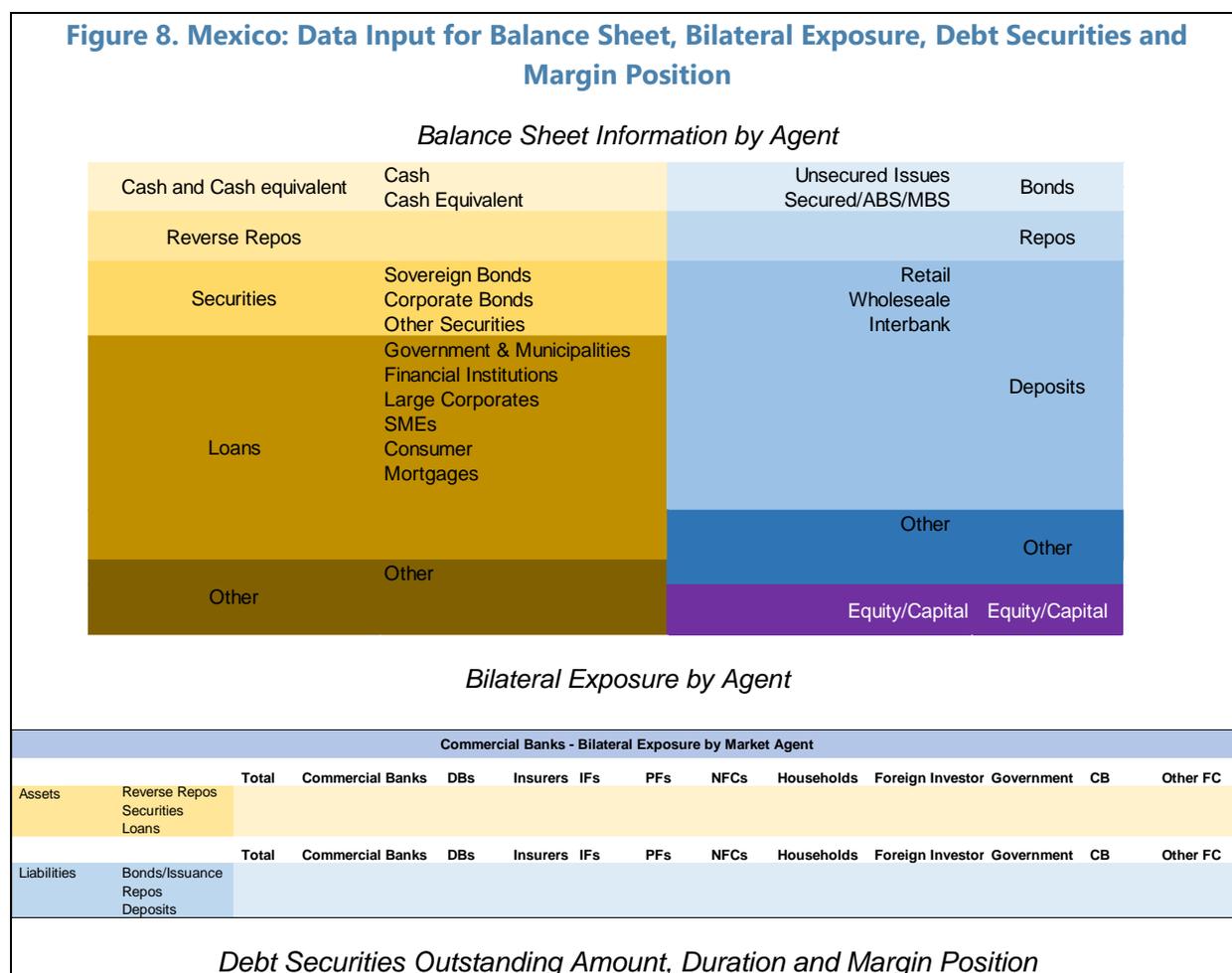
Scope and Data

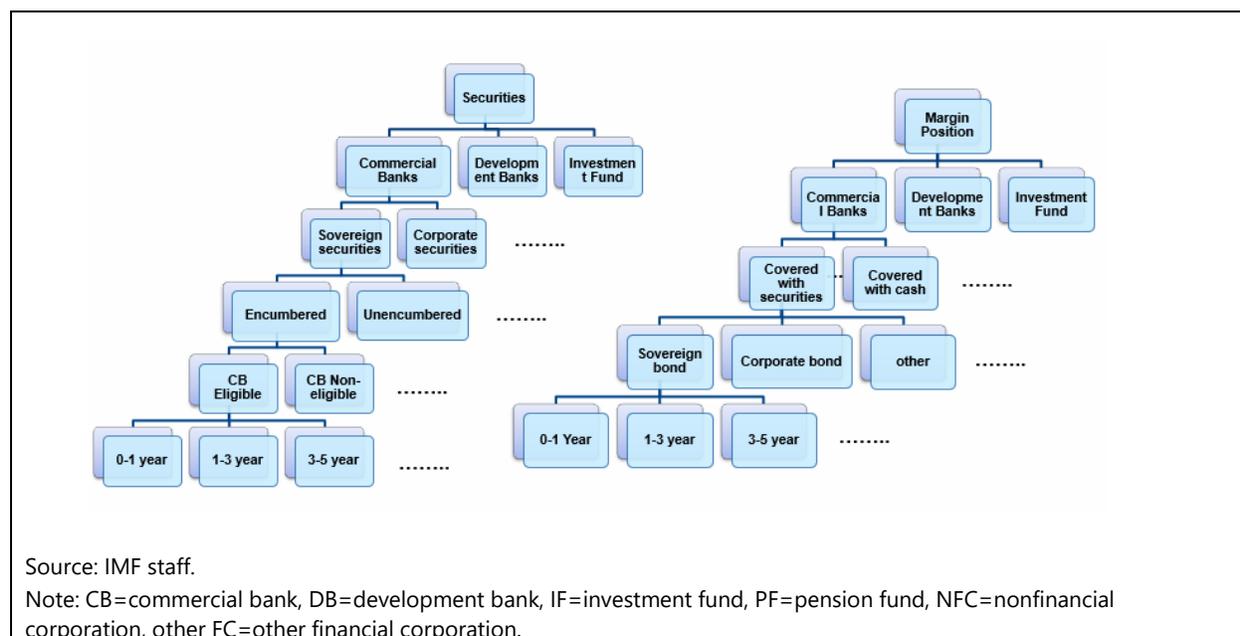
The analysis covers a comprehensive set of financial agents in the system. The systemwide scope of the analysis ensures the inclusion of all major agents, including the central bank and the government, commercial banks, development banks, investment funds, non-financial corporations, households, as well as foreign investors who provide external funding and liquidity to the domestic financial system. The agents in consideration collectively represent about 64 percent of the total financial sector's assets and are closely connected with each other through direct lending and deposits, short-term repos and reverse repos, securities financing, and other types of short and long-term debt issuance.

Data used in the analysis have a high degree of granularity. The data was compiled by Banxico as of December 2021 at the highest consolidation level and at an aggregate balance-sheet level (by agent type) and

is collected in a data template designed by IMF staff. It includes agent-specific balance sheet composition (Figure 8 top panel) and bilateral exposures between agents informed by who-to-whom holdings which, on the asset side includes loans, debt securities, and reverse repo, and on the liability side includes deposits, issuance of debt securities and shares, as well as any form of repo financing (Figure 8 middle panel). For the purpose of estimating market revaluation effects on trading securities due to a systemic liquidity shock, data on existing collateral, both encumbered and unencumbered, and split into central bank eligible and non-eligible, was collected by type of issuer and remaining maturities (Figure 8 bottom panel). Margin positions covered with debt securities under derivative transactions were also provided to capture second-round effects on margin calls associated with volatility in market price of the underlying collateral. Lastly, haircut information for repo transactions were collected by maturity and split into central bank operations and transactions taking place in the secondary market.

Figure 8. Mexico: Data Input for Balance Sheet, Bilateral Exposure, Debt Securities and Margin Position





Narrative Design

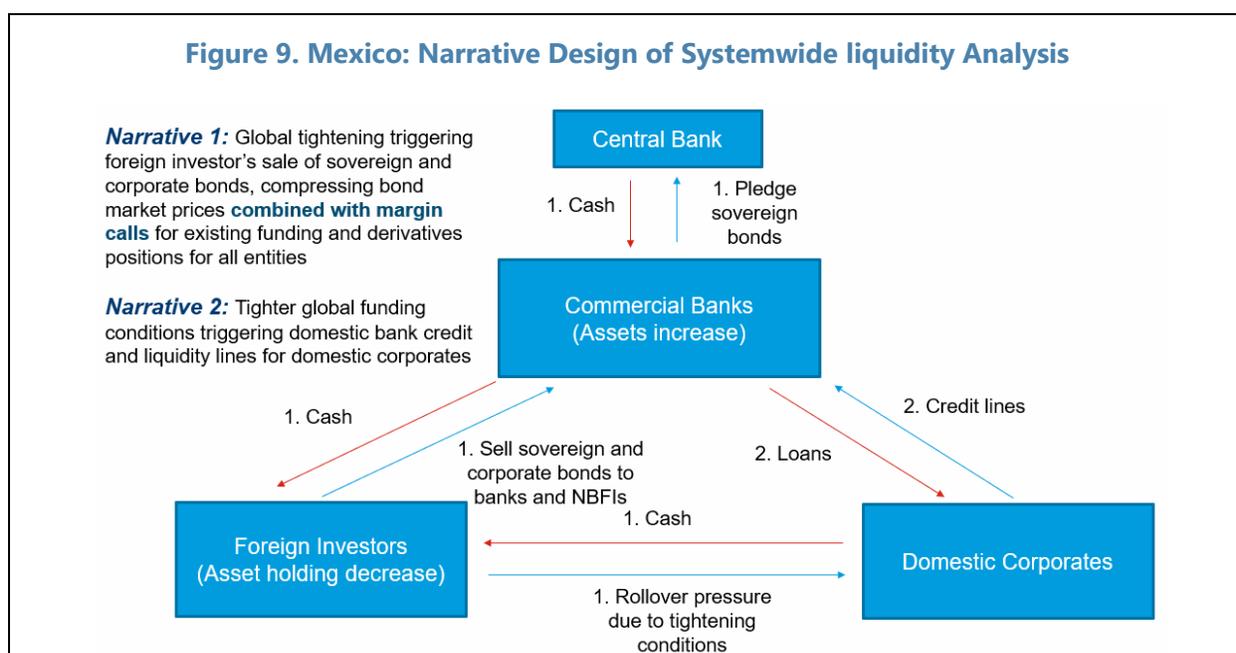
There are four narratives featured in the systemwide liquidity analysis for Mexico, each tailored to a specific type of liquidity risk facing the Mexican financial system:

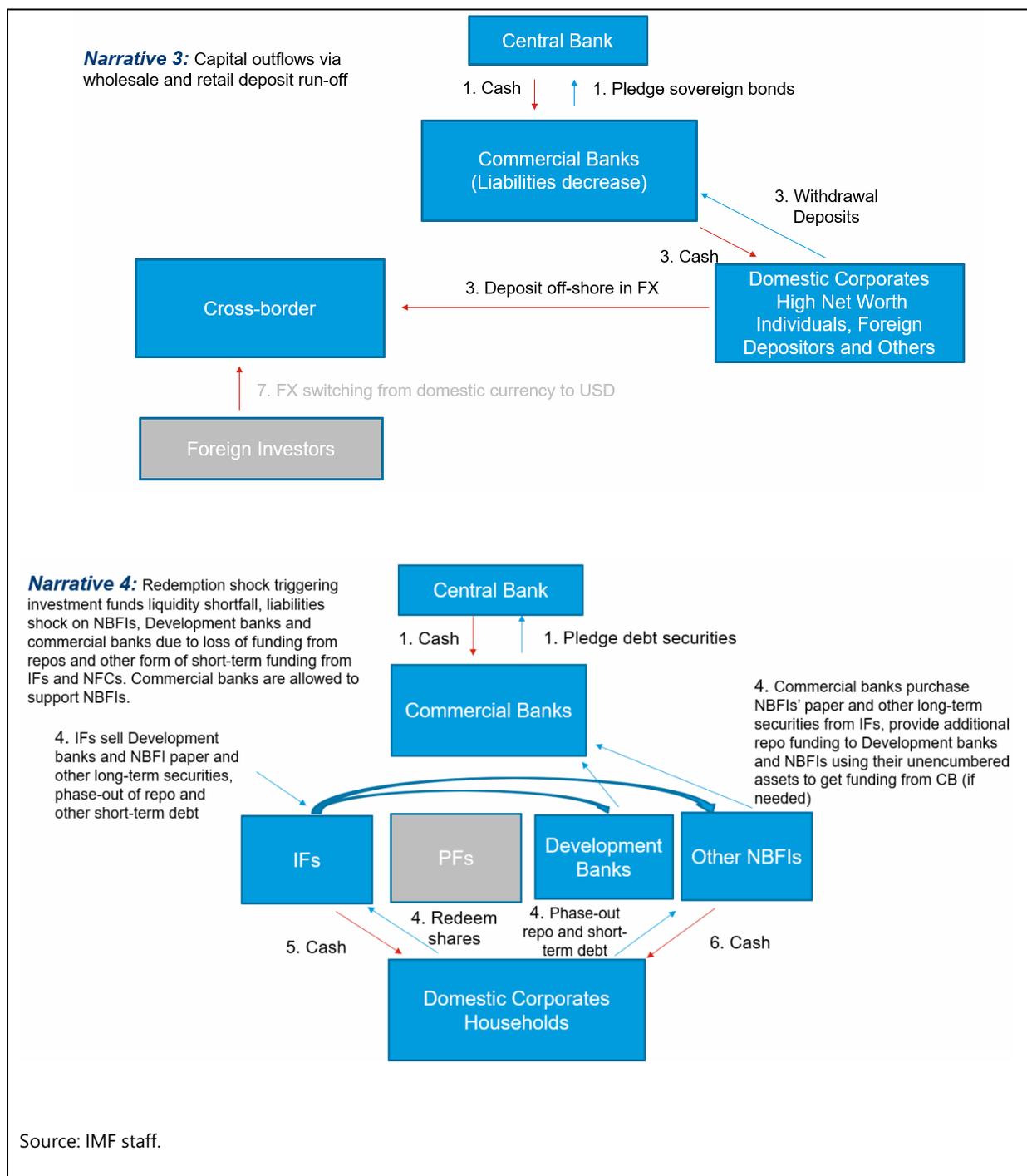
- **Narrative 1: Tighter global financial condition inducing investors' selling of sovereign and corporate bonds; triggering of margin calls for existing funding and derivatives positions.** As a large open economy, Mexico can be vulnerable to sudden capital outflows from the country's sovereign debt market. This can materialize for various reasons, such as tighter US monetary policy, a deteriorating fiscal position, or a subdued risk appetite of foreign investors due to a negative growth outlook or other geopolitical reasons. The March 2020 event is a timely reminder that systemwide stability can be threatened by a sudden freeze of funding following a loss of market confidence or increased uncertainty. The high share of foreign holdings of domestic sovereign securities and corporate shares, currently at around 20 and 33 percent, can form an important external transmission channel to domestic systemwide liquidity. Selling pressures are often accompanied by a decline in the market value of tradable sovereign securities, which comprise most of the agents' liquidity buffers in the system, triggering margin calls for existing funding and derivative positions.
- **Narrative 2: Tighter global funding conditions triggering credit and liquidity lines of corporates.** The March 2020 event also provides an example of how credit and liquidity lines can be activated by corporates as an alternative to external funding when global financial conditions are tighter. In Mexico such lines are sizable at around 3 trillion pesos and, while they were not drawn en masse during the pandemic shock, they could be triggered at a high rate during episodes of global liquidity stress.
- **Narrative 3: Capital outflows via wholesale deposit run-off.** In addition to the risk-off events triggered by foreign investors in narrative 1, wholesale deposit run-offs can be another major source of capital outflows whereby firms move their deposits from on-shore to off-shore markets on fears of

deteriorating domestic financial and economic conditions and weakened currency due to persisting inflationary pressure, further U.S. monetary policy tightening, new waves of COVID-19 pandemic or the need to refinance operations abroad.

- Narrative 4: Share redemption shocks triggering investment funds' liquidity strains.** Such redemptions would in turn trickle down to funding pressure on development banks, commercial banks and other nonbank financial institutions due to loss of repo financing or refinancing options for other maturing short-term funding from investment funds. The impact, however, can be mitigated by the collateralized nature of the transactions, provided that funds' counterparties find other institutions able and willing to accept these collaterals and engage in similar transactions. Under this narrative, fund investors are allowed to deposit a portion of the cash - withdrawn from the investment funds – back to the commercial banks as a form of inflow of deposits.

Figure 9 presents the four narratives with a visualization of flow of liquidity between agents to delineate the transmission of shocks throughout the system.





The framework is also flexible to incorporate other country specific liquidity narratives and relevant sectors. Although the four narratives proposed for Mexico above are quite common and can be applied to other countries with similar characteristics and vulnerabilities, there are other risk factors and sectors that can be more country specific. For example, there are countries where pension funds play a systemic role in providing funding and lending to other sectors in the economy and thus can be added into the framework

provided that data on their own balance sheets and interconnections with other sectors can be obtained. They may also hold a significant amount of sovereign securities and use them as collateral for additional funding to lever up, or place them in a margin account for derivative transactions for hedging purpose, and thus are exposed to risks of margin calls. Some other countries may use covered bond more dominantly as their funding instrument in addition to repo transactions or unsecured wholesale markets, while others may rely on mortgage back securities (MBS) or collateralized debt obligations (CDOs) to transfer liquidity risks outside of their balance sheet or use them as central bank eligible securities for additional funding in times of stress. They can be added as new narratives to be stressed independently or together with the existing narratives to jointly determine the systemwide liquidity impact.

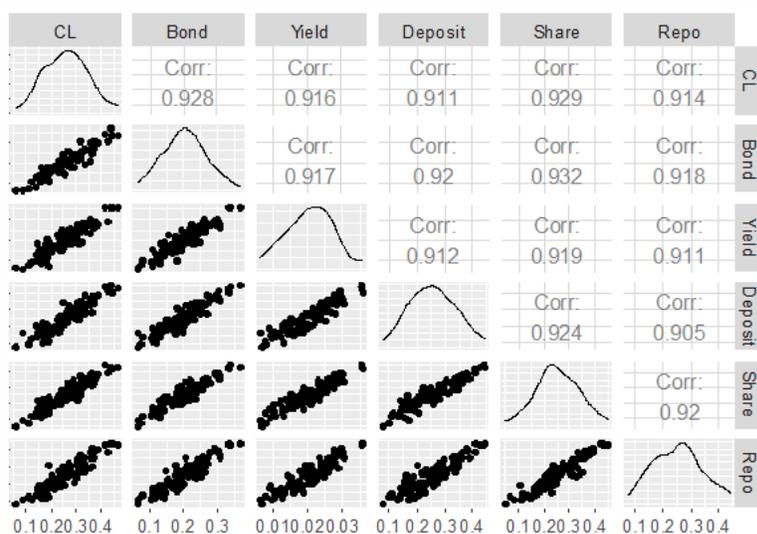
Shock Generation

Shocks were calibrated for variables which were identified as triggering points within each layer of the narratives. For instance, the deposit outflow rate was identified as an exogenous shock representing the source of liquidity stress under narrative 3. Similarly, sovereign bond yield shocks induced by tightening of global financial condition and foreign selloffs of securities, triggering of credit and liquidity lines and investment funds' share redemption were calibrated for narrative 1, 2, and 4, respectively. Adopting the concept of copula, a pre-defined beta distribution with a symmetric bell-curve shape (close to a normal distribution) and upper and lower bound were assigned to each shock as marginal distribution (see Appendix I) with a correlation factor of 0.9 to simulate high co-movement under stress (see Figure 10 bottom panel). Figure 10 top panel provides further details on shock selection and calibration under the analysis. These parameters are exogenous in our framework but can be estimated separately, identified based on historical evidence or via the relevant literature. In this case the peaks of the shocks were closely aligned with the traditional bank cash-flow analysis over a three-month horizon, with additional stress parameters calibrated based on historical volatility or expert judgement in case historical time series are not readily available or they are hard to pin down, such as for share redemption rate of investment funds and phase-out rate of short-term corporate funding (e.g., commercial banks short term funding from corporates that are not rolled over). Depending on the chosen stress testing horizon, the severity of the shocks may also differ, as certain liquidity shocks may unfold in a matter of days, such as a confidence shock induced bank runs, while others take longer to fully materialize, such as an exit from a medium or long-term contractual position.³ Nonetheless, the framework is less prone to scenario uncertainties than other types of liquidity stress test as it covers a range of shocks rather than a single point on the shock distribution.

Figure 10. Mexico: Shock Calibration of Systemwide liquidity Analysis

³ In the model we assume frictionless settlements of securities and money withdrawal from the banks. Since we consider a 3-month time horizon, it is less stringent for the framework to consider intra-day transactions as long as most transactions take place within the considered timeframe. Nonetheless, short-term frictions in settlement could amplify or dampen the initial liquidity shocks. This is not included in the analysis.

Layer	Variable	Range (In percent)
Narrative 1-4	Bond selling rate	[0,40] based on historical maximum selloff
Narrative 1-4	Sovereign bond yield shock	[0,4] with average shock at 200 bps
Narrative 1-4	Corporate bond yield shock	[0,8] with average shock at 400 bps
Narrative 2-4	Credit line triggering rate	[0,40]
Narrative 3-4	Corporate deposit run-off rate	[0,50]
Narrative 3-4	Household deposit run-off rate	[0,20]
Narrative 4	Share redemption	[0,40]
Narrative 4	Short term debt phase-out rate	[0,40]



Source: IMF staff.

Note: All units in the bottom figure are in fraction (not percent). CL = credit line triggering rate, Bond = bond selling rate, Yield = sovereign bond yield shock, Deposit = corporate deposits run-off rate, Share = share redemption rate, Repo = short-term funding (reverse repo, paper, bonds, etc.) phase-out rate.

Shocks to the market value of sovereign securities follow a modified duration approach. Shocks for sovereign and corporates were simulated via a series of parallel shifts of both yield curves along the maturity buckets, while assuming a higher upper bound shift for corporate securities given their inherently higher risk premium (Figure 10 and 11). Shocks to yields on bank bonds were assumed to be higher than sovereign and

$$\Delta P_i = \frac{D_i}{(1 + r_i + s_i)} * \Delta B_i * M_i$$

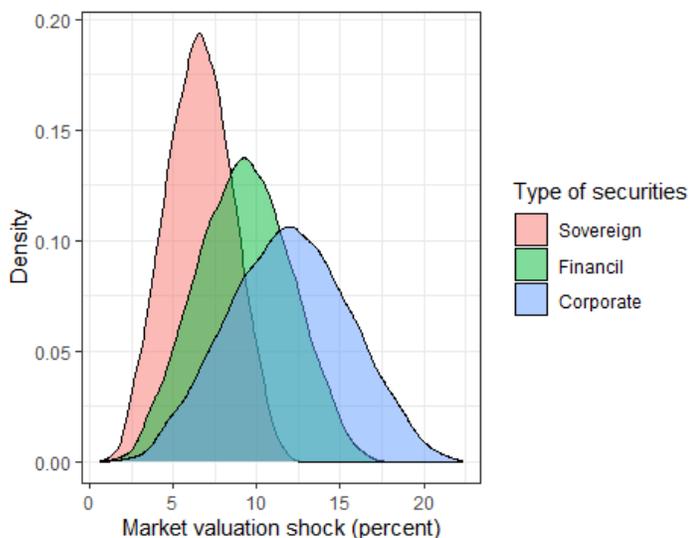
lower than corporate securities under each simulation (Figure 11). As next step, granular information on holdings of corporate and sovereign securities by agents, status of encumbrance, eligibility for central bank operations and by maturity buckets were used as inputs, in conjunction with the calibrated yield shocks, to derive market valuation impacts⁴ using the modified duration approach according to the following formula:

⁴ The market valuation impacts for sovereign bonds, corporate bonds and bank bonds correspond to variables hc_sov_b, hc_corp_b and hc_bnk_b under equations specified in appendix II.

where P represents bond valuation; D represents the duration of debt securities which is selected at the midpoint within each maturity bucket for a given type of instrument; B represents bond yield; M represents the outstanding amount; r represents the risk-free rate and s represents bond spreads assumed in the shock calibration.

Such market revaluations can impact the balance sheet of each agent via two main channels: a reduced market value of unencumbered collateral and margin calls on encumbered collateral underlying both secured funding and derivative margin positions. Both channels can reduce the liquidity buffers of a single agent and may increase the tail risks of a systemwide liquidity stress.

Figure 11. Mexico: Market Valuation Shock on Debt Securities



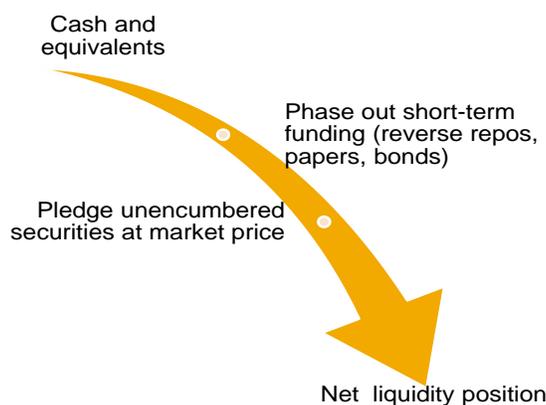
Source: Banxico and IMF staff estimate.

Monte Carlo Simulation to Generate Net Liquidity Position

The last step of the systemwide liquidity analysis involves feeding the generated shocks into the framework by allowing them to propagate through the entire system via the bilateral exposures between agents. Ten thousand Monte Carlo simulations were run using the shocks generated in Step 2 to generate the results in the form of distribution of net liquidity positions for each agent. The results reflect both the direct impact from funding and market stress, and any second-round revaluation effects, such as calls on encumbered collateral for existing funding or margin positions. Behavioral and policy analysis can also be applied on subset of the simulations, such as in cases where banks become reluctant to intermedate the market as their liquidity ratios approach the regulatory minimum, to update and compare distributions of net liquidity positions pre- and post- such behavioral simulations (please refer to section VII for further details).

Market Clearing Mechanism

The analysis follows a specific pecking order of market clearing that mimics the behavioral response of each agent under stress (Figure 12). A preference for highly liquid over less liquid assets is assumed for all agents. This means agents are expected to use cash and cash equivalents as the first line of defense to absorb a liquidity outflow, and only if this is not sufficient, phase out (or not rollover) any outstanding reverse repo transactions or short-term bond investments. In other words, the starting assumption is that the utilization of counterbalancing capacity is very accommodative, and agents start to withdraw liquidity from other agents after they exhaust their own buffers. Finally, depending on remaining liquidity gaps after utilizing cash positions, a repo transaction might be needed to pledge any unencumbered collateral for additional liquidity support. In this case, commercial banks and the central bank are assumed as the main counterparties for such repo transactions to backstop the entire system.

Figure 12. Mexico: Pecking Order of Market Clearing

Source: IMF staff.

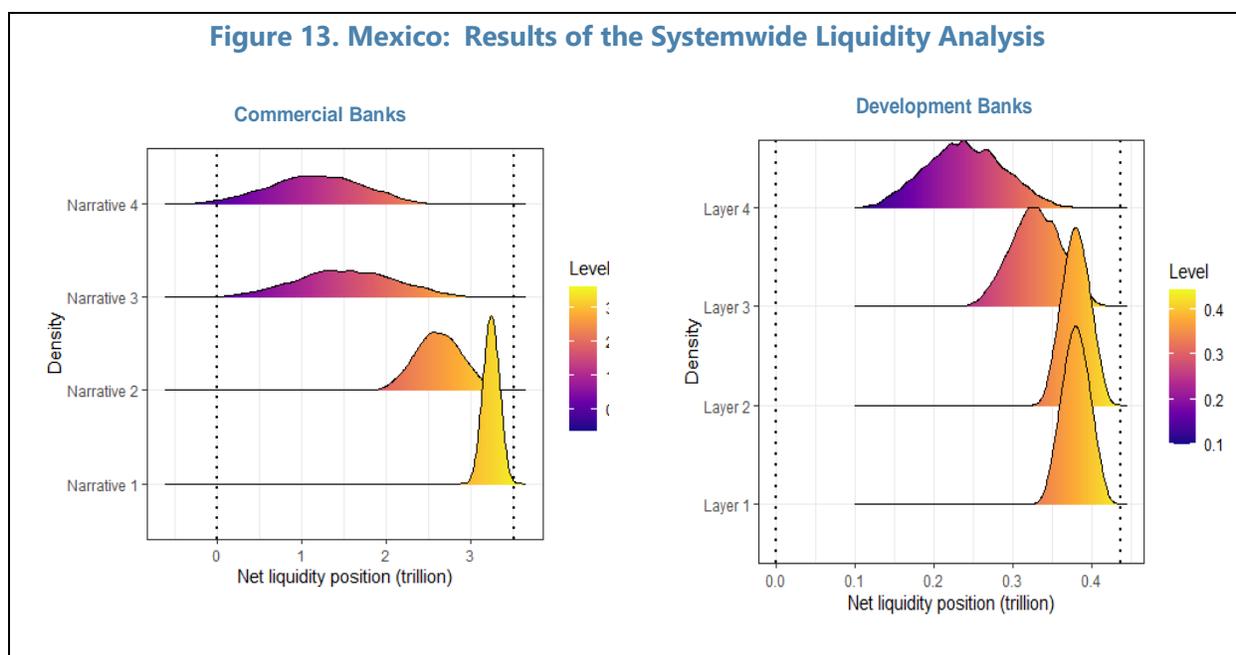
The sovereign securities that are sold off by foreign investors under the narrative 1 are assumed to be absorbed in a pro-rata fashion by all market agents. The amount of absorption by each agent is allocated based on their existing holdings of sovereign securities, as long as they still have sufficient liquidity to purchase these securities from the market after the initial liquidity shock on their balance sheet. As development banks and investment funds face more stringent funding condition, we assumed them to purchase these securities only if they still have cash on balance sheets after the shocks, while leaving the remaining to commercial banks as they can more flexibly trade with the central bank via repo arrangements. In other words, even if commercial banks do not have sufficient cash at hand, they can still purchase the remaining sovereign securities and then immediately pledge them to the central bank to get back the cash they need.

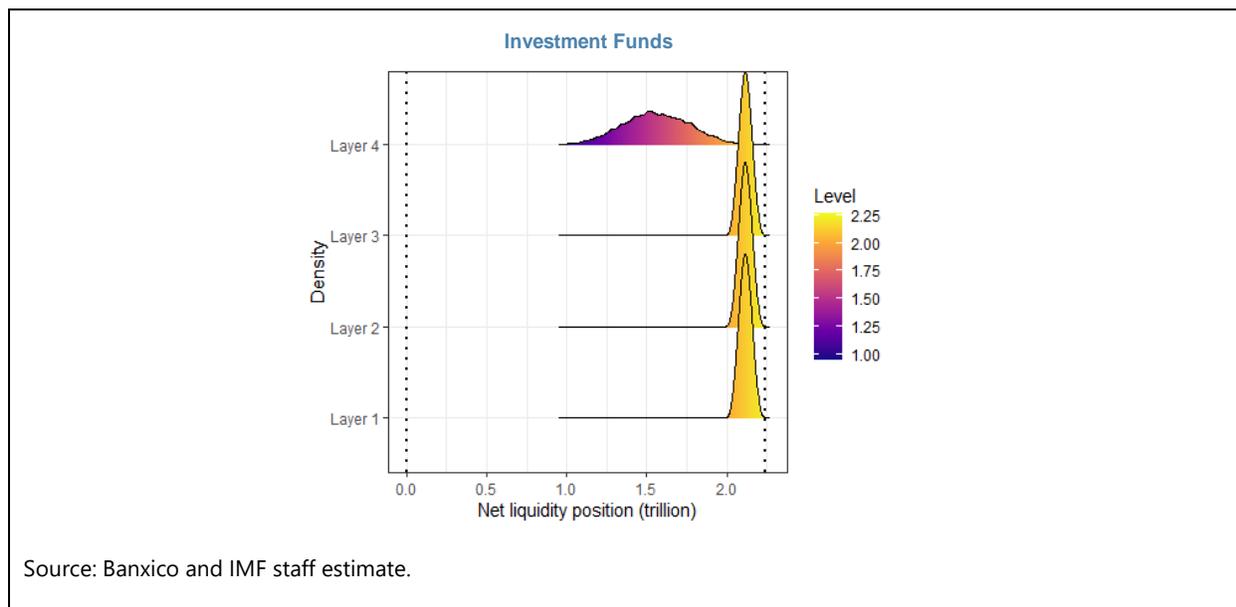
The phase-out of a reverse repo contract is assumed neutral from a liquidity perspective as it entails both an outflow and inflow of liquidity for a counterparty. When a reverse repo contract matures or is revoked by an agent, cash is withdrawn from the counterparty's balance sheet while the underlying collateral, mostly in the form of debt securities, is returned to the counterpart of the transaction. This automatically converts existing encumbered assets back to unencumbered assets, first by reversing the original haircut applied to the repo transaction and then applying the discounted market price specified by the shock, thus increasing the liquid buffer for the counterpart (although at a discounted market price). Due to limited information on the composition of the encumbrance of a repo contract, the released amount of the encumbered collateral upon the termination of a repo is allocated into unencumbered collateral in a pro-rata fashion, based on the relative share of the starting point encumbered corporate and sovereign securities for each agent.

D. Results

For Mexico, the analysis suggests that the financial system remains resilient against the four narratives with commercial banks backstopping liquidity needs of all agents in the system (Figure 13). Under the most severe scenario with combined narratives liquidity shocks and assuming no binding regulatory constraints, commercial banks show only marginal liquidity shortfalls (a thin negative tail in their liquidity distribution) mainly driven by the triggering of contingent credit lines and wholesale deposits' outflows, while acting as a shock absorber by providing liquidity to other agents through repo transactions.

Development banks and investment funds can withstand significant liquidity outflows, although risks could arise depending on agents' risk-off behavior under stress. With binding liquidity constraints for commercial banks (e.g., a mandatory LCR or other behavioral assumptions on minimum liquidity buffers that banks might prefer to hold) or minimum liquidity buffers for investment funds, liquidity positions of agents could deteriorate, and larger liquidity shortfalls could materialize, including for development banks (see section VIII for further details) .





A deeper dive into the contribution to the changes in the net liquidity position of commercial banks reveals larger transmission of shocks from corporates and investment funds (Figure 15, first figure). Corresponding to the minimum cut-off point on the distribution of commercial banks' net liquidity position post-shock under narrative 4, liquidity outflows from corporates contributes the most to the decline of net liquidity position of commercial banks, given their high exposure to wholesale deposits and contingent credit and liquidity lines. This is only marginally offset by a small reduction of margin calls and an increase in unencumbered assets due to the phase-out of the short-term repo financing provided by corporates to commercial banks.

Investment funds, although ranked second in terms of contribution to liquidity outflows, bring roughly an equal amount of inflows to commercial banks. Most of investment funds' transactions with commercial banks take place in either repo transactions (e.g., investment funds provide material repo financing to the rest of the system) or a direct sale of debt securities (e.g., fire-sales) which are in general liquidity neutral, as every transaction involves an exchange of cash liquidity with an underlying collateral such as debt securities. As such, transactions between the two would be mainly an exchange of liquidity, as both cash and debt securities are considered as liquid assets, instead of withdrawing liquidity from the commercial banks.

Development banks place into or obtain from little deposits and credit lines from commercial banks and therefore do not play a significant role in draining liquidity out from the system via capital flight. However, they appear to have the most illiquid asset profile as 46 percent of their assets are lending to the private sector and the rest are holdings of sovereign securities with a high share already encumbered for short term funding.

The Government, although not directly interacting with other agents in the framework, could indirectly influence the dynamics of systemwide liquidity via price impacts and transaction of sovereign securities. Decline in the value of sovereign securities would reduce liquid asset holdings of commercial banks (akin to a liquidity outflow), while the purchase of sovereign securities by commercial banks is considered

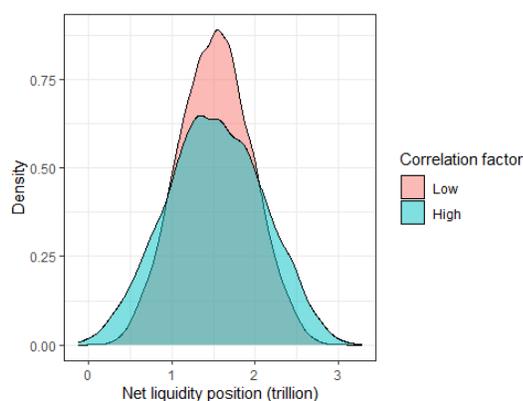
liquidity neutral as such transaction only entails an exchange of cash with another form of liquid assets. Hence the net impact from both channels on the liquidity of commercial banks is negative.

Development banks are vulnerable to outflows from corporates and investment funds (Figure 15, second figure). Breaking down the total liquidity outflows from development banks reveals that corporates and investment funds are major contributors to liquidity outflows, at 45 and 40 percent, respectively. This can be explained by the high share of short-term financing, such as repo and short-term bond investment, extended by both the corporate sector and investment funds to development banks, at 35 and 27 percent out of total short-term financing as of end-2021.

An alternative presentation of the ten thousand simulations reveals persistent high contribution of commercial banks and investment funds to the changes of the system wide liquidity (Figure 15, bottom figure). Unlike the above contribution analysis which only reflect a single point on the agent specific distributions, a representation of relative contribution of each agent to the systemwide liquidity, measured by the changes of each agent's net liquidity position before and after the shock along the entire distribution of simulations, suggests that commercial banks and investment funds contribute the most to liquidity dynamics in the financial system. This can be explained by both their larger balance sheet size as well as higher exposure to market liquidity outflows in nominal terms, such as deposits' withdrawals, drawing on credit and liquidity lines and investment funds' share redemptions.

Finally, a higher correlation of liquidity shocks intensifies the downside risks for systemwide liquidity. An ex-post comparison between different levels of correlation factors gives a flatter distribution of net liquidity position for commercial banks under a high correlation factor of 0.9 than a low correlation factor of 0.2, supporting the hypothesis that a stronger co-movement of liquidity outflows can amplify liquidity stress in the system, evidenced by a fatter tail to the left of the distribution pointing to worsening liquidity condition post shock (Figure 14).

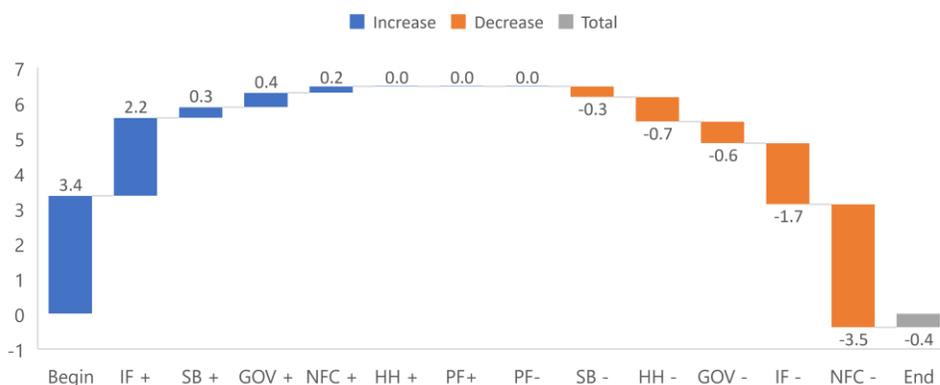
Figure 14. Mexico: A Comparison of Correlation Factor



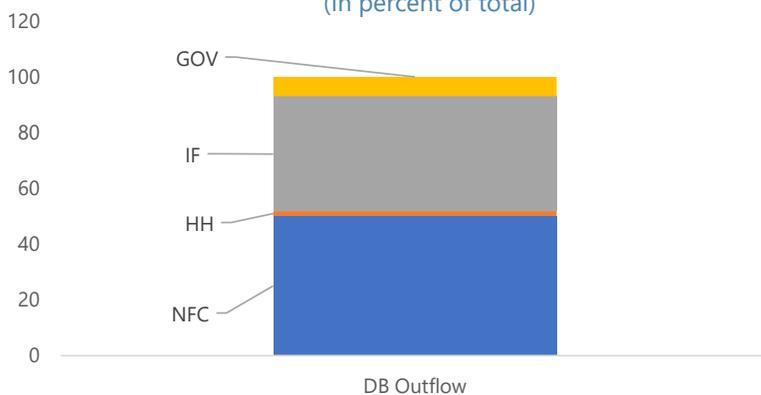
Source: Banxico and IMF staff estimate.

Figure 15. Mexico: Contribution to Systemwide Liquidity Stress (change 3rd figure to “minus post shock net liquidity position”)

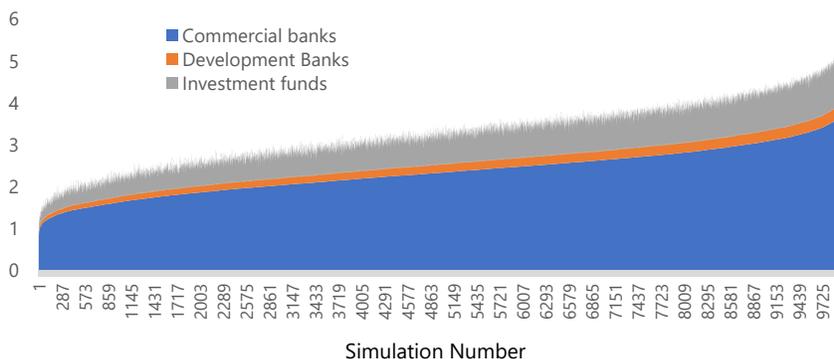
Contribution to Changes in Bank Net Liquidity Position
(In Trillion)



Contribution to Development Bank Total Outflow
(In percent of total)



Contribution to Changes in the System Wide Liquidity
(In trillions, pre-shock minus post-shock net liquidity position)



Source: Banxico and IMF staff estimate.

Note: Top two figures show contributions of liquidity inflows/outflows at the minimum cutoff point on the distribution of the agent's net liquidity position. The third figure reveals contributions of each agent to the change of systemwide liquidity across the entire distribution/simulations.

VI. Policy Experiments

A policy experiment confirms that greater access of investment funds to the repo market could enhance their liquidity position (Figure 16 bottom panel). When assuming higher discount rates⁵ for investment funds which in Mexico only have limited access to the repo market, the distribution of their net liquidity position shift to the left. Conversely, this confirms that a complete lift of such restriction could bolster liquidity position of the investment funds, thus positively contributing to the resiliency of the entire system.

Were commercial banks liquidity preference to change in a downside scenario, development banks could face stress. This could also arise from the implementation of liquidity binding constraints on commercial banks.⁶ Under binding liquidity constraints for commercial banks, development banks would be compelled to resort to the central bank for liquidity support, which merits closer monitoring under stress. A sensitivity analysis was conducted by freezing repo activities of commercial banks as soon as they reach a pre-defined LCR limit⁷ (Figure 16 left panel). This can create knock-on effects to development banks given that a subset of the simulations requires development banks to pledge additional collateral to commercial banks for liquidity via a repo transaction. As a result, a part of the distribution of the development banks is pushed to the left into the negative territory, suggesting liquidity strains induced by the behavioral response of the commercial banks. As an alternative, development banks may reach out to the central bank for direct liquidity support as they are allowed to both participate in the repo market and transact directly with the central banks.

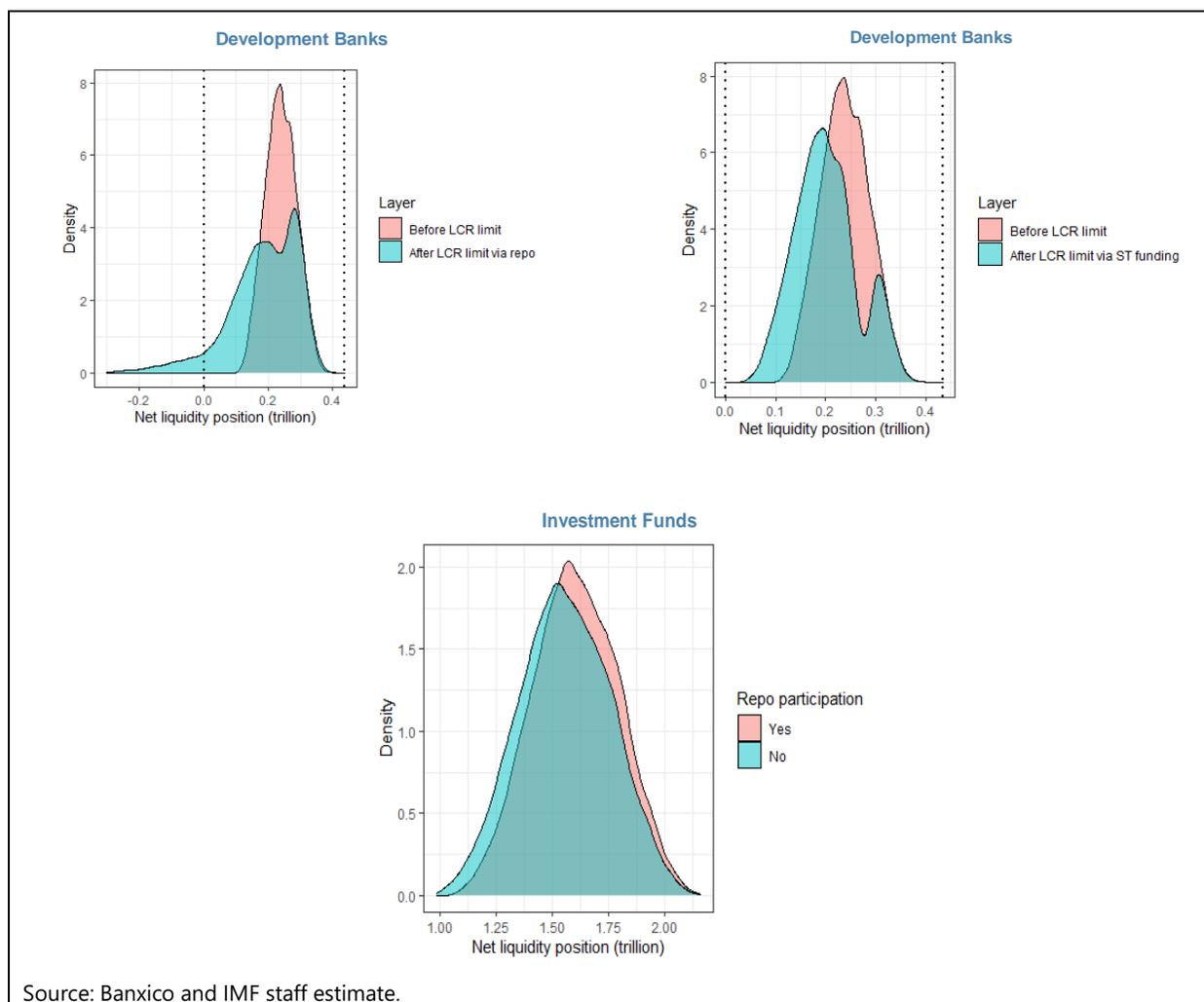
A similar pattern can be observed if commercial banks are assumed to pull back on short-term funding instead of freezing repo activities under the regulatory constrain (Figure 16 right panel). This can take the form of deposit withdrawal or lack of willingness to offer refinancing for the rollover of short-term debt issued by development banks. This behavioral response also pushes the distribution of the net liquidity position of the development banks to the left, even though it is not as severe as in the first experiment as development banks have very limited short-term funding from commercial banks comparing to repo funding. This assumption is deemed to be closer to the likely response of commercial banks under stress, as pulling back short-term funding increases liquidity buffers of commercial banks while the reversal of repo funding made to development banks is considered liquidity neutral.

Figure 16. Mexico: Policy Experiment of the Systemwide Liquidity Analysis

⁵ This is implemented by imposing on the initial market revaluation shock a multiplier of 1.5 for their holdings of sovereign securities, 1.75 for bank securities and 2 for corporate securities. To address risks of over-simplicity, section IX developed a fully-fledged fire-sale scenario simulating additional system-wide liquidity impact due to asset sales of investment funds.

⁶ Findings from such experiments can also be viewed conversely: relaxing the LCR requirement at time of liquidity stress in the system could better promote banks' role as backstop with respect to other agents under stress.

⁷ Given limited mapping between the LCR categories and the balance sheet information obtained for this analysis, we assumed that commercial banks would breach the LCR limit if its liquid assets declines by 50 percent.



VII. Shock Amplification Analysis using Artificial Data

The outcome of the analysis can be underestimated in the absence of ensuing market amplification.

This can be driven by the fire sales by weak agents under severe funding and market illiquidity which can trigger broad-based mark-to-market asset devaluation permeating the entire system. As such, it would be important to conduct further analysis allowing for such additional market amplification mechanisms which can adversely skew the distributions of agents' net liquidity position to the left and enlarge liquidity shortfalls due to the reduction of available liquid assets when subject to higher market discount.

Fire-sales was enabled as an additional behavioral response under the market clearing mechanism (Figure 17). The analysis, which uses artificial data rather than Mexican specific data⁸, treats fire-sales as last line of defense when an agent does not have enough cash to withstand funding outflows nor being able to access secondary markets without incurring heavy discount, such as investment fund. This results in additional market haircuts for sovereign and corporate securities holdings of all market agents, hence further shrinking their balance sheets and liquid assets.⁹ This analysis formulates non-linear relationship between sold volumes of securities and change in their prices in a reduced form based on (Kyle, 1985) and Fukker, Kaijser, Mingarelli, and Sydow (2021):

$$\Psi_{\phi}(S_{\phi}) = B_{\phi}(1 - e^{-S_{\phi}\lambda_{\phi}/B_{\phi}})$$

Where S denotes the total amount sold of a security, λ is known as Kyle's lambda, which represents the price impact parameter, and B is an impact boundary parameter to prevent price to decline below 100 percent, which can be simply set as the most negative return observed in the history of a security. The quantification of additional price reduction following the asset sales was achieved via an iterative process in line with the equation above to reach to equilibrium price post-shock, which was made feasible by binding constraint on the securities that are available for sale and diminishing marginal effect on price due to the non-linear price-volume relationship. The final liquidity positions for each agent were then re-calculated and updated by incorporating the new market price into the valuation of their securities holdings.

Figure 17. Mexico: Pecking Order of Market Clearing with Fire Sale



⁸ The use of artificial data is due to confidentiality reason. It was generated by adding a random component on top of the initial balance sheet data while ensuring that the accounting identity still holds.

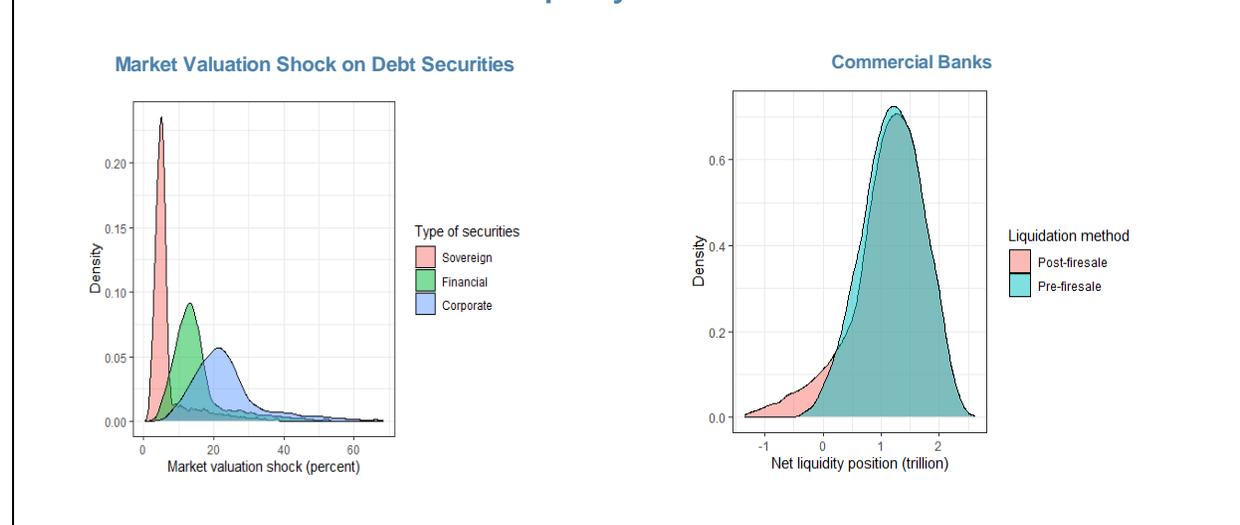
⁹ The key differences between pre-firesale and post-firesale is the additional market price shock on bond portfolios holdings across agents, which further reduce their liquidity buffers and thus net liquidity positions post fire-sales. This is also referred to as an externality to the system as a result of the firesale. The threshold for triggering the fire-sales is at the point when the NBF1 sector (e.g. investment funds.) has exhausted all its cash and equivalents (cash, reverse repo), and is then forced to sell other liquid assets (e.g. sovereign securities) instead of pledging them for cash, assuming that the NBF1 sector does not have direct access to repo markets or central bank facilities.

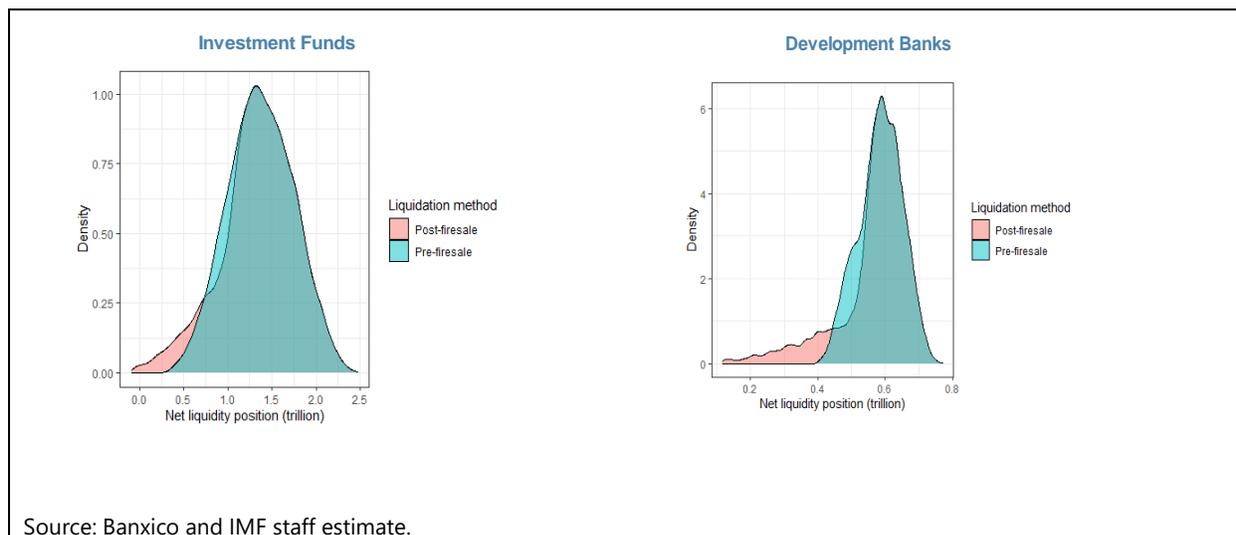
Source: IMF staff.

The result under this additional behavioral layer reveals further deterioration of liquidity position across agents in the system. A direct comparison of distributions of net liquidity positions pre and post fire-sales (Figure 18) reveals higher market discount across all types of tradable securities as well as higher tail liquidity risks, with post fire-sale distribution having longer and fatter left tail across all market agents, consistent with historical evidence. This suggests heightened liquidity condition when accompanied with market illiquidity and rigidity.

The analysis, though not intending to provide precise loss estimate linked to fire-sales, can be used to inform ongoing policy decisions. Although a structural model might be preferable to capture all impact channels associated with the fire-sales but is costly in design, this analysis proposes a solution to link fire-sales with agent's balance sheets, interconnection with other agents and a fully-fledged market clearing mechanism in a coherent and tractable manner, while also allowing balance sheets and risk parameters to dynamically evolve until reaching a solvable steady-state. The qualitative findings of the analysis thus can be used to inform ongoing policy decisions, such as on supportive measures to prevent rapid sell-off in the first place, or to deploy effective policy tools to counteract any price impacts in a swift manner.

Figure 18. Impact of Fire-sales on Market Price of Security Holdings and Agents' Net liquidity Position





VIII. Conclusion

Against the backdrop of growing needs to assess liquidity risks facing the financial market, we developed a novel Systemwide Liquidity (SWL) framework using Mexico as a case study to identify potential liquidity stress in the system beyond commercial banks. The framework, which complements standard liquidity and interconnectedness analyses, leverages copula – a correlated distribution concept - to impose joint liquidity shocks to the system and to trace the flow of liquidity among various agents. Such framework aims at strengthening financial stability by promoting the understanding of the transmission channels and amplification mechanisms of correlated liquidity shocks.

Results from applying the framework to Mexico confirm the commercial banks' role in ensuring the liquidity of the financial system, while signal vulnerabilities in development banks when facing market behavioral constraints under stress. Commercial banks act as a final shock absorber by providing liquidity to other agents through repo transactions. Their liquidity shortfalls are only marginal even under the most severe narratives. Development banks, on the other hand, appear more vulnerable due to their funding concentration. This vulnerability becomes more pronounced when binding liquidity constraints (e.g., mandatory LCRs) are considered.

This framework can be used to inform liquidity relevant policy decisions. For example, commercial banks that are facing regulatory binding constraint or heightened uncertainties might be less willing or able to roll-over existing funding transactions even with liquidity surplus, and, therefore, they would amplify funding stress on development banks. On the flip side, expanding access of investment funds to the repo market could further strengthen systemwide resiliency. Finally, in the absence of adequate policy supports, fire-sale as the last line of defense could represent a significant negative externality to systemwide liquidity via higher market discount and shrinkage of liquid assets and margin positions.

Finally, it is important to note that the framework is still work-in-progress. Future work is still needed to address some limitations of the framework. For instance, the framework currently does not investigate separately the liquidity risks associated with currency denominations, albeit in reality such distinction can be relevant, especially for emerging and low-income economies which have limited international reserves to fend off various types of BOP shocks. In addition, although the framework considers margin calls associated with market valuation shocks on underlying collaterals, it does not quantify the additional margin required due to large fluctuations in the underlying assets, such as stock prices or the benchmark interest rates, and this may underestimate the actual liquidity stress¹⁰. Finally, the dependency structure of the correlated liquidity shocks can be better estimated through either parametric or nonparametric methods based on sufficiently long historical data, rather than applying expert judgement in the calibration of such correlations.

Appendix I – The Use of Copula in Financial Risk Analysis

Copula is a powerful and elegant way to model correlation patterns between random variables. It relies on joint distributions and pairwise correlations to incorporate dependence among the variables. This feature can be useful especially when tail risks stemming from simultaneous materialization of multiple shocks are of critical importance (e.g., episodes of systemic risk) as it offers an integrated perspective by merging the interdependencies and probabilities. For these cases, copula is superior to traditional correlation analysis which is often narrowly defined as a measure of linear dependency and as such prone to underestimating the “true” co-movement of variables, leading to incorrect risk measures¹¹.

Since copula is a multivariate cumulative distribution function within which the marginal probability distribution of each variable is uniform on the interval $[0, 1]$. It can be constructed by first specifying the marginal distributions, and then by providing a dependence structure between the marginal distributions. In this analysis, we allow for high-dimensional marginal distributions, each corresponding to a specific shock parameter, to assess the impact on systemwide liquidity of their joint materialization. The generation of such distributions involves a two-step approach:

1. Generate pairs of values (Z_1, Z_2) from a bivariate normal distribution with a pre-defined statistical dependence (or Rank Correlation Coefficients) between these two variables, and each has a normal marginal distribution. See first equation below.

¹⁰ Our model currently considers a drop in the collateral value under a margin account but not risks associated with the underlying assets a derivative contract is written on. For instance, a fall in stock price on a long position on a stock future contract could also trigger a margin call which could coincide with the drop in collateral value and amplify the liquidity shock.

¹¹ Another example of modeling correlated shocks in IMF stress testing is the two-step estimation of joint expected losses within the Systemic Contingent Claims Analysis (Jobst and Gray 2013) framework. This approach leverages extreme value distribution and is fundamentally driven by modeling nonparametric extreme dependence to quantify possible linkages between expected losses in support of a more comprehensive assessment of common vulnerabilities than would be allowed by balance-sheet-based approaches.

2. Apply a transformation (G_1, G_2) separately to each variable to change the marginal distribution to any types of distribution of interest, by applying the inverse of the Cumulative Distribution Function (CDF) of any distribution to the uniform distribution (U)¹². See second and third equations below.

$$Z = [Z_1, Z_2] \sim N\left([0, 0], \begin{bmatrix} 1 & \rho \\ \rho & 1 \end{bmatrix}\right)$$

$$U = [\Phi(Z_1), \Phi(Z_2)]$$

$$X = [G_1(U_1), G_2(U_2)]$$

where Φ denotes normal cumulative distribution function. Z , Z_1 and Z_2 have standard normal distributions, U has uniform distributions, G_1 and G_2 are inverse CDFs of two possibly different distributions and X has the final and transformed marginal distributions.

In this analysis, we selected beta distributions as the final marginal distribution X of a Gaussian Copula¹³, since unlike a normal distribution, the beta distribution can allow us to set up the boundary of the distribution and hence the severity of the shocks.

The dependence structure under copula can be estimated parametrically, semi-parametrically or non-parametrically. The parametric method assumes parametric models for both the copula and the marginals and then performs maximum likelihood estimation (Oakes 1982). Semiparametric estimation specifies a parametric copula while leaving the marginals nonparametric and was proposed by Genest et al. (1995) and Chen and Fan (2006). The non-parametric method treats both the copula and the marginals parameter-free and thus offers the most generality. Kernel density estimation technique – one example of the non-parametric method – have been proposed by Gijbels and Mielnicuk (1990), Fermanian (2005), Fermanian and Scaillet (2003) and Chen and Huang (2007) and also frequently used as reference to help formulating the underlying parametric copula model.

The application of copula in financial risk analysis is widespread. Early study conducted by Clemen and Reilly (1999) used copula to construct joint distributions with pairwise correlations to incorporate dependence among variables while allowing expert's subjective judgments of marginal distributions and correlations. Hochrainer-Stigler et al. (2018) discussed the advantages and limitations of copulas for risk analyses from the perspectives of modeling, measurement, and management. They found that the use of copula enables more realistic systemic risk assessments and is useful when extreme events affect a system, a symptom of systemic stress. Zhang and Jiang (2019) carried out a time varying copula model to estimate and simulate correlation between the distributions of stock return index of financial industry and fintech industry and showed that not only there are both upper and lower tail correlations between the two indexes, but such correlations at the tails are higher than those at the other positions on the joint distribution. This helped the identification of the nonlinear properties of shock parameters typically observed under stress.

¹² Applying the normal cumulative distribution function (cdf), denoted here by Φ , to a standard normal random variable can result in a random variable that is uniform on the interval $[0, 1]$.

¹³ User can also choose Student's T or other type of copulas to allow increased probability of joint extreme event. In this case, since the ranges (or severity) of the shocks are already pre-defined (see figure 10), the selection of copula is less critical.

Appendix II – Equations of the Model

This section presents formulas embedded in the framework to compute post-shock outflows, inflows, changes in liquidity buffers as well as pecking order of market clearing for each agent considered in the analysis.¹⁴ Specifically, the formulas can be categorized into four main blocks: 1) market revaluation of all tradable securities subject to yield shock, 2) investment fund block, 3) development bank block and 4) commercial bank block.

Market absorption of tradable securities sold by foreign investors subject to yield shock

$$s_{\text{sov_b}_{\text{bnk},i}} = s_{\text{sov_b}} \cdot (1 - hc_{\text{sov_b}_i}) \cdot \frac{\text{sov_b}_{\text{bnk}}}{(\text{sov_b}_{\text{bnk}} + \text{sov_b}_{\text{db}} + \text{sov_b}_{\text{ivf}})}$$

$$s_{\text{sov_b}_{\text{db},i}} = s_{\text{sov_b}} \cdot (1 - hc_{\text{sov_b}_i}) \cdot \frac{\text{sov_b}_{\text{db}}}{(\text{sov_b}_{\text{bnk}} + \text{sov_b}_{\text{db}} + \text{sov_b}_{\text{ivf}})}$$

$$s_{\text{sov_b}_{\text{ivf},i}} = s_{\text{sov_b}} \cdot (1 - hc_{\text{sov_b}_i}) \cdot \frac{\text{sov_b}_{\text{ivf}}}{(\text{sov_b}_{\text{bnk}} + \text{sov_b}_{\text{db}} + \text{sov_b}_{\text{ivf}})}$$

1. Investment fund block

Outflow:

$$O_{\text{ivf},i} = m_{\text{sov_b}_{\text{ivf}}} \cdot hc_{\text{sov_b}_i} + m_{\text{corp_b}_{\text{ivf}}} \cdot hc_{\text{corp_b}_i} + (s_{\text{hh}} + s_{\text{corp}}) \cdot r_i$$

Liquid assets:

$$LA_{\text{ivf},i} = \text{cash}_{\text{ivf}} + \text{cash_eq}_{\text{ivf}} + \text{bnk_rev_repo}_{\text{ivf}} + \text{db_rev_repo}_{\text{ivf}} + \text{other_rev_repo}_{\text{ivf}} + \text{db_b}_{\text{ivf}} + \text{bnk_b}_{\text{ivf}} \cdot (1 - hc_{\text{bnk_b}_i}) + \text{corp_b}_{\text{ivf}} \cdot (1 - hc_{\text{corp_b}_i}) + \text{sov_b}_{\text{ivf}} \cdot (1 - hc_{\text{sov_b}_i})$$

Net liquidity position:

$$B_{\text{ivf},i} = LA_{\text{ivf},i} - O_{\text{ivf},i}$$

Pecking order of market clearing:

if $B_{\text{ivf},i} < 0$

$$a_{\text{s_sov_b}_{\text{ivf},i}} = 0$$

$$\text{ivf_db_repo}_i = \text{db_rev_repo}_{\text{ivf}}$$

$$\text{ivf_db_nonrepo}_i = \text{db_b}_{\text{ivf}}$$

$$\text{ivf_bnk_repo}_i = \text{bnk_rev_repo}_{\text{ivf}}$$

$$\text{ivf_bnk_nonrepo}_i = LA_{\text{ivf},i} - (\text{cash}_{\text{ivf}} + \text{cash_eq}_{\text{ivf}} + \text{bnk_rev_repo}_{\text{ivf}} + \text{db_rev_repo}_{\text{ivf}} + \text{db_b}_{\text{ivf}})$$

if $B_{\text{ivf},i} > 0$ & $\text{cash}_{\text{ivf}} + \text{cash_eq}_{\text{ivf}} > O_{\text{ivf},i}$

$$a_{\text{s_sov_b}_{\text{ivf},i}} = \min(\text{cash}_{\text{ivf}} + \text{cash_eq}_{\text{ivf}} - O_{\text{ivf},i}, s_{\text{sov_b}_{\text{ivf},i}})$$

$$\text{ivf_db_repo}_i = 0$$

$$\text{ivf_db_nonrepo}_i = 0$$

¹⁴ This set of equations defines a general framework to help readers understand how liquidity buffers, inflows and outflows—hence the net liquidity position of an agent—are calculated and impacted by a series of liquidity shocks. This general framework does not necessarily match a single narrative but offers a way to compute the ending liquidity position of each agent after various types of liquidity shocks, introduced as different variables in the equation (deposit outflows, triggering of credit lines, margin calls, etc.) under the different narratives discussed in the text. The definition of variables in the appendix helps identify the types of liquidity shocks included in the framework.

$$\begin{aligned} \text{ivf_bnk_repo}_i &= 0 \\ \text{ivf_bnk_nonrepo}_i &= 0 \end{aligned}$$

$$\begin{aligned} \text{if } B_{\text{ivf},i} > 0 \text{ \& } \text{cash}_{\text{ivf}} + \text{cash_eq}_{\text{ivf}} < O_{\text{ivf},i} \text{ \& } \text{cash}_{\text{ivf}} + \text{cash_eq}_{\text{ivf}} + \text{db_rev_repo}_{\text{ivf}} > O_{\text{ivf},i} \\ \text{a_s_sov_b}_{\text{ivf},i} &= 0 \\ \text{ivf_db_repo}_i &= O_{\text{ivf},i} - (\text{cash}_{\text{ivf}} + \text{cash_eq}_{\text{ivf}}) \\ \text{ivf_db_nonrepo}_i &= 0 \\ \text{ivf_bnk_repo}_i &= 0 \\ \text{ivf_bnk_nonrepo}_i &= 0 \end{aligned}$$

$$\begin{aligned} \text{if } B_{\text{ivf},i} > 0 \text{ \& } \text{cash}_{\text{ivf}} + \text{cash_eq}_{\text{ivf}} + \text{db_rev_repo}_{\text{ivf}} < O_{\text{ivf},i} \text{ \& } \text{cash}_{\text{ivf}} + \text{cash_eq}_{\text{ivf}} + \text{db_rev_repo}_{\text{ivf}} + \\ \text{bnk_rev_repo}_{\text{ivf}} > O_{\text{ivf},i} \\ \text{a_s_sov_b}_{\text{ivf},i} &= 0 \\ \text{ivf_db_repo}_i &= \text{db_rev_repo}_{\text{ivf}} \\ \text{ivf_db_nonrepo}_i &= 0 \\ \text{ivf_bnk_repo}_i &= O_{\text{ivf},i} - (\text{cash}_{\text{ivf}} + \text{cash_eq}_{\text{ivf}} + \text{db_rev_repo}_{\text{ivf}}) \\ \text{ivf_bnk_nonrepo}_i &= 0 \end{aligned}$$

$$\begin{aligned} \text{if } B_{\text{ivf},i} > 0 \text{ \& } \text{cash}_{\text{ivf}} + \text{cash_eq}_{\text{ivf}} + \text{db_rev_repo}_{\text{ivf}} + \text{bnk_rev_repo}_{\text{ivf}} < O_{\text{ivf},i} \text{ \& } \text{cash}_{\text{ivf}} + \text{cash_eq}_{\text{ivf}} + \\ \text{db_rev_repo}_{\text{ivf}} + \text{bnk_rev_repo}_{\text{ivf}} + \text{db_b}_{\text{ivf}} > O_{\text{ivf},i} \\ \text{a_s_sov_b}_{\text{ivf},i} &= 0 \\ \text{ivf_db_repo}_i &= \text{db_rev_repo}_{\text{ivf}} \\ \text{ivf_db_nonrepo}_i &= O_{\text{ivf},i} - (\text{cash}_{\text{ivf}} + \text{cash_eq}_{\text{ivf}} + \text{db_rev_repo}_{\text{ivf}} + \text{bnk_rev_repo}_{\text{ivf}}) \\ \text{ivf_bnk_repo}_i &= \text{bnk_rev_repo}_{\text{ivf}} \\ \text{ivf_db_nonrepo}_i &= 0 \end{aligned}$$

$$\begin{aligned} \text{if } B_{\text{ivf},i} > 0 \text{ \& } \text{cash}_{\text{ivf}} + \text{cash_eq}_{\text{ivf}} + \text{db_rev_repo}_{\text{ivf}} + \text{bnk_rev_repo}_{\text{ivf}} + \text{db_b}_{\text{ivf}} < O_{\text{ivf},i} \\ \text{a_s_sov_b}_{\text{ivf},i} &= 0 \\ \text{ivf_db_repo}_i &= \text{db_rev_repo}_{\text{ivf}} \\ \text{ivf_db_nonrepo}_i &= \text{db_b}_{\text{ivf}} \\ \text{ivf_bnk_repo}_i &= \text{bnk_rev_repo}_{\text{ivf}} \\ \text{ivf_bnk_nonrepo}_i &= O_{\text{ivf},i} - (\text{cash}_{\text{ivf}} + \text{cash_eq}_{\text{ivf}} + \text{bnk_rev_repo}_{\text{ivf}} + \text{db_rev_repo}_{\text{ivf}} + \text{db_b}_{\text{ivf}}) \end{aligned}$$

2. Development bank block

Short-term repo funding phase-out by investment fund and corporates:

$$\begin{aligned} \text{ivf_db_repo_sov}_i &= \text{ivf_db_repo}_i \cdot \frac{(\text{sov_b}_{\text{db}} \cdot \text{e_sov_b}_{\text{db}})}{(\text{sov_b}_{\text{db}} \cdot \text{e_sov_b}_{\text{db}} + \text{corp_b}_{\text{db}} \cdot \text{e_corp_b}_{\text{db}})} \cdot \frac{1}{(1 - \text{hh_sov_b}_i)} \\ \text{ivf_db_repo_corp}_i &= \text{ivf_db_repo}_i \cdot \frac{(\text{corp_b}_{\text{db}} \cdot \text{e_corp_b}_{\text{db}})}{(\text{sov_b}_{\text{db}} \cdot \text{e_sov_b}_{\text{db}} + \text{corp_b}_{\text{db}} \cdot \text{e_corp_b}_{\text{db}})} \cdot \frac{1}{(1 - \text{hh_corp_b}_i)} \\ \text{corp_db_repo_sov}_i &= \text{db_repo}_{\text{corp}} \cdot \text{repo_ror_corp}_i \cdot \frac{(\text{sov_b}_{\text{db}} \cdot \text{e_sov_b}_{\text{db}})}{(\text{sov_b}_{\text{db}} \cdot \text{e_sov_b}_{\text{db}} + \text{corp_b}_{\text{db}} \cdot \text{e_corp_b}_{\text{db}})} \\ &\quad \cdot \frac{1}{(1 - \text{hh_sov_b}_i)} \end{aligned}$$

$$\begin{aligned} \text{corp_db_repo_corp}_i &= \text{db_repo}_{\text{corp}} \cdot \text{repo_ror_corp}_i \cdot \frac{(\text{corp_b}_{\text{db}} \cdot \text{e_corp_b}_{\text{db}})}{(\text{sov_b}_{\text{db}} \cdot \text{e_sov_b}_{\text{db}} + \text{corp_b}_{\text{db}} \cdot \text{e_corp_b}_{\text{db}})} \\ &\cdot \frac{1}{(1 - \text{hh_corp_b}_i)} \end{aligned}$$

Outflow:

$$\begin{aligned} O_{\text{db},i} = & \max(0, \text{sov_b}_{\text{db}} \cdot \text{e_sov_b}_{\text{db}} - \text{ivf_db_repo_sov}_i - \text{corp_db_repo_sov}_i) \cdot \text{hc_sov_b}_i + \max(0, \text{corp_b}_{\text{db}} \cdot \\ & \text{e_corp_b}_{\text{db}} - \text{ivf_db_repo_corp}_i - \text{corp_db_repo_corp}_i) \cdot \text{hc_corp_b}_i + \text{ivf_db_repo}_i + \text{ivf_db_nonrepo}_i + \\ & \text{db_dep}_{\text{corp}} \cdot \text{dep_ror_corp}_i + \text{db_dep}_{\text{hh}} \cdot \text{dep_ror_hh}_i + \text{db_repo}_{\text{corp}} \cdot \text{repo_ror_corp}_i + \text{db_b}_{\text{corp}} \cdot \text{b_ror_corp}_i \end{aligned}$$

Liquid assets:

$$\begin{aligned} LA_{\text{db},i} = & \text{cash}_{\text{db}} + \text{cash_eq}_{\text{db}} + \text{bnk_rev_repo}_{\text{db}} + \text{other_rev_repo}_{\text{db}} + \text{bnk_b}_{\text{db}} \cdot (1 - \text{hc_bnk_b}_i) + \text{corp_b}_{\text{db}} \cdot (1 \\ & - \text{e_corp_b}_{\text{db}}) \cdot (1 - \text{hc_corp_b}_i) + \text{sov_b}_{\text{db}} \cdot (1 - \text{e_sov_b}_{\text{db}}) \cdot (1 - \text{hc_sov_b}_i) \\ & + (\text{ivf_db_repo_sov}_i + \text{corp_db_repo_sov}_i) \cdot (1 - \text{hc_sov_b}_i) + (\text{ivf_db_repo_corp}_i \\ & + \text{corp_db_repo_corp}_i) \cdot (1 - \text{hc_corp_b}_i) \end{aligned}$$

Net liquidity position:

$$B_{\text{db},i} = LA_{\text{db},i} - O_{\text{db},i}$$

Pecking order of market clearing:

if $B_{\text{db},i} < 0$

$$a_s_sov_b_{\text{db},i} = 0$$

$$\text{db_bnk_repo}_i = \text{bnk_rev_repo}_{\text{db}}$$

$$\text{db_bnk_nonrepo}_i = LA_{\text{db},i} - (\text{cash}_{\text{db}} + \text{cash_eq}_{\text{db}} + \text{bnk_rev_repo}_{\text{db}})$$

if $B_{\text{db},i} > 0$ & $\text{cash}_{\text{db}} + \text{cash_eq}_{\text{db}} > O_{\text{db},i}$

$$a_s_sov_b_{\text{db},i} = \min(\text{cash}_{\text{db}} + \text{cash_eq}_{\text{db}} - O_{\text{db},i}, s_sov_b_{\text{db},i})$$

$$\text{db_bnk_repo}_i = 0$$

$$\text{db_bnk_nonrepo}_i = 0$$

if $B_{\text{db},i} > 0$ & $\text{cash}_{\text{db}} + \text{cash_eq}_{\text{db}} < O_{\text{db},i}$ & $\text{cash}_{\text{db}} + \text{cash_eq}_{\text{db}} + \text{bnk_rev_repo}_{\text{db}} > O_{\text{db},i}$

$$a_s_sov_b_{\text{db},i} = 0$$

$$\text{db_bnk_repo}_i = O_{\text{db},i} - (\text{cash}_{\text{db}} + \text{cash_eq}_{\text{db}})$$

$$\text{db_bnk_nonrepo}_i = 0$$

if $B_{\text{db},i} > 0$ & $\text{cash}_{\text{db}} + \text{cash_eq}_{\text{db}} + \text{bnk_rev_repo}_{\text{db}} < O_{\text{db},i}$

$$a_s_sov_b_{\text{db},i} = 0$$

$$\text{db_bnk_repo}_i = \text{bnk_rev_repo}_{\text{db}}$$

$$\text{db_bnk_nonrepo}_i = O_{\text{db},i} - (\text{cash}_{\text{db}} + \text{cash_eq}_{\text{db}} + \text{bnk_rev_repo}_{\text{db}})$$

3. Commercial bank block

$$\begin{aligned}
ivf_bnk_repo_sov_i &= ivf_bnk_repo_i \cdot \frac{(sov_b_{bnk} \cdot e_{sov_b_{bnk}})}{(sov_b_{bnk} \cdot e_{sov_b_{bnk}} + corp_b_{bnk} \cdot e_{corp_b_{bnk}})} \cdot \frac{1}{(1 - hh_{sov_b_i})} \\
ivf_bnk_repo_corp_i &= ivf_bnk_repo_i \cdot \frac{(corp_b_{bnk} \cdot e_{corp_b_{bnk}})}{(sov_b_{bnk} \cdot e_{sov_b_{bnk}} + corp_b_{bnk} \cdot e_{corp_b_{bnk}})} \cdot \frac{1}{(1 - hh_{corp_b_i})} \\
db_bnk_repo_sov_i &= db_bnk_repo_i \cdot \frac{(sov_b_{bnk} \cdot e_{sov_b_{bnk}})}{(sov_b_{bnk} \cdot e_{sov_b_{bnk}} + corp_b_{bnk} \cdot e_{corp_b_{bnk}})} \cdot \frac{1}{(1 - hh_{sov_b_i})} \\
db_bnk_repo_corp_i &= db_bnk_repo_i \cdot \frac{(corp_b_{bnk} \cdot e_{corp_b_{bnk}})}{(sov_b_{bnk} \cdot e_{sov_b_{bnk}} + corp_b_{bnk} \cdot e_{corp_b_{bnk}})} \cdot \frac{1}{(1 - hh_{corp_b_i})} \\
corp_bnk_repo_sov_i &= bnk_repo_{corp} \cdot repo_ror_{corp_i} \cdot \frac{(sov_b_{bnk} \cdot e_{sov_b_{bnk}})}{(sov_b_{bnk} \cdot e_{sov_b_{bnk}} + corp_b_{bnk} \cdot e_{corp_b_{bnk}})} \\
&\quad \cdot \frac{1}{(1 - hh_{sov_b_i})} \\
corp_bnk_repo_corp_i &= bnk_repo_{corp} \cdot repo_ror_{corp_i} \cdot \frac{(corp_b_{bnk} \cdot e_{corp_b_{bnk}})}{(sov_b_{bnk} \cdot e_{sov_b_{bnk}} + corp_b_{bnk} \cdot e_{corp_b_{bnk}})} \\
&\quad \cdot \frac{1}{(1 - hh_{corp_b_i})}
\end{aligned}$$

Outflow:

$$\begin{aligned}
O_{bnk,i} &= cl_{corp} \cdot clr_i + s_{sov_b_{bnk,i}} + (s_{sov_b_{ivf,i}} - a_{s_{sov_b_{ivf,i}}}) + (s_{sov_b_{db,i}} - a_{s_{sov_b_{db,i}}}) \\
&\quad + \max(0, sov_b_{bnk} \cdot e_{sov_b_{bnk}} - ivf_bnk_repo_sov_i - db_bnk_repo_sov_i \\
&\quad - corp_bnk_repo_sov_i) \cdot hc_{sov_b_i} + \max(0, corp_b_{bnk} \cdot e_{corp_b_{bnk}} - ivf_bnk_repo_corp_i \\
&\quad - db_bnk_repo_corp_i - corp_bnk_repo_corp_i) \cdot hc_{corp_b_i} + m_{sov_b_{bnk}} \cdot hc_{sov_b_i} \\
&\quad + m_{corp_b_{bnk}} \cdot hc_{corp_b_i} + ivf_bnk_repo_i + ivf_bnk_nonrepo_i + db_bnk_repo_i \\
&\quad + db_bnk_nonrepo_i + bnk_dep_{corp} \cdot dep_ror_{corp_i} + bnk_dep_{hh} \cdot dep_ror_{hh_i} \\
&\quad + bnk_repo_{corp} \cdot repo_ror_{corp_i} + bnk_b_{corp} \cdot b_{ror_corp_i} + s_{hh} \cdot r_i \cdot dep_ror_{hh_i} + s_{corp} \\
&\quad \cdot r_i \cdot dep_ror_{corp_i}
\end{aligned}$$

Liquid assets:

$$\begin{aligned}
LA_{bnk,i} &= cash_{bnk} + cash_{eq_{bnk}} + other_rev_repo_{db} + bnk_b_{bnk} \cdot (1 - hc_{bnk_b_i}) + corp_b_{bnk} \cdot (1 \\
&\quad - e_{corp_b_{bnk}}) \cdot (1 - hc_{corp_b_i}) + sov_b_{bnk} \cdot (1 - e_{sov_b_{bnk}}) \cdot (1 - hc_{sov_b_i}) \\
&\quad + (ivf_bnk_repo_sov_i + corp_bnk_repo_sov_i + db_bnk_repo_sov_i) \cdot (1 - hc_{sov_b_i}) \\
&\quad + (ivf_bnk_repo_corp_i + corp_bnk_repo_corp_i + db_bnk_repo_corp_i) \cdot (1 - hc_{corp_b_i}) \\
&\quad + s_{sov_b_{bnk,i}} + (s_{sov_b_{ivf,i}} - a_{s_{sov_b_{ivf,i}}}) + (s_{sov_b_{db,i}} - a_{s_{sov_b_{db,i}}}) + (s_{hh} + s_{corp}) \\
&\quad \cdot r_i + db_bnk_nonrepo_i + ivf_bnk_nonrepo_i
\end{aligned}$$

Net liquidity position:

$$B_{bnk,i} = LA_{bnk,i} - O_{bnk,i}$$

Variable	Definition
bnk	Commercial bank
db	Development bank

ivf	Investment fund
i	Simulation number
s_sov_b	Sovereign securities sold by foreign investors
hc_sov_b	Valuation shock to sovereign securities due to yield shock
sov_b	Holdings of sovereign securities
O	Liquidity outflow
LA	Liquid Assets + Liquidity inflow
B	Net liquidity position
m_sov_b	Margin position on sovereign securities
m_corp_b	Margin position on corporate securities
hc_corp_b	Valuation shock to corporate securities due to yield shock
s	Investment fund shares
r	Redemption rate on investment fund shares
cash	Cash
cash_eq	Cash equivalents
bnk_rev_repo	Reverse repo claims on commercial banks
db_rev_repo	Reverse repo claims on development banks
other_rev_repo	Reverse repo claims on commercial others
db_b	Holdings of development bank securities
bnk_b	Holdings of commercial bank securities (commercial papers, etc.)
hc_bnk_b	Valuation shock to commercial bank securities (commercial papers, etc.) due to yield shock
corp_b	Holdings of corporate securities
a_s_sov_b	Purchase/Absorption of sovereign securities sold by foreign investors
ivf_db_repo	Investment fund withdrawal of reverse repo funding to development banks
ivf_db_nonrepo	Investment fund withdrawal of funding other than reverse repo to development banks
ivf_bnk_repo	Investment fund withdrawal of reverse repo funding to commercial banks
ivf_bnk_nonrepo	Investment fund withdrawal of funding other than reverse repo to commercial banks
ivf_db_repo_sov	The release of sovereign securities collateral associated with investment fund withdrawal of reverse repo funding to development banks
e_sov_b	Share of encumbered sovereign securities in total sovereign securities
e_corp_b	Share of encumbered corporate securities in total corporate securities
hh_sov_b	Haircut on encumbered sovereign securities when pledged for reverse repo transactions
ivf_db_repo_corp	The release of corporate securities collateral associated with investment fund withdrawal of reverse repo funding to development banks
hh_corp_b	Haircut on encumbered corporate securities when pledged for reverse repo transactions
corp_db_repo_sov	The release of sovereign securities collateral associated with corporate withdrawal of reverse repo funding to development banks
corp_db_repo_corp	The release of corporate securities collateral associated with corporate withdrawal of reverse repo funding to development banks
repo_ror_corp	The rate of corporate withdrawal of reverse repo funding
db_repo	Repo liability of development banks

db_dep	Deposit liability of development banks
dep_ror_corp	Corporate deposit run-off rate
dep_ror_hh	Household deposit run-off rate
b_ror_corp	The rate of corporate withdrawal of bond funding
db_bnk_repo	Development bank withdrawal of reverse repo funding to commercial banks
db_bnk_nonrepo	Development bank withdrawal of funding other than reverse repo to commercial banks
ivf_bnk_repo_sov	The release of sovereign securities collateral associated with investment fund withdrawal of reverse repo funding to commercial banks
ivf_bnk_repo_corp	The release of corporate securities collateral associated with investment fund withdrawal of reverse repo funding to commercial banks
db_bnk_repo_sov	The release of sovereign securities collateral associated with development bank withdrawal of reverse repo funding to commercial banks
db_bnk_repo_corp	The release of corporate securities collateral associated with development bank withdrawal of reverse repo funding to commercial banks
corp_bnk_repo_sov	The release of sovereign securities collateral associated with corporate withdrawal of reverse repo funding to commercial banks
bnk_repo	Repo liability of commercial banks
corp_bnk_repo_corp	The release of corporate securities collateral associated with corporate withdrawal of reverse repo funding to commercial banks
bnk_dep	Deposit liability of commercial banks
cl	Bank credit lines to corporate
clr	Triggering rate of corporate credit lines

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