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Systemwide Liquidity Stress Testing Tool

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ABSTRACT: Developing a systemic liquidity stress testing tool is challenging due to data constraints and hard-to-model behavioral factors. There has yet to be a uniformly accepted model partly because the nature of systemic liquidity risks differs significantly across countries. This paper offers a simple Excel-based tool to assess the high-level impact of aggregate liquidity stress on the whole economy and gauge its spillover across banks, non-bank financial institutions (NBFIs), and non-financial economic sectors. It primarily uses the balance sheet approach (BSA) data—a sector-aggregate matrix of financial exposure by counterpart—that have become increasingly available for various economies with all income levels. The results can identify systemically important financial linkages to be analyzed further and help calibrate macroprudential measures and a liquidity support framework. When liquidity stress stems from capital outflows, the tool can enrich policy discussion based on integrated policy framework (IPF) and international reserve adequacy perspectives.

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WORKING PAPERS

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Prepared by Hiroko Oura[1]

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Contents

Glossary

ABM	Agent Based Model
AE	Advanced Economy
ARA	Assessing Reserve Adequacy
BOP	Balance of Payment
BSA	Balance Sheet Approach
CCyB	Countercyclical Capital Buffer
CFM	Capital Flow Management
CCP	Central clearing parties
CP	Commercial paper
DGI	Data gap initiative
ECB	European Central Bank
ELA	Emerging Liquidity Assistance
EM	Emerging market
EMDE	Emerging Market and Developing Economies
FDI	Foreign Direct Investment
FMI	Financial Market Intermediary
FSAP	Financial Stability Assessment Program
FX	Foreign Exchange
GFC	Global Financial Crisis
GIR	Global Institutional Reserves
HQLA	High-Quality Liquid Assets
ICAAP	Internal Capital Adequacy Assessment Process
IF	Investment fund
IMF	International Monetary Fund
IPF	Integrated Policy Framework
IV	Institutional View
LC	Local Currency
LCR	Liquidity Coverage Ratio
LOLR	Leader of Last Resort
NBFI	Non-Bank Financial Institution
NFC	Non-Financial Corporate
NSFR	Net Stable Funding Ratio
NIR	Net International Reserves
RR	Required reserve
SDDS	Special Data Dissemination Standard
SRB	Systemic Risk Buffers

Executive Summary

A systemic liquidity crisis is one of the most notable symptoms of a financial crisis. It occurs when multiple financial institutions simultaneously face liquidity stress. A systemic liquidity crisis can take numerous forms depending on the financial system structure. Historically, a systemic banking crisis materialized as a massive bank run to multiple or systemically important banks when many of their clients (corporates and households) experienced profound liquidity shocks or panic.

More recently, the role of non-bank financial institutions (NBFIs) and capital markets rose. The global financial crisis (GFC) showed that a run could also happen in financial markets. Unlike idiosyncratic bank runs, runs on markets tend to be systemic, affecting everyone trading in the distressed markets and also likely to spill over to other markets. The COVID-19 crisis showed another example of a systemic liquidity crisis caused by freezing economic activity and cashflows among households and corporates. Massive liquidation of safe assets caused turmoil even in the safest asset markets, such as U.S. treasury markets.

There is rich academic literature on the theory of systemic liquidity crises, and financial regulators monitor the risk regularly. Historical bank run experiences led to the development of the microeconomic theory of banking and financial crisis, applying game theoretic models. Studies following the GFC focused on understanding various mechanisms that turn initial idiosyncratic shocks into a systemic crisis through various amplification channels, including "run on repos" and collateral channels, fire sales, and the interaction of market and funding liquidity, the leverage cycle, and cash hoarding. At the same time, regulators monitor liquidity risks, closely related to market surveillance and following various quantity and price/spread indicators in key liquidity markets. They often conduct sector-specific liquidity stress tests for banks and investment funds.

However, systemic liquidity stress tests have been limited so far, because of data constraints and analytical challenges. Systemic liquidity stress tests need to incorporate interconnectedness among banks, NBFIs, non-financial sectors, and, if relevant, foreign investors. Such models and needed data are still limited despite substantial global efforts. An exception is the balance sheet approach (BSA) data summarizing sector-aggregate financial accounts by counterparts. Analytical challenges include the importance of behavioral factors, which are hard to pin down and can change the results noticeably. Moreover, some granular data need special resource-intensive data processing tools. Lastly, systemic liquidity stress tests are hard to standardize, because liquidity events could take noticeably different patterns across systems.

Against this backdrop, this paper proposes a simple Excel-based "systemwide liquidity stress testing" tool using a rather limited data environment, mostly just with BSA data. Systemwide liquidity stress is a sub-category of systemic liquidity stress and is caused by aggregate liquidity shocks to the system. The tool's main feature is its ability to formulate sector-by-sector cashflow liquidity stress tests akin to typical bank liquidity stress tests and to link them in order to gauge the possibility of domestic contagion through the network of direct financial linkages. In a typical liquidity stress test, an institution or a sector may become resilient against liquidity shock by liquidating its liquid assets. In a systemwide liquidity stress test, however, the sector may be simply transferring liquidity stress to another sector. In that case, the whole system that includes both sectors may not be resilient.

The tool is a high-level vulnerability assessment approach to identifying critical liquidity risk propagation channels that could be investigated more in depth with granular data. Because the tool primarily relies on sector-aggregate BSA data, it has limited scope to assess systemic liquidity risks from idiosyncratic shocks that become systemic through various amplification channels, caused by individual agents' risk-propagating behavior. Still, the benefit of this tool is that it is applicable to numerous countries. And as a simple Excel-based tool, it can be executed with few resources.

The core concept of this simple tool is also applicable to more advanced analyses. The principles include the importance of liquidity contagion across sectors because someone's liquid asset buffers are someone else's funding instruments; and the criticality of assessing alternative sets of behavioral and parameter assumptions instead of narrowing them down too much because of the risk that the models and estimates may not be correct—i.e., the model risk. This paper also consciously avoids modeling second-rounds effects because of the concerns about model risk.

Still, the stress test results could inform macroprudential policies, a crisis management framework, and priorities to improve risk analyses and data. Both ex-ante preventive policies and ex-post safety net tools are vital pillars of a robust financial stability policy framework. Once critical behavioral patterns are identified, risk monitoring, prudential tools, and crisis management tools could be set to incentivize agents to act in supporting financial stability. Also, such exercises could set priorities for closing the data gap, possibly expanding the scope of risk monitoring to NBFIs and even NFCs if they are systemically important. The tool could also quantify how much is needed for liquidity support and to what extent prudential measures should be relaxed on shocks, depending on various macrofinancial and behavioral assumptions. Understanding such quantifications could also help the central bank avoid offering unnecessarily generous liquidity support, such as blanket guarantees.

When stress scenarios include the balance of payment (BOP) shocks, the test can help assess the sufficiency of international reserves for the central bank to play the lender of last resort (LOLR) role. To remain resilient against liquidity stress from BOP shocks, an economy without reserve currency needs to count on international-reserve qualifying assets in public and private sectors. When the private sector liquidity is insufficient, the central bank may wish to be the LOLR. However, the capacity of the central bank in such economies is usually constrained by international reserves. The systemwide liquidity stress testing tool can estimate potential foreign exchange (FX) liquidity needs from the private sector in crisis scenarios, which then could be compared with the stock of international reserves. Indeed, the recent IMF papers on the new Institutional View (IV) on capital flow measures highlighted this tool's importance in assessing risks stemming from external and financial stability linkages—that is, FX liquidity or maturity mismatch risks.

However, this tool is not intended to offer a comprehensive assessment of reserve adequacy. A full reserve adequacy assessment should also incorporate other external stability factors such as import coverage as outlaid in the IMF's framework for assessing reserve adequacy. Instead, our tool could supplement and enrich international reserve needs assessment for maintaining financial stability.

This tool and conceptually similar methods have already been applied in IMF work in several countries and can further contribute to improving macrofinancial surveillance in the future. Some exercises focused on the extent of domestic liquidity contagion. Others examined the impact of foreign liquidity loss on financial institutions' liquidity and central bank balance sheets. Going forward, the tool can strengthen the integration of Financial Sector Assessment Programs (FSAPs) and Article IV consultations. It could also be one of the tools effective in enriching policy dialogue under the integrated policy framework (IPF).

Introduction

Background

A systemic liquidity crisis is one of the most notable symptoms of a financial crisis. It occurs when multiple financial institutions simultaneously face liquidity stress. A systemic liquidity crisis can take numerous forms depending on the financial system structure. Historically, a systemic banking crisis materialized as a massive bank run to multiple or systemically important banks when many of their clients (corporates and households) experienced profound liquidity shocks or panic. The global financial crisis (GFC) showed that a run could also happen in financial markets (IMF 2011). We also observed the stress of investment and money market funds and their contagion, including dollar funding shocks to banks engaging in cross-border activities (IMF 2019a). Such market dislocation affects financial institutions that rely on market funding and investing in financial markets through amplification effects of fire sales, the leverage cycle, cash hoarding, and network effects. Unlike idiosyncratic bank runs, runs on markets tend to be systemic, affecting everyone trading in the distressed markets and also likely to spill over to other markets. The COVID-19 crisis showed another example of a systemic liquidity crisis caused by freezing economic activity and cashflows among households and corporate, and their spillover to financial institutions (including through credit lines, Kapan and Minoiu, 2021). Substantial sales of liquid assets caused unusual turmoil even in the U.S. treasury market—the safest and most liquid market in the world (Vissing-JØrgensen, 2021).

Systemic liquidity risks in financial markets are also closely related to non-bank financial institution (NBFI) risks and risks from broader market participants. NBFIs are generally more exposed to financial market risks as many of them tend to rely on market funding or fickle investments such as investment funds, except for insurers and pension funds. Their assets are primarily marketable instruments, though some provide bank-loan-like products. Therefore, they are generally more prone to market liquidity and asset valuation change risks than banks. Indeed, for some NBFIs, such as asset managers, liquidity risks and their propagation through interconnectedness in markets are more relevant than solvency risks. One of the main risks to financial market infrastructures (FMIs), such as central clearing counterparties (CCPs), are liquidity stress of their clearing members (usually banks and other NBFIs) through jumps in margin calls when members' positions lose substantial value from market volatilities. Liquidity stress from margin calls affects even a typically-stable pension fund: U.K. pension funds suffered from sudden jumps in margin calls due to sharp valuation losses of gilts in October 2022. Furthermore, market stress events could be caused by non-financial market participants such as highly-leveraged real estate developers or commodity firms when real estate and commodity price change drastically.

There is rich academic literature on the theory of systemic liquidity crises. Historical bank run experiences developed the microeconomic theory of banking and financial crisis. The pioneering work by Diamond and Dibvig (1985) focused on an idiosyncratic run on a bank, while later studies, such as Allen and Gale (1998, 2000, 2004), Morris and Shin (1998), Holmstrom and Tirole (1998, 2010), Freixas, Parigi, and Rochet (2000), and Rochet and Vives (2004), focused on a systemic run affecting a large part of the banking system caused by economy-wide stress such as recession and shock-amplifying behavior that turns small shocks into a systemic bank run due to uncertainty.[1] Studies following the GFC focused on understanding various mechanisms that turn initial idiosyncratic shocks into a systemic crisis through various amplification channels, including “run on repos” and collateral channels (Gorton and Metrick 2012), fire sales, and the interaction of market and funding liquidity (Brunnermeier and Pedersen 2008), the leverage cycle (Adrian and Shin 2010), and cash hoarding due to uncertainty and network effects (Allen and Gale 2004; Allen and others 2009).

Financial regulators, central banks, and international organizations like the IMF identify key liquidity markets, monitor them regularly, and conduct some sector-specific microprudential stress tests. Existing operational work on systemic liquidity has mainly been qualitative analyses or monitoring of the ongoing situation. For example, in the IMF and World Bank’s FSAPs, “systemic liquidity assessment” usually describes key liquidity markets, participants, and the broad direction of liquidity flows and assesses the adequacy of market infrastructure and its regulation/supervision and contingent crisis management framework, including emergency liquidity assistance (ELA). Liquidity risk monitoring is closely related to market surveillance and monitors various quantity and price/spread indicators in key liquidity markets. Academic finance literature also proposes several liquidity measures, including trade size, trade volume, trading frequency, bid-ask spreads, and yield curve noise.[2] While NBFI supervisors have been strengthening their stress testing exercises, they tend to focus on the resilience of their supervised sectors without systemwide views incorporating the resilience of other sectors interlinked with their sectors of responsibility.

However, data constraints have limited truly systemic liquidity stress tests so far. Systemic liquidity stress tests need to incorporate interconnectedness among banks, NBFIs, foreign investors, and, if relevant, non-financial sectors (households, corporates, and sovereigns) (IMF 2021). Such interconnectedness analyses usually suffer from data gaps. Cross-sectoral financial exposures and transaction data in certain markets—so-called activity-based data usually collected by financial market intermediaries (FMIs) such as clearinghouses and depository agencies—are critical for the analyses. Such data little existed before the GFC. Post-crisis efforts such as G20 data gap initiatives[3] (DGI, G20 2009) encouraged countries to start collecting relevant data, including sector-aggregate data (such as balance sheet approach, BSA, data by IMF (IMF 2015); who-to-whom financial account data collected by the European Central Bank, ECB; and flow-of-funds data by counterparts). Yet, more comprehensive and detailed data (institution-level by counterparts and instruments—especially at the security level combined with liquidity and capital buffer of participants) usually do not exist. Moreover, much of the highly granular data are treated with the highest confidentiality and accompany strong

[1] While many bank run theories emphasize the role of pure panic using game theoretic models with multiple equilibria, historical observation seems to suggest that bank runs tend to occur when there are underlying issues with bank health or macro-level adverse shocks (see, for example, Gorton 1988 and Calomiris and Mason, 2003). Moreover, Morris and Shin (1998) applied the so-called global game approach—an equilibrium-selection approach to identifying unique equilibrium by introducing uncertainty over higher-order beliefs (that is, an infinite sequence of beliefs in “I know that she knows that I know…(infinite repetition)…I choose this action”)—to a typical multiple-equilibrium game. They showed that a slight change in fundamentals could lead to a sudden shift from the unique “good” equilibrium to the unique “bad” equilibrium with a run.

[2] For example, Amihud (2002) defines illiquidity as the average ratio of the absolute daily return to the dollar trading on that day. Benos and Zikes (2016) assume that, during normal times, arbitrage smooths out the yield curve and keeps pricing errors (that is, noise) small. They constructed the measure of noise as a deviation from the smoothed yield curve. Liquidity is also measured as the price impact of trading. Kyle's lambda measures the price impact of net trading activities. Cont and Schaanning (2017) assume a certain functional form for the market impact of trading size on the relative price change, controlling for daily volatility of price changes. There are also a series of studies by Duffie (for example, Duffie 2010 and Chen and Duffie 2021) examining the impact on asset price dynamics of demand or supply shocks.

[3] See IMF webpage for the background of the initiatives and progress reports.

firewalls even among financial regulators within an economy. Therefore, creating comprehensive data combining various regulatory reporting is administratively challenging.[4]

Furthermore, technical and modeling challenges exist even when data are available. Highly granular data at the transaction level tend to be "big" and require special resource-intensive data processing tools. Liquidity stress test results also depend on the hard-to-model behaviors of economic agents. The theoretical literature provides direction but does not quantitatively pin down the behaviors and contagion effects. For example, it is very hard to robustly estimate the fire-sales effects and asset price distress channel during crisis episodes, especially if the main drivers are different each time. They also tend to be highly-stylized models and focus on one behavioral factor. Incorporating combinations of multiple behavioral patterns in a theoretically coherent manner is challenging. Lastly, a systemic liquidity stress test is hard to standardize because liquidity events could take noticeably different patterns across systems, as we learned from past systemic liquidity crises.

Contribution of This Paper

Against this backdrop, this paper proposes a simple Excel-based "systemwide liquidity stress testing" tool primarily using BSA data. Systemwide liquidity stress is defined as a sub-category of systemic liquidity stress and is caused by aggregate liquidity shocks to the system,[5] such as the economy-wide earnings shocks we saw during the COVID-19 crisis and balance of payment (BOP) shocks (Box 1). The tool's unique feature is its ability to formulate sector-by-sector cashflow liquidity stress tests akin to typical bank liquidity stress tests (such as Basel III liquidity coverage ratio—LCR) and link them in order to gauge the possibility of domestic contagion through the network of direct financial linkages. In a typical liquidity stress test of financial institutions, an institution or sector A may be resilient against liquidity shock if they have sufficient liquid assets to cash. In a systemwide liquidity stress test, however, sector A may simply transfer stress to sector B if the liquidated assets include financial liabilities issued by sector B. In that case, the system that includes both sectors may not be resilient.

The tool can be applied to assess liquidity spillover risks from NBFIs and even the non-financial sector depending on the structure of BSA data. The tool could be used to understand potential systemic liquidity risks in certain markets and NBFIs, if BSA data have details about financial instruments and the NBFI sector, separating, for example, insurers, pension funds, asset managers, and other types of NBFIs. Consider a country where the non-financial sector, such as non-financial corporates (NFCs) and sovereign, has a

[4] For example, it is important to combine transaction-level data in markets with participants' liquid asset buffer data to conduct accurate systemic liquidity stress. Transaction data are usually maintained by FMIs and their supervisors, while participants' liquid asset data are managed by their sectoral supervisors (e.g., bank supervisors, securities supervisors for asset managers, and pension and insurance supervisors). Multiple supervisory agencies need to work together to create a comprehensive data set. Moreover, it is very difficult to obtain liquid asset data for unregulated (such as NFCs) or lightly regulated (such as hedge funds) entities. Some macroprudential supervisors are given legal powers to request any data from any type of entities (such as the Philippines—see 2021 FSAP report—where NFCs play significant role for financial stability). However, such arrangements are unusual.

[5] Some "systemic liquidity events" materialize without aggregate liquidity shocks. For instance, the events like the October 2022 UK gilts market turbulence and its impact on pension funds could happen when only domestic investors change their portfolio allocation-say from gilts to bank deposits. However, in that case, there is no change in total liquidity in the country since the money invested in gilt just moved to banks. In principle, pension funds' stress could be moderated if banks provide short-term liquidity to meet sudden margin calls using the money they receive. But making such arrangements in a day or two is challenging in practice. Having said that, the October events likely accompanied some capital outflows from foreign investors' sales of gilts because the British pound depreciated sharply as well. If this is indeed the case, the event is considered a systemwide liquidity event following this paper's definition.

noticeable footprint in the financial system. Then, the tool can assess the liquidity spillover risks from them to local financial institutions as long as BSA data captures their exposures reported by regulated financial institutions. BSA data are still not comprehensive in many countries and often miss details of instruments and financial linkages that do not involve domestic financial institutions (e.g., direct linkage between NFCs and households). Yet, one can gain some ideas about key financial vulnerabilities, though not precisely, from BSA data supplemented with financial statements and supervisory reporting of regulated financial institutions and central banks with proxy assumptions.

The tool should be considered as a high-level vulnerability assessment approach to identifying critical liquidity risk propagation channels that should be investigated more in-depth with granular data. The data constraints limit the accuracy of assessments. BSA data alone are insufficient to assess market liquidity risks from margin calls or liquidity spillovers from off-balance sheet items (such as bank credit lines). Furthermore, it is not suited for systemic liquidity analysis caused by idiosyncratic shocks that become systemic through various amplification channels, which often depend on individual agents' risk-propagating behavior averaged out in aggregate data.[6] Analyses including such micro-level behavior require more granular data[7] and a richer modeling approach, such as an agent-based model (ABM).[8, 9] The benefit of this simple tool, by comparison, is that it is applicable to numerous countries, including EMDEs, as BSA data are increasingly available for them in addition to AEs.[10] And as a simple Excel-based tool, it can be executed with few resources. Furthermore, it can be easily enhanced to incorporate institution- and instrument-level data—such as banks, investment funds, and their exposures in specific markets like FX swaps—without jumping to substantially more complex approaches like ABMs.

Still, the stress test results could inform macroprudential policies and crisis management frameworks to prepare for a potential systemic liquidity event. Prudential requirements for financial institutions could encourage them to self-insure against systemwide liquidity stress ex-ante. In particular, if they are encouraged to hold and use global safe assets first during BOP-related liquidity stress, such measures can help mitigate domestic spillover of initial liquidity stress. Moreover, a robust financial stability framework should include a contingent crisis management framework where the central bank plays the role of the lender of last resort (LOLR). But such a framework should be designed to avoid moral hazard, with appropriate collateral, collateral valuation and haircut, and terms and changes. Building up macroprudential buffers first and then relaxing them

[6] An implicit assumption of our tool is that liquidity allocation within a sector, for example, the banking sector, continues to work smoothly through the interbank market, which could be achieved when a central bank actively intermediates in the market to ensure that liquidity continues to flow from liquidity-surplus banks to those facing liquidity shortages.

[7] Examples include Fache, Jukonis, Letizia, and Gravanis (2020), who examine European derivatives transaction data; and HÜser, Lepore, and Veraart (2021), who analyze the gilt repo market. Paddrik, Rajan, and Young (2020) and Levels, de Sousa van Stralen Koon Patrescu, and van Lelyveld (2018) examine contagion in the credit default swap (CDS) market using activity-based data from clearinghouses. Huang and others (2019) modeled interconnectedness through central counterparties (CCP) using CCP-collected data.

[8] ABM is a simulation-based approach that allows economic and financial system dynamics "from the bottom-up" based on individual agents, including firms, households, banks, NBFIs, and sovereigns, as needed. Some agents follow optimized rules similar to those obtained in a dynamic stochastic general equilibrium (DSGE) model. Still, others could follow more heuristic behavioral rules because of bounded rationality and other factors emphasized in behavioral finance literature.

[9] Baranova, Douglas, and Silvestri (2019) conduct a simulation-based stress analysis in the UK corporate bond market. Paddrik, Hayes, Todd, Yang, Beling, and Scherer (2012) apply ABM to E-Mini S&P 500 futures market to account for flash crash events, and Liu, Paddrik, Yang, and Zhang (2020) apply it to model how interbank network is formed.

[10] IMF's statistical department has provided technical assistance (TA) to develop BSA data in many EMDEs. Also, the IMF's Financial Sector Stability Review (FSSR)—a new TA tool initiated in 2017 that provides diagnostics on which financial sector reform programs can be built and implemented—usually includes a statistics module to construct BSA data.

before deploying LOLR facilities is another way to ensure incentive compatibility.[11] The stress test could also estimate potential liquidity injection needs during a systemwide-distress episode under various macrofinancial and behavioral assumptions. Depending on the liquidity needs of the private sector, the central bank can gauge whether releasing the existing liquidity buffer is sufficient or it needs to provide additional ELA. When the ultimate source of liquidity stress is outside the banking sector, the central bank may need to consider expanding collaterals for facilities and counterparties. In addition, macroprudential supervisors may need to consider expanding their legal power so that they can at least request data from any financial supervisors and broader economic agents, including NFCs when they are relevant for systemic risks.

In countries without reserve currencies, the test can help assess the sufficiency of international reserves for the central bank to play the LOLR role. A local central bank can supply sufficient public liquidity to mitigate local private liquidity stress as long as residents continue to value the central bank money. However, as discussed in Box 1, the capacity of a central bank without reserve currencies to play the role of LOLR when it faces foreign liquidity shocks is usually constrained by international reserves. Our systemwide liquidity stress testing tool can estimate potential FX liquidity needs from the private sector in crisis scenarios, which then could be compared with the stock of international reserves. If existing international reserves are insufficient, the central bank could consider reducing the private sector's liquidity gap with tighter prudential requirements and strengthening its LOLR capacity by building international reserves and seeking bilateral central bank swaps, multilateral contingent financing, including IMF credit lines, and private sector credit lines, if accessible. Indeed, the recent IMF papers on the new Institutional View (IV) on capital flow measures (IMF 2022a, 2022b) highlighted this tool's importance in assessing risks stemming from external and financial stability linkages—that is, FX liquidity or maturity mismatch risks.

However, this tool is not intended to offer a comprehensive assessment of reserve adequacy. A full reserve adequacy assessment should also incorporate other external stability factors such as import coverage as outlaid in the IMF's framework for assessing reserve adequacy (ARA, see IMF 2016a). Instead, our tool could supplement and enrich an international reserve needs assessment for maintaining financial stability, where IMF (2016b) kept analytical options open, given the wide variations of systemic liquidity stress phenomenon.[12] It is also a detailed stress test version of the "international reserves and foreign currency liquidity" data compiled and released under IMF's special data dissemination standard (SDDS, see IMF 2013a).[13]

This tool and conceptually similar methods have already been applied in IMF work in several countries and can further contribute to improving macrofinancial surveillance in the future. Some exercises focused on the extent of domestic liquidity contagion (the Philippines's examination of the effects of COVID-19-related loan moratoria on relative liquidity position between banks and NFCs; and Luxembourg's examination of the bank-investment fund linkages). Others examined the impact of foreign liquidity loss on financial

[11] A long history of central banking and bank crises established the role of the central bank as the LOLR (Bagehot 1873). For instance, the U.S. Federal Reserve Board was established in 1913 to issue national currency (i.e., inject liquidity) in response to the 1907 bank crisis. A series of Diamond-Dibvig-type studies supported creating deposit insurance and central bank ELA, despite their possible side effects (moral hazard). More recently, the GFC and COVID showed how the ELA is critical to managing a systemic crisis that affects the whole economy in addition to financial institutions.

[12] For EMDEs, the ARA framework accounts for financial stability risk by including a certain percentage of M2 in the ARA metric. Our approach could provide more accurate estimates of potential liquidity loss, incorporating the economy's current financial system status.

[13] The foreign currency liquidity data compares international reserves to predetermined short-term (one year) and contingent net drains on foreign currency assets. Its underlying principles are similar to Basel III's LCR.

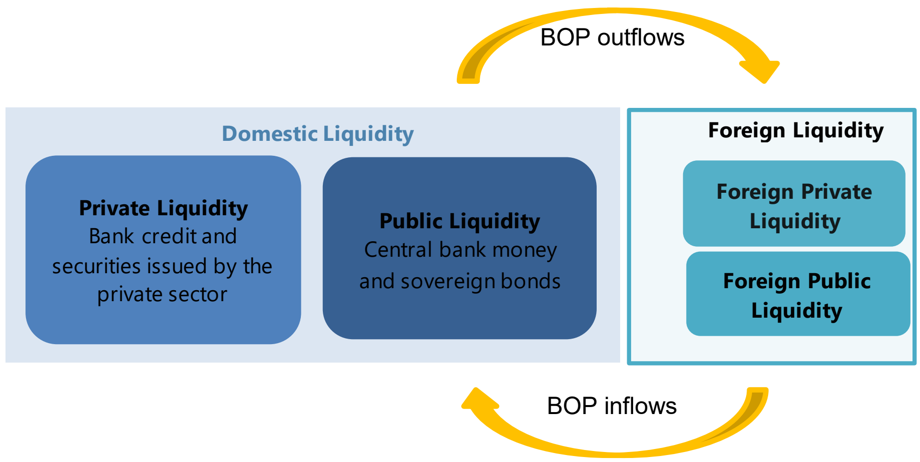
institutions' liquidity and central bank balance sheets (Andorra, Mauritius, and Sweden). The 2018 Armenia FSAP and IMF lending program recommended changing the design of reserve requirements based on the systemwide FX liquidity concept without laying out quantitative details. Some technical assistance to emerging markets and low-income economies also applied the tool. Going forward, the tool could strengthen the integration of FSAP and Article IV—the critical area to improve IMF's surveillance as discussed in the latest surveillance reviews (IMF 2021b and 2021c). It could also be one of the tools valuable for enriching policy dialogue under the integrated policy framework (IPF, IMF 2020).

Moreover, recent FSAPs have been increasingly incorporating systemwide liquidity analysis, using and often enriching the tool with additional granular and often confidential data. The Philippines FSAP supplemented BSA with institution-level data of banks and NFCs to obtain more details about liquid asset buffers and funding instruments. 2021 Chile FSAP work used institution-level data of banks and some NBFIs and showed institution-level vulnerabilities in addition to aggregate risks in response to the sudden reallocation of individuals' pension portfolios away from domestic to foreign assets. 2022 Mexico FSAP used highly granular BSA data, including institution-level data for banks and some NBFIs, their detailed exposure to local sovereign bonds (cash, repo, and derivatives), and detailed liquid asset buffer information (including unencumbered securities that are not pledged as collaterals for secured funding and some derivative transactions). They considered a capital outflow scenario from local sovereign bonds and its impact on bond valuation and liquidity needs to fill in margin calls from repo and derivatives positions.

The rest of the paper is organized as follows. This paper first explains the concept of the tool in general, then demonstrates how the tool can be applied in practice using illustrative EMDE data focusing on NFC-bank-central bank FX liquidity linkages. When explaining the tool, the paper focuses on aggregate FX liquidity stress from capital outflow, which is particularly relevant for EMDEs and advanced economies without a reserve currency. Such stress is also a key channel interlinking external and financial stability. I then discuss the roles of various prudential and crisis management policies and how the stress test can be used to inform them quantitatively. Details of some country cases are provided before concluding the paper.

Box 1. Why Are BOP Shocks and Foreign Liquidity Special in Systemwide Liquidity Analysis?

Liquidity in an open economy could be grouped into four broad categories depending on its source. Liquidity created by domestic agents (local currency and other financial claims) is domestic liquidity, and financial claims issued by foreign agents are foreign liquidity. Liquidity could be created by the private sector (bank loans, commercial papers, bonds, and others) or by the public sector (currency and sovereign bonds). Both domestic and foreign liquidity could be denominated in local and foreign currencies. The concept of public and private liquidity follows the tradition in the literature on private and public liquidity (see Holmstrom and Tirole 1998; Tirole 2008, 2011, among others).



Only foreign liquidity channeled by BOP flows can add or remove net liquidity from the economy. Domestic agents alone cannot create net liquidity in the system. The net supply of domestic liquidity is zero, because somebody's financial assets are somebody else's liabilities. For example, deposit outflows from a bank do not change the total gross liquidity of an economy if depositors place the money in other domestic banks or non-bank financial institutions or use it to purchase bonds and equity issued by domestic agents. It simply reallocates money among domestic agents. However, if non-residents withdraw their deposits and repatriate them to their home country, the money is lost from the economy—causing an aggregate liquidity shock.

In the related literature on the theory of money, such aggregate liquidity shocks are interpreted as the loss of "outside" money. Money (or liquidity) is grouped into "inside" and "outside" money of a system in the theory of money (see, for example, Holmstrom and Tirole 1998, 2011; Lagos 2010; Bolton, Santos, and Scheinkman 2011). A "system" could be defined as a part of the domestic financial system, such as the banking sector or the whole economy's financial system. In the first case, outside money is a deposit from households and corporates. In contrast, interbank claims are inside money. They are IOUs among banks in the system, and their net supply is zero, because somebody's claims are somebody else's liability within the system. Only outside money can supply or remove money in the net, causing aggregate, non-diversifiable shocks to the system. If the system means the whole financial system of an economy, then all domestic liquidity is inside money, and foreign liquidity is outside money.

Box 1. Why Are BOP Shocks and Foreign Liquidity Special in Systemwide Liquidity Analysis? (continued)

The literature provides theoretical support for the central banks' LOLR function. The private and public liquidity literature usually considers a closed economy and defines a system as private financial markets and institutions. Private liquidity is inside money, and their net supply is zero, because somebody's assets are somebody else's liability. A systemic liquidity crisis means that the gross amount of private money falls sharply as transactions in the financial market freeze, and the size of the financial balance sheets of multiple economic sectors shrinks. In this context, public money—that is, central banks' liquidity facility and public debt—is outside money and can mitigate the contraction of private liquidity by adding a positive net supply of liquidity to the system. In other words, only outside money can be the source of LOLR amid a systemic liquidity crisis.

Extending the above discussion to an open economy highlights the unique role of foreign liquidity as a source of LOLR facilities. Chapter 6 of Holmstrom and Tirole (2011) considers domestic private, domestic public, and international liquidity—similar to the figure above. Without financial frictions, the international capital market provides opportunities to insure and diversify away country-specific aggregate shocks, because foreign liquidity is outside money. However, such insurance opportunities are limited by collateral constraints—an economy can borrow from international capital markets only up to the amount of pledgeable assets, that is, tradable goods. If we narrowly define "tradable goods" as the existing stock of foreign liquidity produced by selling tradable goods in the past, excluding future export receipts, the pledgeable assets of an economy are limited to foreign assets held by residents. In particular, the amount of money the local central bank can deploy to manage aggregate liquidity shock to the system as the LOLR is limited to international reserves.

Therefore, an economy without a reserve currency needs to carry a certain level of international reserves to prepare for potential systemwide liquidity stress—a financial stability risk. Reserve currency issuers can be interpreted as those with plenty of pledgeable assets, so they need not worry about losing access to international capital markets, even in a crisis. In contrast, others, especially EMDEs, have far less pledgeable assets. EMDEs could benefit from access to international capital markets and insurance opportunities the markets provide during normal times but could occasionally suffer from a sudden loss of foreign liquidity—a financial crisis—due to scarcity of pledgeable assets.[1] These perspectives underscore the need to consider financial stability factors when assessing the adequacy of international reserves, as discussed by the IMF (2013a, 2022a, 2022b).

As a side note, FX liquidity stress differs from currency mismatch risks. "Currency mismatch" means that the amount of FX assets and liabilities (including all maturities) is uneven, creating profit losses or gains when exchange rates move. It is a solvency risk and is usually monitored and regulated with net open FX limits to banks. In contrast, FX liquidity risk stems from the maturity mismatch of FX assets and liabilities. Even when there are no currency mismatch risks, FX liquidity risks arise if the maturity of FX assets is substantially longer than that of FX liabilities.

1/ However, it may not be optimal to hold too many international reserves to fully self-insure against foreign liquidity dry-up risks, because accessing the international market even at the cost of occasional crisis could be part of the optimal design of the system, as discussed by Holmstrom and Tirole (2011) and Allen and Gale (1998).

Assessing Systemwide Liquidity Risks: Conceptual Framework

Systemwide liquidity stress tests include four steps. The first is understanding the key sectors and financial linkages to identify critical risks and vulnerabilities. Visualizing the network structure of the financial system BSA in financial network forms and understanding the sectoral balance sheet structure—main funding instruments and their maturity and structure of liquid assets—are helpful (see the illustrative example section for details). This step aims to identify relevant macro-financial liquidity stress scenarios matching with underlying vulnerabilities. The second step is to formulate cashflow liquidity stress testing at a sector-aggregate level for systemically important sectors. The sectoral cash flow analysis is very similar to standard bank liquidity stress tests. The third is gauging the extent of contagion effects from one sector to another under several behavioral assumptions. This step differentiates the systemwide liquidity stress test from standard sector/institution-specific tests. The last step is to consider the impact of various central banks' liquidity policy options to see whether the economy as a whole can withstand the stress with or without policy support.

Varieties of aggregate liquidity shocks to the system cause systemwide liquidity stress depending on the economic and financial system structure. As Box 1 shows, the source could be both foreign and domestic agents. Foreign investors may withdraw local deposits, sell securities issued by the county, and not refinance maturing debt. External debt covenants could trigger early, unexpected repayment. Even when foreign investors are selling off local currency (LC)-denominated assets (local equity, investment fund shares, deposits, commercial papers, corporate and sovereign bonds, among others, depending on the structure of the local financial system), there would eventually be FX liquidity outflows when they convert the proceeds to hard currency for repatriation. Domestic agents could also cause capital outflows. Portfolio reallocation away from domestic assets to foreign assets (including holding hard currency cash under mattresses) causes capital outflows from residents. If domestic banks and NBFIs have exposures to foreign derivatives and leveraged transactions, foreign asset market turbulence may reduce the value of the exposures and result in additional margin calls. Domestic agents living abroad may reduce remittance flows depending on the economic conditions in the destination countries. Changes in asset prices, exchange rates, and interest rates also affect net liquidity flows. Higher foreign interest rates (including a credit risk premium against the borrowers) and LC depreciation elevate FX cash outflows for debt services abroad. The decline of commodity prices reduces export proceeds without changes in export quantity. The BSA matrix and its network visualization help identify which sectors are affected by various BOP shocks.

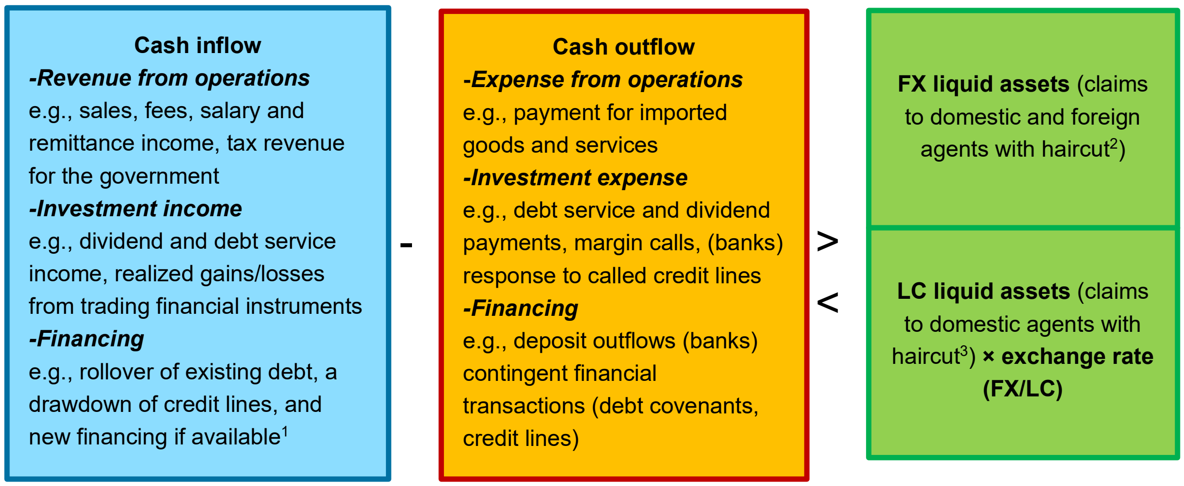
Once the main sources of aggregate liquidity shocks are identified, one can build macro-financial scenarios that generate such shocks. The process is similar to scenario design work for bank solvency stress tests. First, one should identify qualitative scenarios that matter to the country. Capital outflows shocks are often triggered by global financial condition tightening as well as higher country risks (weak macroeconomic fundamentals and balance sheet structures). Global demand shock and lower commodity prices could also generate aggregate liquidity stress. Second, specific assumptions over asset prices (including interest and exchange rates) and funding shocks could be calibrated using one of the following approaches.

- ***Macro scenario approach**.* This approach is feasible when there is a functioning macrofinancial model that can produce quantitative scenarios. Key macrofinancial variables include policy, exchange, and market interest rates. It could also include public finance forecasts and government cashflows (for example, additional fiscal deficits and external financing plans). Trade projection could also inform NFCs' export receipts and import bills. Macroeconomic models may not include all the necessary parameters for stress testing. In that case, one can set up an empirical model to forecast necessary variables as a function of variables included in the macro model (for example, forecasting bank lending rate as a function of policy rate). This approach may need to be supplemented with the statistical approach when the liquidity stress testing horizon is much shorter than the macro scenario horizon. For example, the volatility of the annual average exchange rate tends to be much smaller than the volatility of the weekly exchange rate. Exchange rate assumptions based on the annual average could be too benign for a one-month stress test.

- ***Statistical and historical approach.*** This approach relies on historical data of various macrofinancial variables. One can obtain an empirical distribution of a parameter by matching the time window of the distribution with the length of stress testing. For example, when a stress test has a one-week horizon, one can take weekly parameter changes to create the distribution. Then, a stress tester can aim certain likelihood of stress to pick the corresponding assumption. If the tester takes the worst two percentile points of weekly interest changes (i.e., the value at risk, VaR) of one-sided tail 2 percent), the test aims at one week per year event. When estimating empirical distributions, it is essential to include long-enough history—ideally long enough to include some crisis events. If a country does not have significant stress events, one can also apply peer countries' experiences.

The second step is to conduct sectoral cash flow liquidity stress tests similar to standard bank liquidity stress tests similar to liquidity coverage ratio (LCR) for banks (BCBS, 2013). As Figure 1 shows, a cash flow stress test compares cash inflows and outflows within a test horizon and examines whether liquid asset buffers can cover net cashflow gaps. A sector can withstand liquidity stress if they can cover their net liquidity flows by their liquid asset buffer. Cash flows consist of revenues and expenses from operations (i.e., salary, payments, and receipts of goods and services), flows from contractual financial services (i.e., interests, dividends, debt service, realized gains and losses from financial investments, margin calls), and financing activities (i.e., rollover/issuance of debts, demand deposit outflows for banks, and contingent financings such as credit lines and covenants). Liquid assets consist of cash and highly-liquid cash-like instruments (e.g., bank deposits, sovereign securities, highly-rated private sector bonds). The value of liquid assets declines in a scenario including generalized market distress, especially if they are riskier and less liquid—higher risk premiums reduce bond valuation (i.e., haircut LCR), exchange rate depreciation reduces the value of the local currency (LC) denominated liquid assets (expressed in FX). In a typical bank FX liquidity stress test, a 100 percent haircut is applied to LC assets and excludes them fully from liquid asset buffers. When additional data are available, the definition of liquid assets could be further narrowed down to "rapidly usable" liquid assets, excluding required reserves for banks and encumbered assets already pledged as collateral for secured funding such as repos.

Figure 1. **Cashflow Liquidity Stress Test**



Source: Author.
1/ An agent can try to fill the net cashflow gap by borrowing instead of liquidating liquid assets. However, borrowing amid liquidity stress is usually challenging. The most conservative (pessimistic) assumption is to exclude any new financing. Existing credit lines can increase cash inflows.
2/ In the middle of a liquidity crisis, even high-quality liquid assets could lose some value. Haircut accounts for such potential valuation losses and is usually linked to asset price assumptions in a stress scenario.
Note: FX = foreign exchange; LC = local currency.

The third contagion step is unique to systemwide liquidity stress, because it could happen even when the sector directly affected by a BOP shock can withstand the stress.[14] For example, one can consider bank-investment fund (IF) linkages as Figure 2 shows. Both sectors have foreign financing: banks' liabilities include FX deposits by non-residents and international bonds, and foreign investors hold some of IFs' shares (in LC). When the global financial condition tightens, there could be outflows of such funding. Also, capital outflows depreciate LC, reducing LC asset valuation in FX terms. If foreign investors directly hold other domestic securities—such as LC sovereign bonds and equities—their valuation declines, reducing the size of liquid asset buffers. Also, if banks and IFs have repo transactions using LC securities as collaterals or derivative exposures, sudden valuation changes could cause margin calls, which should be satisfied immediately by posting additional collaterals or cash. The affected banks and IFs need to fill the liquidity gap using their liquid asset buffers. Let's say IFs have sufficient domestic bank deposits to withstand a capital outflow shock. However, their resilience comes at the cost of transferring the liquidity shock to banks—deposit withdrawal from IFs. Depending on banks' balance sheet structures, there could be a situation where banks can withstand the initial loss of foreign funding but not the total effects, including the liquidity contagion from IF deposit withdrawal. On the contrary, banks may transfer their initial foreign funding shock to IFs if they liquidate substantial IF shares.

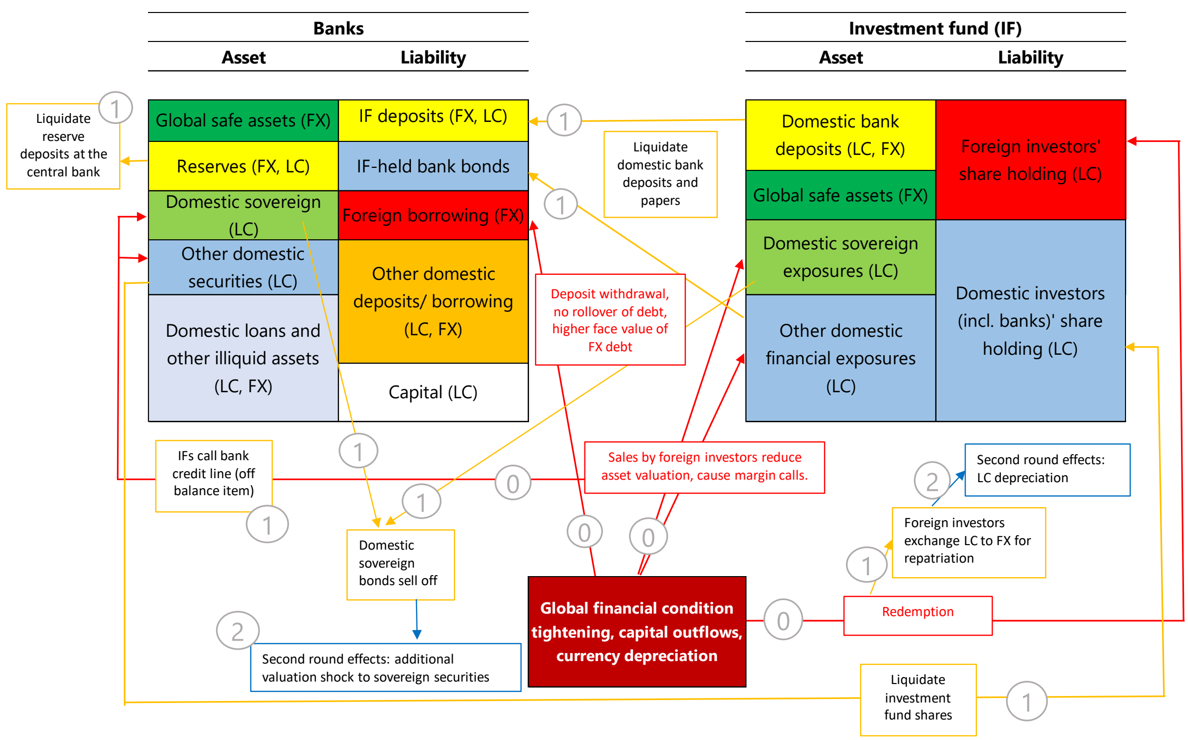
The strength of the contagion effects depends substantially on the pecking order of asset liquidation. Using the same example in Figure 2, there are no contagion effects from IFs to banks if IFs have sufficient global safe assets to withstand the initial foreign funding shock and liquidate them first before tapping into domestic bank deposits. Similarly, there are no contagion effects from banks to IFs if banks have sufficient

[14] In typical network models of contagion applied to banks and FMIs, a trigger of contagion is the "failure" or "default" of a network member, that is, banks/FMIs cannot meet required capital ratios after initial stress.

global safe assets, central bank reserves, and sovereign bonds to withstand the foreign financing shock and liquidate them first before selling IF shares. Such dependency on agents' behavior is typical with most liquidity stress testing tools. In this paper, we examine a range of outcomes under multiple pecking orders of asset liquidation rather than assuming specific behavior—such as pro-rata liquidation of all assets often assumed in typical liquidity stress tests. Box 2 summarizes which types of liquid assets are "better" in limiting domestic contagion effects.

Figure 2. Domestic Propagation of Balance-of-Payment Shocks: Example—Banks and Investment Funds

Step 0: Initial capital outflow and asset price shocks.
Step 1: Domestic liquidity contagion across sectors caused by the reaction of sectors directly affected by the initial shocks
Step 2: Second-round effects: impact of liquid asset sales on asset prices



Source: Author.
Note: FX = foreign exchange; IF = investment fund; LC = local currency. Global safe assets include deposits at the central bank and sovereign securities of reserve currency issuers, which can preserve their liquidity and value during global distress episodes.

Box 2. Liquid Asset Buffer Structure and Contagion Effects
(Countries without Reserve Currencies[1])

Liquid asset buffer	Impact of FX BOP liquidity shock (in FX terms)
Local currency assets, domestic issuers (inside money, accepted only for domestic transactions)	• **Contagion to other domestic private-sector institutions** (through, for example, bank deposit withdrawal, sales of securities, redemption of investment funds, repos, contingent financing with domestic agents) • **Possible contagion to the local central bank** (even without ELA) through domestic banks' LC reserve deposits and access to standing liquidity facilities with LC securities as collateral • Valuation losses from local currency depreciation
FX assets, domestic issuers (inside money, accepted only for domestic transactions)	• **Contagion to other domestic private-sector institutions** (through, for example, bank deposit withdrawal, sales of securities, repos, the redemption of investment funds, contingent financing with domestic agents) • **Possible contagion to the local central bank** (even without ELA) in fully or partially dollarized economies through domestic banks' FX reserve deposits and access to standing liquidity facilities with FX securities as collateral • No valuation losses from local currency depreciation
Global safe assets (FX assets, outside money, accepted for cross-border and domestic transactions**)**	• **No contagion to other domestic private-sector institutions** if sold to foreign agents, creating an offsetting capital inflow • **No contagion to the local central bank** unless it takes foreign securities as collateral for standing liquidity facilities • No valuation losses from local currency depreciation

1/ The key constraint for these countries is that foreigners accept only hard currency payments (that is, global safe assets) for cross-border payments even if they take domestic currency and assets in the local market (that is, purchase of equity and bonds within local markets). When foreigners sell local currency assets and repatriate them back to their home country, they convert the LC proceeds to hard currency.

The last step of the systemwide liquidity stress test is to examine the role of active and passive central bank liquidity policies. In recent systemic liquidity events, central banks have often invented new ways to actively intervene and provide liquidity in markets (see the policy discussion section for details). However, the contagion effects impact the central bank even without active liquidity measures such as ELA and even when private sectors can withstand the shock on their own. Usually, only banks are allowed to be direct counterparts of a central bank. Therefore, BOP shocks could eventually transmit to a central bank when banks are affected directly and indirectly through contagion. More specifically, there are a couple of distinct contagion channels for the central banks:

- ***Liquidity demand from banks***: In Figure 2, a part of banks' liquid assets is reserve deposits at the central bank. Indeed, reserve deposits (excess reserves and, often, required reserves) are a significant portion of banks' high-quality liquid assets (HQLA) where Basel III LCR is implemented). If banks can maintain their required LCR ratio after liquidity shocks with excess reserves, standard LCR assesses that banks are resilient. But even in this case, the central bank experiences an outflow of reserve reposits, i.e., contagion effects. Also, banks can fill their liquidity gap by using standing (i.e., normal time) central bank facilities with qualifying collaterals.

- ***FX liquidity provision through intervention***: Figure 2 shows that LC asset sales by foreign investors eventually create FX liquidity outflows from the country when they convert LC proceeds to FX for repatriation. If foreign investors may exchange currencies with local banks, then it creates FX liquidity outflows from banks. If banks use FX reserve deposits, the liquidity demand spills over to the central bank. Alternatively, banks may exchange LC and FX in FX markets. FX liquidity demand spills over to the central bank if it intervenes in the market to limit excessive volatility.

Such liquidity demand analysis of the central bank could help gauge the extent of necessary liquidity provision measures during distress episodes. For example, if banks exhaust all liquidity other than required reserves, the test can quantify how much percentage points reduction of reserve requirements is needed to restore the liquidity balance of banks. If NBFIs and non-financial sectors are experiencing severe liquidity stress, then a central bank may need to consider introducing new liquidity provision tools or provide liquidity to banks so that they can on-lend to the distressed sectors.

The analysis could also inform central banks' international reserve adequacy to sustain financial stability. The FX liquid assets held by central banks are mostly global assets and qualify as international reserves. Therefore, the impact analysis of the central bank balance sheet is closely related to the international reserve adequacy assessment (IMF 2016a).[15] The systemwide liquidity stress test approach in this paper is different from a typical reserve adequacy discussion, as it also considers (private) sectoral FX liquidity stress, their domestic contagion effects, and the role of international-reserve-qualifying assets held by the private sector explicitly.

Illustrative Example

This section explains the Excel-based tool in detail, using hypothetical emerging market (EM) data for illustration. Artificial data mimicking a vulnerable emerging market are created to highlight risks from substantial external borrowings and partial dollarization—a common issue found in man EMDEs. One of the main external and financial stability risks to such an economy is capital outflows, as the global liquidity condition tightens or country risk premia jump. In contrast with the example explored in Figure 2, in EMs, the NBFI sector and capital markets tend to be underdeveloped, and banks and NFCs (and possibly sovereign) tend to have a large footprint in the financial system. After a series of EM crises, many EM banks now manage their currency and liquidity mismatch well. However, if (unregulated) NFCs are building up external debt, bank liquidity stress tests alone could miss systemwide liquidity risks. It becomes critical to link balance sheets between NFCs and banks and assesses liquidity risks from systemwide perspectives.

[15] The contagion effects on the central bank are more substantial in a fully dollarized economy or those with currency-board-like arrangements. Any liquidity stress is FX liquidity shock in such economies; therefore, any banks' withdrawal of central bank liability reduces its balance sheet. Such withdrawal also reduces international reserves, as 100 percent of central bank assets are international reserves (Figure 2; El Hamiani Khatat and Veyrune 2019). Similar effects arise for the economies with currency-board-like fixed exchange rate arrangements where all or a high share of central bank liabilities are required to be backed by international reserves.

Identifying Systemically Important Sectors and Linkages

The first step of systemwide liquidity analysis is to examine the BSA data. Standard BSA matrixes and their network visualization (Table 2 and Figure 3) are common methods used to obtain broad financial linkages across sectors. There are seven economic sectors, including the general government, central bank, banks, asset managers, NFCs, households, and external.

Table 1. Balance Sheet Approach Matrixes

(In millions of USD)

All currencies, all instruments, in millions of USD

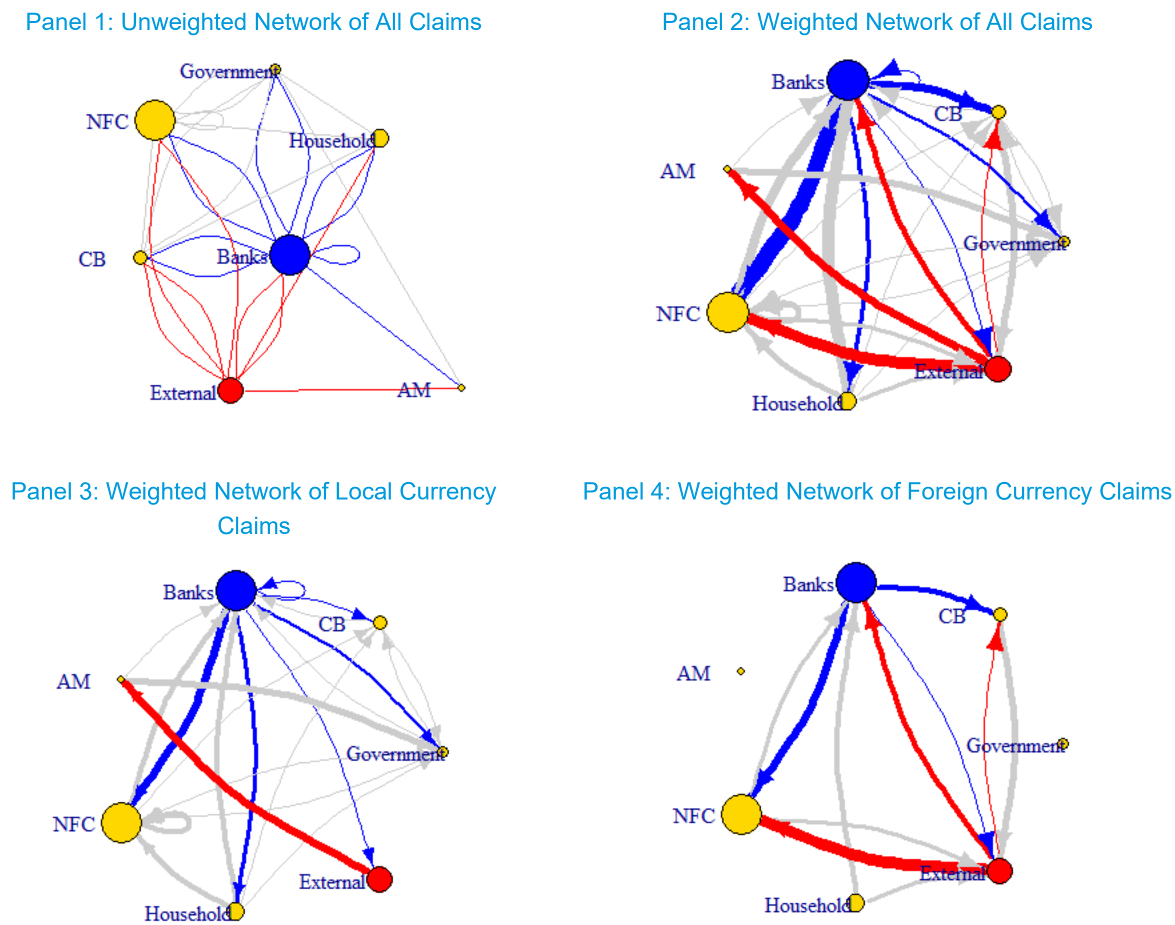
Borrower \ Creditor	GenGov	CB	Banks	AM	NFC	House	External	Sum by borrower
GenGov	0	50	140	380	100	50	0	720
CB	50	0	400	0	20	100	50	620
Banks	100	100	10	20	500	590	300	1620
AM	0	0	0	0	0	0	400	400
NFC	100	0	800	0	300	320	600	2120
House	0	0	200	0	0	0	0	200
External	0	350	60	0	200	200	0	810
Sum by creditor	250	500	1610	400	1120	1260	1350	
Asset+liability	970	1120	3230	800	3240	1460	2160	
Asset-liability	-470	-120	-10	0	-1000	1060	540	

FX exposures, all instruments, in millions of USD

Borrower \ Creditor	GenGov	CB	Banks	AM	NFC	House	External	Sum by borrower
GenGov	0	0	0	0	0	0	0	0
CB	0	0	280	0	0	0	50	330
Banks	0	0	0	0	200	300	300	800
AM	0	0	0	0	0	0	0	0
NFC	0	0	400	0	0	0	600	1000
House	0	0	0	0	0	0	0	0
External	0	350	42	0	200	200	0	792
Sum by creditor	0	350	722	0	400	500	950	
Asset+liability	0	680	1522	0	1400	500	1742	
Asset-liability	0	20	-78	0	-600	500	158	

Source: Author.
Note: AM = asset managers; CB = central bank; GenGov = general government; NFC = non-financial corporates.

Figure **3. Financial Linkage: Hypothetical System**



Source: Author.
Note: Blue = domestic bank credit and claims to the other sectors; red = external credit and claims to domestic residents; node bubble size = proportional to the sum of the sector's financial assets and liabilities outstanding; arrow size in weighted network = proportional to the amount outstanding; only includes balance sheet exposures shown in Table 3. AM = asset managers; CB = central bank; NFC = non-financial corporates.

Table 2 and Figure 3 exhibit the following characteristics of the system.

- ***Who is systemically important?*** The systemic importance of sectors and institutions is often judged by size and interconnectedness. The map (panel 1) shows that banks and NFCs have large financial footprints (measured as their financial balance sheet size defined as the sum of gross financial assets and liabilities).[16] They are also highly connected to other domestic sectors and overseas exposures. Asset managers are small but critical in connecting foreign investors and domestic government bond markets.

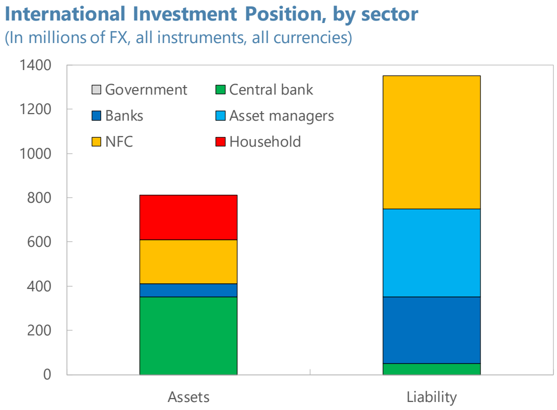
[16] The size of financial institutions is typically measured by their financial assets, which mostly match up with their size of financial liabilities. However, NFCs tend to have larger financial liabilities than financial assets, as they have substantial real assets (e.g., factories). I use the sum of financial assets and liabilities as the indicator of size to avoid underestimating the financial footprint of NFCs by using financial assets to measure size.

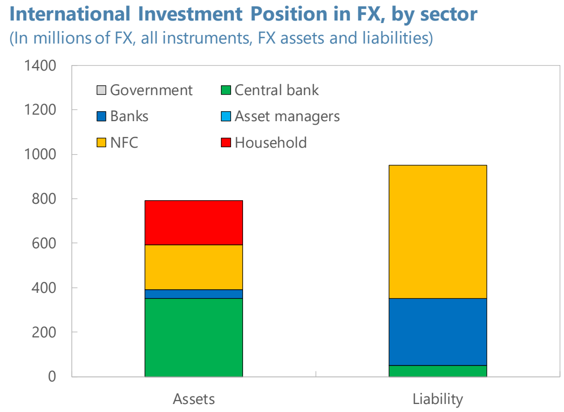
- ***Who is exposed to capital outflow shocks directly?*** Panel 2 and Figure 4 show that NFCs are mostly exposed to foreign investors, followed by AMs and banks. Panels 3 and 4 show that these exposures are mostly in FX, except for AMs, who are a mere conduit for foreign investors to purchase LC government bonds. All foreign liabilities are in FX except for investments in LC government bonds.

Figure 4. International Investment Position: Hypothetical System

NFCs, banks, and AMs have significant foreign liabilities. The private sector has substantial foreign assets, more considerable than international reserves.

Foreign investors hold AMs' LC-denominated shares, notably reducing net FX international investment position.





Source: Author. Based on the illustrative example in the attached Excel file.
Note: AM = asset managers; NFC = non-financial corporates.

- ***What are the domestic transmission channels of capital outflow shocks?*** Figure 4 and sectoral balance sheet data in the next subsection indicate that NFCs' FX liquid asset buffer includes substantial global safe assets, followed by domestic FX deposits. Therefore, NFCs' stress could spill over to banks. Redemption from domestic asset managers causes domestic financing challenges to the government, and it needs to find alternative (domestic) investors, especially banks. Redemptions eventually lead to FX liquidity shocks when foreign investors convert LC process to FX for repatriation. Banks' FX liquid assets are mostly FX reserve deposits; therefore, their stress will transmit to their central bank and reduce international reserves. The government does not have any additional global safe assets, so international reserves are the only FX liquid asset buffers of the broad public sector.

- ***Any additional channels?*** The household sector holds substantial FX deposits at local banks and global safe assets (including FX cash at home). However, banks are likely to amplify the liquidity stress at the time of stress. They may panic or become highly risk averse to domestic LC assets when they see capital outflows, sharp exchange rate depreciation, and potential bank distress. Banks could reallocate their assets away from LC assets and domestic FX bank deposits to global safe assets, including FX cash at home. If they behave like this, their global safe assets buffer does not help the whole economy withstand the shock. Rather, the household sector increases capital outflows and amplifies stress.

In this example, banks' FX liquidity stress spills over substantially to the central bank balance sheet and international reserves, paradoxically because the quality of HQLA is high. Over 90 percent of banks' FX HQLA (before haircut) is excess and required reserve deposits. The quality of HQLA is high according to the Basel III definition of HQLA, which treats central bank reserves as the safest type of liquid assets. However, FX reserve deposits account for about three-quarters of gross international reserves. Even with high FX reserve requirements of 20 percent of FX customer deposits, about half of the international reserves echo banks' excess reserves, which could be withdrawn quickly and substantially when banks face FX liquidity stress.

Sectoral Balance Sheet

Non-financial corporates

Table **2. Non-Financial Corporate Balance Sheet**

(In millions of USD)

NFC balance sheet									
Asset					Liability				
	LC	FX	Total	%/TA		LC	FX	Total	%/TA
Cash and cash equivalent	**420**	**400**	**820**	**39**	**Accounts payable**	**300**	**0**	**300**	**14**
Cash	20	0	20	1	**Loans**	**400**	**760**	**1160**	**55**
Bank deposits, domestic	300	200	500	24	Domestic banks	400	400	800	38
Bank deposits, external	0	200	200	9	Banks abroad	0	360	360	17
Government bond	100	0	100	5	**Bonds**	**0**	**240**	**240**	**11**
Accounts receivable	**300**		**300**	**14**	Domestic banks	0	0	0	0
Fixed assets	**900**	**0**	**900**	**42**	International	0	240	240	11
Intangible assets	**100**	**0**	**100**	**5**	**Equity**	**420**	**0**	**420**	**20**
					State owned	100	0	100	5
					Domestic private	320	0	320	15
Total	**1720**	**400**	**2120**		**Total**	**1120**	**1000**	**2120**	

Source: Author.
Note: FX = foreign exchange; LC = local currency; TA = total assets.

NFCs have substantial currency and FX maturity mismatch and are exposed to external financing risks. Nearly half of their liabilities are in FX, including domestic bank loans, international bank loans, and bonds. Sixty percent of FX borrowings are from external sources, making them vulnerable to stress in global capital markets. Since a large part of NFC assets is usually fixed assets and intangibles (that is, intellectual property rights), their balance sheets typically show significant liquidity mismatch. In this example, NFCs have quite a bit of liquidity (cash and cash equivalent), at about 40 percent of total assets. Still, they could suffer from FX liquidity shocks, as their liquid FX assets are about 40 percent of FX borrowings.

NFCs could transfer their FX liquidity shocks to banks significantly. Half of their FX liquid assets are deposits at local banks, and the other half are bank deposits abroad. If they primarily use domestic bank deposits to absorb liquidity shocks, it would transfer the stress to domestic banks. But if they use bank deposits abroad (that is, international-reserve qualifying foreign assets in the NFC sector), then spillover effects would be limited. The domestic bank deposit withdrawal rates also depend on bank lending. If banks refinance all existing loans, it would reduce the FX cashflow gap and needs to tap into FX liquid asset buffer. NFCs' liquidity gap would become even smaller if banks extend additional loans, for instance, as part of fiscal or central bank liquidity support programs to corporates during the COVID-19 crisis. Such programs transfer NFCs' liquidity stress to the government and the central bank via banks.

Banks

Table 3. **Domestic Bank Balance Sheet**

(In millions of USD)

Bank Balance Sheet

Asset	LC	FX	Total	%/TA
Cash + CB reserve	**120**	**280**	**400**	**25**
Required reserve	62	106	168	10
Excess reserve	58	174	232	14
Sovereign security	**140**	**24**	**164**	**10**
Local	140	0	140	9
Foreign (global safe assets)	0	24	24	1
Interbank	**10**	**30**	**40**	**2**
Local	10	0	10	1
External_intra group	0	12	12	1
External_other banks	0	18	18	1
Loan	**606**	**400**	**1006**	**62**
NFC, local	400	400	800	49
Household	200	0	200	12
National NFC, abroad	6	0	6	0
Foreign NFC, abroad	0	0	0	0
Fixed, intangible assets	**10**	**0**	**10**	**1**
Total	**886**	**734**	**1620**	

Liability	LC	FX	Total	%/TA
Resident Deposits	**620**	**500**	**1120**	**69**
Household	200	300	500	31
NFC	300	200	500	31
AM	20	0	20	1
GenGov	100	0	100	6
Nonresident Deposits	**0**	**30**	**30**	**2**
Interbank	**110**	**180**	**290**	**18**
Central bank	100	0	100	6
Local	10	0	10	1
External_intra group	0	60	60	4
External_other banks	0	120	120	7
International bonds	**0**	**90**	**90**	**6**
Equity	**90**	**0**	**90**	**5.6**
Total	**820**	**770**	**1620**	

Memo

Reserve requirement (FX)	20 percent of FX customer deposits
Reserve requirement (LC)	10 percent of LC customer deposits

Source: Author.
Note: AM = asset managers; CB = central bank; FX = foreign exchange; LC = local currency; NFC = non-financial corporates; TA = total assets.

Banks have little currency mismatch but face considerable FX liquidity risks. This economy is highly dollarized, with nearly half of bank assets and liabilities in FX. However, banks' FX assets are about 95 percent of FX liabilities, suggesting little currency mismatch. However, about 60 percent of FX assets are loans (including customer and interbank loans), highlighting the importance of FX liquidity risks. About two-thirds of FX borrowings are bank deposits, mostly from domestic NFCs and households, but there are small non-resident deposits that could run off in a capital outflow episode. Only NFCs may withdraw their deposits to cover their FX cashflow gaps, because households do not have any FX borrowing. However, both deposits could run off when confidence in the stability of domestic monetary and financial systems deteriorates—referred to as a "panic run" in this paper.

The stability of banks' international borrowings is likely to differ across instruments and counterparts. In addition to non-resident deposits, banks' international borrowings consist of loans from other banks in the same financial group (for foreign banks' branches and subsidiaries in the economy), loans from unrelated banks abroad, and international bonds. Intragroup borrowings are likely to be stable. Indeed, they could be a part of foreign direct investment (FDI), which tends to have long maturities and high rollover rates at maturity. Bonds tend to have longer maturities than loans, so contractual FX outflows from debt service at short horizons (like weeks and months) are likely to be small unless there's a bunching of maturities. Yet, they may not be rolled over much during a capital outflow episode. Moreover, there could be additional contingent outflows if bond covenants (often linked with financial market indicators such as exchange rates, interest rates, and the financial health of the borrower) are triggered. Loans from unrelated banks are usually most unstable, with relatively short maturities and low rollover rates amid a stress event.

Central bank

Table 4. **Central Bank Balance Sheet**
(In millions of USD)

Central Bank Balance Sheet									
Asset					**Liability**				
	LC	**FX**	**Total**	**%/TA**		**LC**	**FX**	**Total**	**%/TA**
International reserves	**0**	**370**	**370**	**60**	**FX liabilities**	**0**	**330**	**330**	53
Gold	0	20	20	**3**	***External borrowing***	***0***	***50***	***50***	8
FX deposit abroad	0	350	350	56	***Bank reserves***	***0***	***280***	***280***	**45**
Domestic assets	**250**	**0**	**250**	**40**	**LC liabilities**	**290**	**0**	**290**	47
Credit to banks	100	0	100	16	***Currency issued***	***137***	***0***	***137***	22
Government bond	50	0	50	8	Household	100	0	100	16
Fixed assets	100	0	100	16	NFC	20	0	20	3
					Government	5	0	5	1
					Bank	12	0	12	2
					Bank reserves	***108***	***0***	***108***	***17***
					Government deposit	***45***	***0***	***45***	***7***
					Operation (net)	***-50***	***0***	***-50***	***-8***
					Equity	***50***	***0***	***50***	***8***
Total	**250**	**370**	**620**		**Total**	**290**	**330**	**620**	100

Source: Author.
Note: AM = asset managers; CB = central bank; FX = foreign exchange; LC = local currency; NFC = non-financial corporates; TA = total assets.

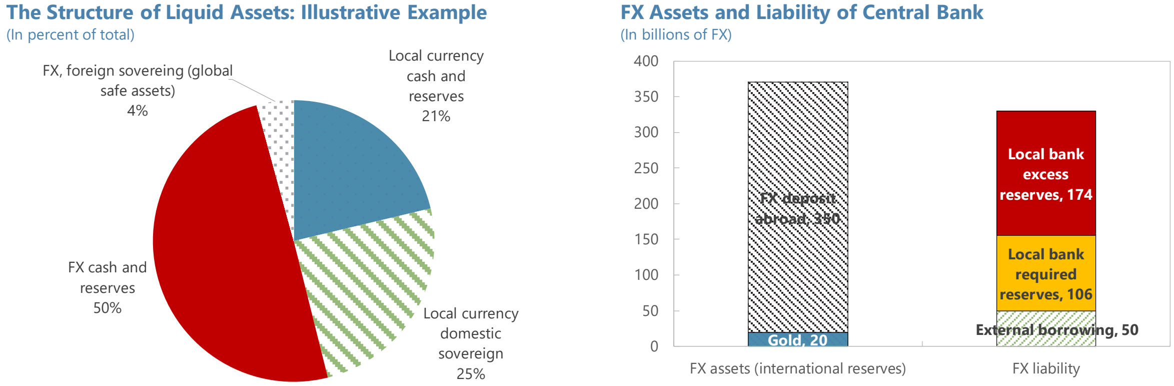
The central bank's international reserve is highly vulnerable to domestic spillover effects from banks' FX liquidity stress. Banks' reserves are 45 percent of the central bank's total liabilities, and excess reserves alone are nearly 30 percent of the central bank's total liabilities and three-quarters of international reserves. International reserves are global safe assets but not stable in the sense that they are funded with borrowed money. In other words, there's a massive gap between gross international reserve (GIR) and net international reserve (NIR). This paper defines NIR as the international reserves net of FX borrowings.[17] Only 10 percent of GIR is the central bank's own NIR. The banking sector has high-quality HQLA consisting largely of central bank reserves, which is good from individual banks' stability perspectives. But it simultaneously means international reserves are not funded with stable sources of money as they could be rapidly when domestic banks withdraw them to withstand their liquidity stress.

[17] NIR is defined differently depending on context (such as ARA and BOP statistics—BPM6). This paper's definition differs from the ARA metric, which defines net reserves as the measure subtracting predetermined short-term drains from the official reserve position. See IMF guidance note on the NIR definition.

Figure 5. FX Reserve Deposits and International Reserves: Hypothetical System

If a substantial part of banks' liquid assets is FX reserves at the local central bank, the quality of banks' liquid assets is good…

…but it means international reserves could drop abruptly and substantially when banks suffer from FX liquidity stress.



Source: Author. Based on the illustrative example in the attached Excel file.

Stress Testing Design and Scenario

The illustrative example examines risks from capital outflows. The balance sheets of the hypothetical economy are calibrated so that the primary sources of systemwide FX liquidity shock are the stress from FX debt service of NFCs, capital outflows from household and non-resident deposits, and foreign investors' demand for FX to repatriate the sales of LC investment. In line with these BOP shocks, the domestic currency is assumed to depreciate by 30 percent. Lower-quality domestic liquid assets—that is, securities in LC and FX issued by domestic agents—lose their value due to market sell-off (that is, haircut assumptions). However, FX reserves at the central bank and global safe assets maintain their full value. Haircut assumptions could be taken from some macro scenario if available or calibrated by applying actual observations from past crisis episodes, historical worst, or statistical methods.[18] The test horizon is set to one month so that one can resort to LCR benchmark assumptions if needed. The test horizon can be easily adjusted in the accompanying Excel file.

Given the nature of the foreign liquidity shocks and the structure of the financial system, the stress test focuses on the central bank, banks, and NFCs. Other sectors play a straightforward role in the overall analysis and do not require full-fledged sector-level stress tests. For instance, the government does not have any FX exposures. While they rely on financing from foreign investors in local sovereign bond markets, FX liquidity stress from their sell-off is felt by banks. The role of asset managers is the same as the government. Households have no FX liabilities or LC liabilities financed directly by foreigners. Their role in the systemwide stress test is to potentially intensify banks' FX liquidity stress by converting their LC deposits to FX deposits and withdrawing them to hold as cash or invest in foreign assets. Therefore, their roles are well captured by bank, NFC, and central bank stress tests.

[18] For example, for a stress test with a one-month horizon, one can calculate the monthly changes of asset values using long enough historical data and take X percentage point shock. If one takes the lowest one percentile shock, it means to assume a once-in-100-months (8⅓ years) shock.

A simplified cash flow-based bank FX liquidity stress test technique is applied to the three sectors. For non-financial sectors, FX cash inflows could consist of cash inflows from operation (that is, FX sales), investment income, and new gross FX financing, and outflows include debt service and FX expenses such as import bills.[19] For banks, investment incomes and debt service are their cash flows from operation (banking). Other profit and loss statement items, such as salaries paid in FX, are usually excluded in bank liquidity stress tests. The definition of liquid asset broadly follows that of HQLA of the LCR for all sectors. Following bank FX liquidity stress test practice, the example excludes all LC cashflows and LC liquid assets, though the tool allows alternative LC asset haircut assumptions. One exception is the demand for FX from bank customers (such as foreign investors in the asset management sector) who want to convert LC to FX with banks to fill their FX cashflow gap.

Following standard bank liquidity stress tests, the tests focus on the "first-round" impact of exogenous shocks. All the price assumptions, such as haircuts to liquid assets, exchange rates, and the size of BOP shocks are calibrated outside the Excel file. The resulting fire sales of liquid assets limit refinancing opportunities and increase the costs of agents who finance themselves in these markets. However, the tests do not consider the "second-round" impact of fire sales on asset prices, exchange rates, and additional spiral effects thereafter.

The main outputs of sectoral tests are the decline of liquid assets and their composition, rather than the pass or fail of each sector. The tool focuses on the domestic contagion effects of BOP shocks rather than the health of each agent and sector. Therefore, the template does not set any hurdle rate to judge pass or fail for sectoral stress tests. Instead, they produce the size of liquidated assets by asset type depending on the pecking order of liquidation. It also estimates additional financing needs to close the liquidity gap if a sector runs out of all liquid assets. For each sector, one option of the pecking order is first to liquidate all domestic FX assets (excluding required reserves) and then to liquidate global safe assets. The other option assumes liquidating global safe assets first and then domestic FX assets. Banks may liquidate all types of asset pro-rata, then the results would like somewhere between the two extremes. As a benchmark, banks are not allowed to liquidate required reserves. In the policy experiment section, I discuss the effects of relaxing reserve requirements, a frequently observed crisis management policy, when systemic liquidity shock materializes (for example, the GFC and the COVID-19 crisis).

The "Calculation" sheet in the Excel file implements the stress tests, and it has sector-level stress testing blocks for banks, NFCs, and the central bank. A few rows on top of the sheet list common assumptions, such as exchange rate, stress test horizon, FX reserve requirements (in percent of FX customer deposits, set at 20), and the behaviors of banks and NFCs. Users can choose whether banks liquidate FX reserves or other FX liquid assets first and whether NFCs liquidate FX deposits at local banks or other assets first.

[19] Data on FX cashflows from non-financial sectors' operations (such as import and export receipts) may not be available. For listed NFCs, their financial statements often report the share of overseas sales, but the information on import or currency decomposition of expense and debt service could be limited. If current account data are available by economic sector, such data could be used as proxies, assuming all transactions are in FX. For the governments, government financial statistics could give a fuller picture. Otherwise, FX cashflows from operations of non-financial sectors could be treated as zero, so the test would focus on cash flows from financial contracts following the bank liquidity stress tests.

Additional Stress Testing Parameters

Liquidity stress tests include several types of parameters that need to be calibrated with different approaches. There are four types of parameters, macro scenario, data-related, behavioral, and liquidity policy parameters. Table 5 summarizes the desirable approaches to calibrating them. Macro scenario parameters are variables aligned with the scenario, such as interest and exchange rates. These are usually linked with scenarios. Some parameters are proxies for missing granular data. For example, if the debt service schedule is available at a sufficiently high frequency—say, one month—then actual data provide expected cashflows from debt assets and liabilities. However, it may not be available, especially for sectors other than regulated banks and the central bank. Then some proxy assumptions, such as prorating the annual debt service schedule, are necessary. Behavioral parameters such as deposit withdrawal rates are the hardest to calibrate. One can take benchmark assumptions from Basel III LCR, apply the statistical approach and past crisis experiences, and reference peer countries' experiences. Tests should try a range of behavioral assumptions, because they tend to impact stress test results significantly. Lastly, there are variables related to the central bank's liquidity-related policies, such as reserve requirements.

Some parameters should be set consistently across domestic economic sectors—unique characteristics of systemwide tests in contrast with institution-specific tests. For instance, domestic banks' refinancing assumption of maturing loans to NFCs should be the same as the rollover rate of maturing domestic bank loans of NFCs. Similarly, NFCs and households' deposit withdrawal rates should be the same as assumptions for banks.

The refinancing rates of debts between domestic banks and other domestic sectors can be altered to see the sensitivity of the results. As explained in Box 1, the net supply of domestic liquidity is zero. These assumptions determine liquidity allocation among domestic economic sectors without changing the total net supply of domestic liquidity. If banks do not refinance maturing debt assets to conserve their liquidity, it will create a liquidity gap in other sectors. Moreover, if these sectors have domestic bank deposits as liquid assets, banks may eventually lose liquidity as depositors withdraw in response to their liquidity gap. Assuming a high refinancing rate of domestic bank loans concentrates the economy's liquidity gap in the banking sector. It could help quantify potential ELA needs and GIR losses, if the central bank provides liquidity to all economic sectors suffering from liquidity stress directly and indirectly. On a side note, LCR assumes a 50 percent refinancing rate for customer loans.[20]

[20] LCR assumes 50 percent net inflows from customer loan services. This could mean a 100 percent repayment rate (no default) and 50 percent refinance rate or an alternative combination of repayment and refinance rate such as a 50 percent default rate and 100 percent refinance rate. In the template, the default rate is implicitly set to 0, and the refinancing rate determines net inflows.

Table 5. Stress Testing Parameters and Their Calibration Approach

Parameter types	Examples	Approach
Macro scenario	Exchange rate, interest rates (policy, sovereign bonds, bank lending/borrowing rates), government, and NFC sector cashflows from operations	• Macroeconomic model that generates scenarios usually produces these assumptions. Government budget, cashflow projections, and debt sustainability analysis could inform cashflows from operations in the liquidity stress test of the government. Similarly, trade projection could inform NFC's FX cashflows from operations. • The model may not include all the necessary variables. In that case, one can set up an empirical model to forecast necessary variables as a function of variables included in the macro model. • Alternatively, a statistical approach. • Needs a statistical approach if the horizon of the macro scenario is too long (e.g., one year) compared with the liquidity stress test horizon (e.g., one month), because the volatility of asset prices and interest rates is much higher in a shorter time horizon. • Needs to be supplemented by proxy assumptions. For example, if the scenario is available annually, some flow projections (public finance, export receipts, and import bills) could be prorated to obtain monthly or weekly projections to match the stress test horizon.
Granular data	Instruments by counterpart, remaining maturity structure of assets and liabilities, contingent financing options/obligations (e.g., credit lines and covenants to debts), bond duration, instrument-specific interest rates	• Some parameters require granular data beyond existing BSA. For example, it is good to have high-frequency (such as month compared with annual) external debt service projections instead of arbitrarily prorating lower-frequency data to increase stress test accuracy. • Even when sector-specific data are unavailable (e.g., a maturity and repayment schedule of sovereign bonds held by banks), aggregate data could provide proxies (e.g., a repayment schedule of all domestic sovereign debt from the government's debt management office). • Off-balance-sheet commitments such as credit lines and debt covenants can give more accurate contingent financing options and needs than judgmental assumptions. • A detailed breakdown of liquid assets by instrument and counterpart type could improve the accuracy of interest rate payments/receipt cash flow assumption. •Granular bond asset information (duration, convexity, coupon, original maturity, issuance date, etc.) and interest rate assumptions. One approximation of haircut is bond duration × interest rate changes in the scenario.
Behavioral	Refinancing and rollover of maturing debt and assets, deposit withdrawal rates, pecking order to liquidate assets (e.g., domestic or foreign assets)	• Hard to pin down and need to rely on judgment. • Historical information could help, but history-based assumptions could give a false sense of security if a country has not experienced a significant financial crisis. • Basel III LCR assumption could provide a benchmark. • But additional country-specific modification is highly recommended. Supervisory process such as internal capital adequacy assessment process (ICAAP) could help one to understand the contingent behavior of banks. • Consider a range and alternative sets of assumptions, including the best and worst cases, to examine what types of behavior are more critical.
Liquidity-related policy	Central bank policy rate, reserve requirements, FX market intervention, ELA	Consider a range of policy instruments and their levels to examine the role of different policy options—hypothetical policy experiments.

The same consideration applies to domestic inter-financial-institution exposures. The benchmark assumption in the template is that financial institutions receive 100 percent of contractual inflows from other financial institutions (including the central bank), and all of them are refinanced, resulting in 0 net cash inflows. The refinancing rate for such exposures only changes the distribution of liquidity among financial institutions. It is essential to consider when the focus is in order to identify which banks could suffer from liquidity shortages. Also, when liquidity is distributed unevenly among banks, some banks might ask for ELA even when sector-aggregate liquid assets are sufficient to absorb sector-aggregate liquidity shocks. The benchmark template assumes away such distributional issues among domestic financial institutions to focus on the impact of aggregate, non-diversifiable shocks. Nonetheless, it is possible to extend the tests to examine the role of cash hoarding or network effects in amplifying the initial shocks. Indeed, the LCR that focuses on the health of individual banks, not the whole system, assumes 100 percent repayment rates from financial institutions and central banks and a 0 percent refinancing rate for these services, that is, a form of cash hoarding.

Incorporating these considerations, the main scenario assumptions are summarized in Table 6. The main risk is capital outflows from banks, NFCs, and LC sovereign bond markets with local currency depreciations. The paper also considers the sensitivity of the stress test results to crucial behavioral assumptions.

Table 6. **Stress Testing Parameter Assumptions Used in the Example**

Parameter	Value
FX deposit reserve requirement, %	20
Exchange rate depreciation rate, %	30
Banks: nonresident deposit outflows, % of stock	50
Banks: rollover of maturing external debt from parent banks, % of maturing debt	90
Banks: rollover of maturing external borrowing from unrelated banks, % of maturing debt	0
Banks: rollover of maturing external bonds, % of maturing bonds	0
Banks: rollover rate of maturing borrowing from domestic central banks and banks, % of maturing exposures	100
Banks: household panic deposit run, % of stock	0, 5 [1]
Banks: NFC panic deposit run, % of remaining deposits after using them to fill NFC liquidity gap	0, 10 [1]
NFCs: rollover of domestic bank loans, % of maturing loans	50 [2]
NFCs: rollover of FX borrowing, excluding domestic bank loans, % of maturing debt	0
Sovereign: liquidation rate of LC sovereign debt held by foreign investors, % of outstanding debt	30
Central bank: FX market intervention, USD	5 million

1/ 5% is the LCR assumption for stable retail deposits. 10% is the LCR assumption for less stable deposits.
2/ 50% is 50% net inflows from maturing customer loans, which reflect a 0% default rate and 50% rollover rate, among other possibilities.

Results and Interpretation

Figure 6 shows how each type of stress affects the FX liquidity balance of banks and the central bank. Panels 1-4 assume no customer deposit run due to confidence loss, and panels 5-6 include a panic deposit run. Panels 1-2 and 5-6 assume NFCs use domestic bank deposits first and banks use excess reserve first, and panels 3-4 assume they use other liquid FX assets first. In all cases, the stock of required reserves declines when banks experience FX customer deposit outflows subject to reserve requirements. Each bar shows the impact of stated shocks such as cashflow from operations (that is, contractual flow), outflows from FX liabilities, and outflows related to the conversion of LC sovereign bond sales proceeds by foreign investors for repatriation. In panels 2, 4, and 6, the central bank cashflow bar shows the impact of amortization of external FX borrowing, which is not rolled over. As for the FX demand from LC-to-FX conversion, while banks do not need to respond to such demand, we assume that they do.[21, 22] If banks do not have sufficient usable liquid FX assets (shown as "gap" in panels 1, 3, and 5), they ask for central bank liquidity support. The central bank is assumed to provide full support so that the post-stress international reserves represent the severity of the total systemwide liquidity shortage. Any central bank FX transactions that do not accompany a reduction of FX liability reduce net international reserves. In Figure 6, FX market intervention and FX liquidity support for banks, both of which are reflected in bar 6 in panels 2, 4, and 6, lower net international reserves.

Both deposit outflows and sales of LC sovereign bonds are significant drivers, reducing FX liquidity of banks and the central bank when NFCs use domestic bank deposits first. NFCs have 200 million FX liquid assets in domestic banks and another 200 million in foreign banks. They can absorb all the liquidity shocks with foreign bank deposits alone if they choose. However, if they use domestic deposits first, banks suffer from US$80 million deposit outflows just to fill NFCs' liquidity gap. With a 50 percent outflow of non-resident deposits, total deposit outflows without panic are US$95 million, similar to US$92 million in outflows related to the sales of LC sovereign bonds by foreign investors. In addition, net cash outflows from operations total US$24 million, and a domestic customer deposit run due to panic totals USD US$27 million. The last two factors matter for the overall stress test results but less so than the first two factors.

The pecking order to liquidate assets, especially that of NFCs, alters financial stability impact substantially, because NFCs have substantial foreign assets. The central bank holds two-thirds of foreign FX liquid assets, and NFCs hold most of the remaining third (Figure 7). Without panic, NFCs withdraw 40 percent of domestic liquid assets if they use local deposits first, but withdrawal rates decline to zero if NFCs use foreign deposits first. Banks' pecking order also matters but far less so than NFCs, because only US$24 million out of a total of US$304 million FX liquid assets are foreign assets. Indeed, banks' share in the nation's foreign FX liquid assets is negligible. The difference in combined impact on the central bank balance sheet is stark. Banks' excess reserve deposit withdrawal rate declines from 100 to 60 percent.

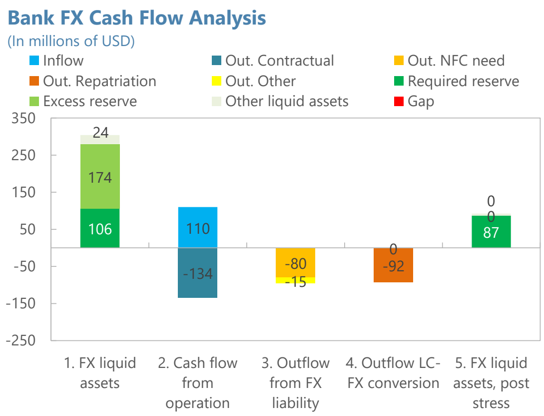
The pecking order affects stress test results more than panic deposit runs. Under the standard LCR assumptions for customer deposit outflow rates (Table 6), Figure 6 shows that the impact of NFC deposit outflows from the pecking order (US$80 million) is much larger than the impact of panic runs (US$27 million). Of course, arbitrarily severer outflows from panic runs could turn around the results. Indeed, if the panic-related deposit outflow rate exceeds 15½ percent, then runs would have a severer impact. Then, the task of stress testers is to assess how likely panic runs from the whole banking system (not individual banks) could exceed the threshold using the statistical approach, for instance.

[21] Alternatively, the central bank, rather than banks, could be the ultimate counterpart to provide FX in the foreign exchange market. Such transactions are recorded as additional FX intervention.

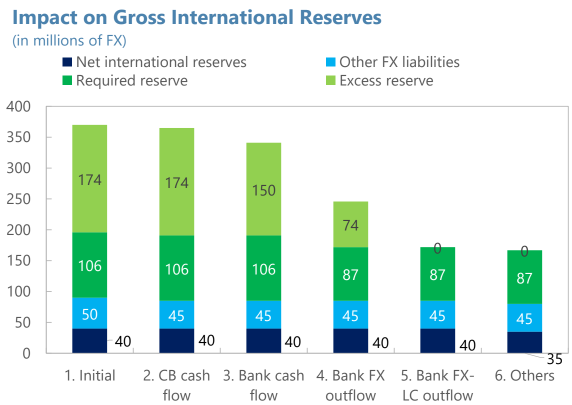
[22] Liquidation of LC sovereign bonds alone does not cause FX liquidity outflow. It results in outflows only when LC proceeds are converted to FX in the foreign exchange market and repatriated back to investors' home countries.

Figure 6. Results: Impact on Bank and Central Bank FX Liquidity Buffers

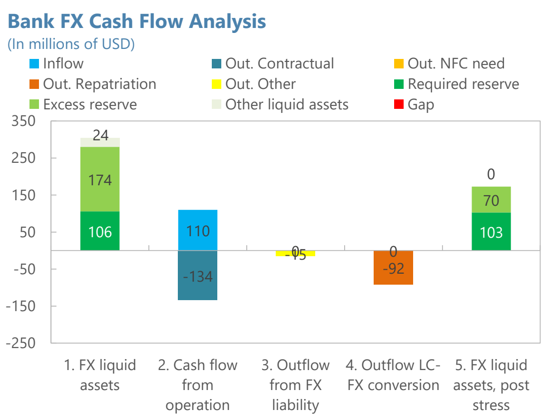
Panel 1. Without panic run, and liquidate domestic bank deposit/excess reserve first.



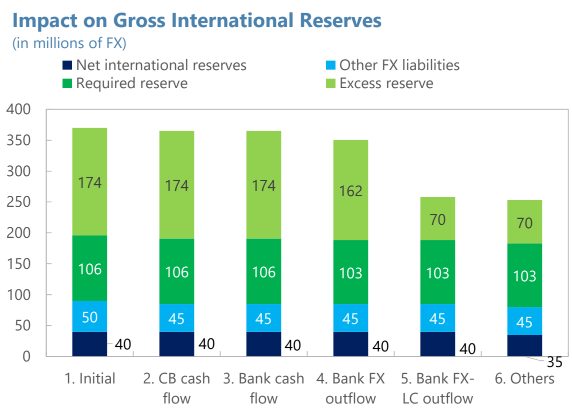
Panel 2. Without panic run, and liquidate assets other than domestic bank reposit/excess reserve first.



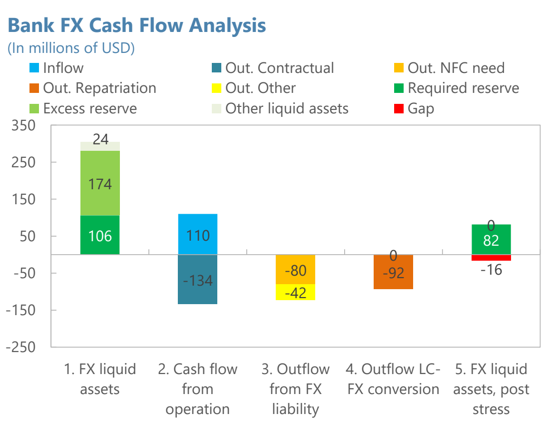
Panel 3. Without panic run, and liquidate domestic bank deposit/excess reserve first.



Panel 4. Without panic run, and liquidate assets other than domestic bank deposit/excess reserve first.



Panel 5. With panic run, and liquidate domestic bank deposit/excess reserve first.



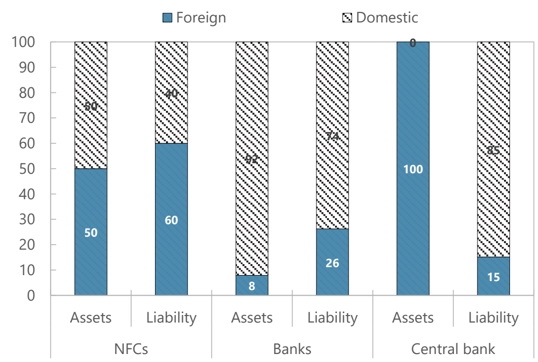
Panel 6. With panic run, and liquidate assets other than domestic bank reposit/excess reserve first.

Source: Author.
Note: FX = foreign exchange; LC = local currency; NFC = non-financial corporates.

Figure 7. Sectoral Distribution of FX Liquidity and Liability
(In percent)

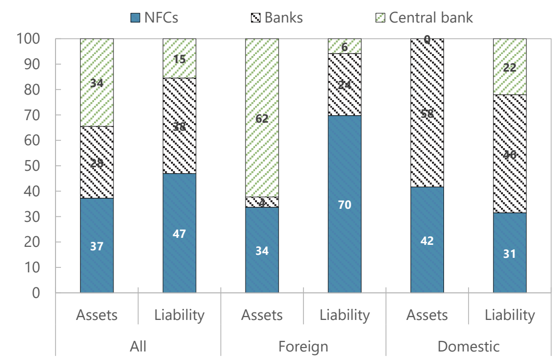
About half of NFC FX liquid assets and liabilities are foreign, while most banks' exposures are vis-à-vis domestic sectors. All of the central bank's FX liquid assets are foreign, whereas most of its liabilities are with domestic banks.

FX liquid assets and liabilities by sources
(In percent of total)



Two-thirds of FX foreign liquid assets are the central bank's international reserves, and the rest are mostly NFCs'. Banks hold a majority of LC liquid assets. Seventy percent of FX foreign liabilities are of NFCs, followed by banks. Banks have the largest share in domestic FX liabilities; both NFCs and the central bank hold notable shares of the rest.

FX liquid assets and liabilities: Sectoral distribution
(In percent of total)



Source: Author.
Note: FX = foreign exchange; LC = local currency; NFC = non-financial corporates.

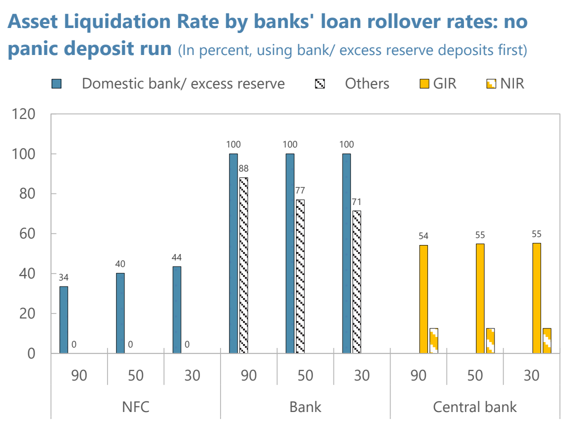
In this example, banks run out of their usable FX liquid asset buffers and need to ask for FX liquidity support only when there is a panic run, and NFCs use domestic deposits first. In panels 5 and 6 of Figure 6, banks' overall FX liquidity gap is US$16 million, which is absorbed by NIR. Yet, both GIR and NIR remain positive, suggesting that the central bank can withstand the stress even in the worst-case scenario considered.

Alternatively, the central bank can adjust reserve requirements, which will change the impact on the central bank balance sheet and NIR. Lowering the reserve requirement by four percentage points to 16 percent eliminates the need for liquidity support need. Post-stress GIR is the same when the central bank uses liquidity support or reserve requirement adjustment. Nonetheless, NIR is higher with reserve requirement adjustment, because it reduces the central bank's liability and balance sheet size. In contrast, liquidity support does not change the central bank's balance sheet size, because it replaces NIR with domestic assets (FX claims to domestic banks). Such a difference causes opposite monetary policy impacts. The policy discussion section further investigates such interaction of monetary and financial stability policy.

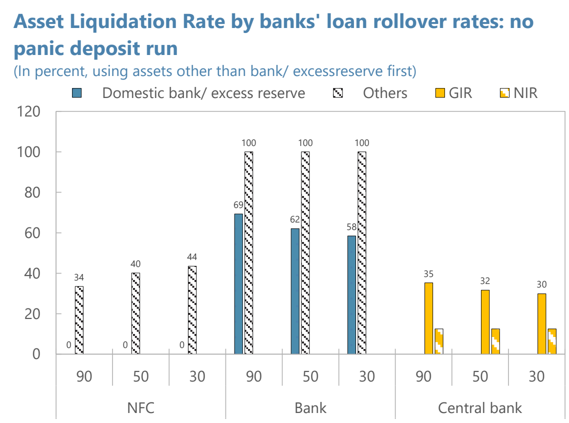
At the same time, changes in banks' customer loan refinancing rates do not change results substantially. Reducing refinancing rates helps banks and the central bank conserve their liquidity at the cost of increasing stress to NFCs initially. Figure 8 shows sensitivity test results assuming the same parameters as Figure 6 but with three alternative domestic customer loan refinancing rates, 90, 50, and 30 percent. Lower refinancing rates shift liquidity from NFCs to banks but also increase NFCs' deposit withdrawal rate. However, in this example, the net effects on banks' liquidity are positive, and banks' asset liquidation rates decline with lower customer loan refinancing rates. Nonetheless, the impact on international reserves remains the same when NFCs and banks liquidate domestic assets first (panels 1 and 3), because banks exhaust all excess reserves even with 0 percent rollover rates. When banks retain some excess reserves after stress (panels 2 and 4), lower refinancing rates also help conserve international reserves. Still, changing the refinancing rate has a much smaller impact on the financial sector's liquidity than changing NFCs' pecking order of asset liquidation. It is because NFCs have a stronger liquidity position against the considered stress—NFCs' overall asset liquidation rate is significantly less than that of banks and, in some cases, than that of the central bank. NFCs also have much more foreign assets than banks (Figure 7). They can withstand the shocks with their foreign assets alone.

Figure 8. Results: Sensitivity Test for Alternative Bank Loan Rollover Rate Assumptions[1]

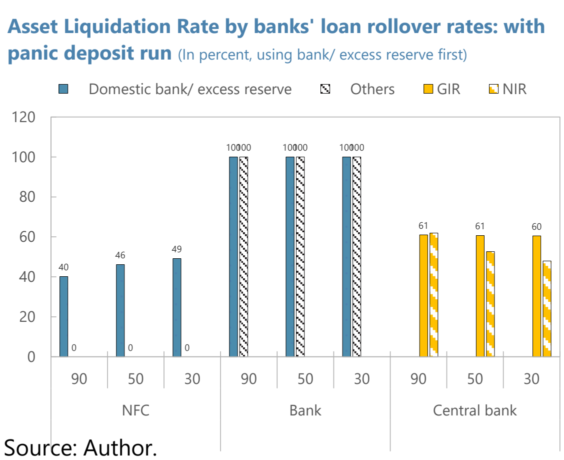
Panel 1. Liquidating domestic bank deposit/reserve first without panic run



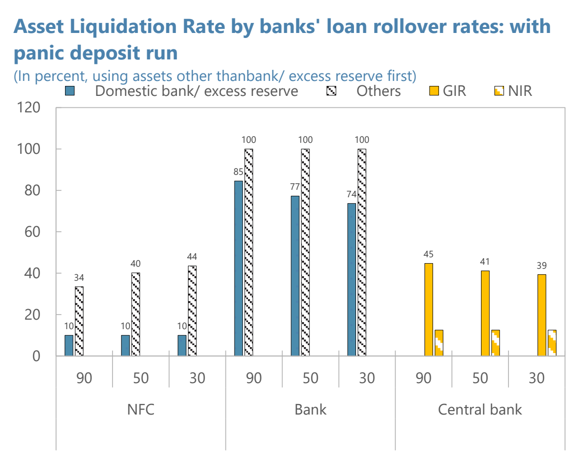
Panel 2. Liquidating assets other than domestic bank deposit/reserve first without panic run



Panel 3. Liquidating domestic bank deposit/reserve first with panic run



Panel 4. Liquidating assets other than domestic bank deposit/reserve first with panic run



Source: Author.

Note: GIR = gross international reserve; NIR = net international reserve.

1/ Domestic agents (especially NFCs) withdraw domestic bank FX deposits only to cover their FX cashflow gap. No additional loss-of-confidence-related deposit outflows. One-month horizon with a 30 percent LC depreciation rate. Reserve requirement is set at 20 percent for FX deposits, and foreign investors liquidate 10 percent of their LC sovereign bond holdings. Interbank and central bank exposures are repaid and refinanced fully, generating no net cash flows.

Policy Discussion

Financial stability risks are managed by both *ex-ante* preventive policies and *ex-post* safety-net tools. Preventive policies include microprudential tools (including both Basel minimum—Pillar 1—and additional Pillar 2 requirements tailored to each bank's risk profile) and macroprudential tools. They aim to limit financial institutions' exposures to systemic liquidity risks and increase their buffer to absorb shocks. Many macroprudential tools are countercyclical, such as the countercyclical capital buffer (CCyB), though some tools like systemic risk buffers (SRBs) target systemically important structural risks in some jurisdictions (IMF 2014a, b, and c and 2021d). Safety-net tools are crisis management instruments for financial institutions. Temporary tools to counter systemic liquidity crisis include releasing macroprudential buffers (that is, allowing banks to go below required LCR levels temporarily), lowering reserve requirements, systemic and emergency liquidity support (temporary liquidity facilities in addition to standing facilities, usually with expended collateral assets and sometimes for wider counterparts), and asset purchase programs (Dobler and others 2016; IMF and the World Bank 2020; IMF 2020b; FSB 2021; and Annex 1). FX liquidity provision is often backstopped with bilateral central bank swaps to ensure its credibility. Facing capital outflow pressures, some emerging market economies also have used FX intervention and capital flow measures (IMF 2022c).

It is critical to establish robust prudential measures to avoid moral hazards associated with liquidity support measures (Carlson and others 2015). Central bank liquidity support—once associated with a serious stigma before the GFC—is now widely expected when systemic liquidity stress materializes. Indeed, when a "never-happened-before" liquidity stress emerges, central banks have invented new ways to provide liquidity to the system. For example, in March 2020, unexpected segments of the financial market experienced liquidity distress when COVID-19 was recognized as a pandemic. NFCs experienced a significant funding squeeze as their expected earnings dropped and the commercial paper (CP) funding market froze. The U.S. treasury market—the safest and most liquid asset market in the world—experienced unusual volatility partly because many central banks in the world needed to get cash by liquidating U.S. treasury bonds that they held as a part of their international reserves. In response, the FRB introduced Commercial Paper (CP) Funding Facility to provide funding to facilitate the issuance of CP by eligible issuers and Foreign and International Monetary Authorities (FIMA) repo facility so that foreign central banks can repo-in their U.S. treasury instead of selling outright in cash markets. Several EM central banks have provided FX liquidity to banks so that they can on-lend to some NFCs (such as exporters, see Annex 1 for details). Given such recent practice, the private sector may take excessive risks that increase the chance of a systemic liquidity crisis without appropriate prudential measures. Indeed, until the GFC, the Basel bank oversight framework focused only on solvency regulation. The post-GFC reforms introduced liquidity requirements for the first time, based on the lessons learned from the liquidity stress experienced during the GFC.

Preventive prudential measures are more relevant in countries where the central bank has limited capacity to be the LOLR. The FX-liquidity support firepower of central banks without reserve currency is often limited to its international reserves. Bilateral central bank swaps could supplement them, but reserve-currency issuers usually offer international reserves only to advanced economies and major emerging markets with solid fundamentals. The amount may not be sufficient to withstand the shock, either.[23] In these cases, preventive measures to strengthen resilience within the private sector become even more important. The measures could include limiting the exposures to systemic liquidity risks and encouraging the building up of liquidity buffers (that is, self-insurance). The data for macroprudential policy tools (Alam and others 2019) show that limits on FX position are the most frequently used macroprudential measures among EMDEs. In addition to FX limits, some economies have extensive reporting requirements for external borrowings by all sectors, including hedging information.

Some macroprudential policies to build resilience against FX liquidity shocks are closely related to capital flow management measures (CFM) to cope with volatile capital flows (IMF 2016 b, 2017a, and 2022c). The IMF emphasizes that macroeconomic policy adjustments should be the first line of defense against continued BOP inflows or outflows and pressures against the exchange rate peg. However, the papers suggest prudential measures—especially currency-based macroprudential measures—could play a role when the BOP shock stems from the changes in the supply of global liquidity due to the changes in risk aversion among global investors, short-term speculations, or monetary policy stance of major jurisdictions. Currency-based macroprudential measures usually fall into one of three categories: (i) asset-side measures, such as higher risk weights on foreign-currency-denominated loans to unhedged borrowers; (ii) asset-liability matching measures, such as currency-differentiated LCRs and NSFRs; and (iii) liability-side measures, such as higher reserve requirements on FX deposits.[24]

National authorities may need to consider modifying prudential tools' design to better manage FX liquidity risks.

- **Liquidity coverage ratio**. As discussed earlier, high-quality foreign assets can substantially limit liquidity spillover effects among domestic sectors. In this sense, global safe assets are “higher quality” than domestic liquid assets, including reserve deposits at the local central bank. However, Basel liquidity regulation treats foreign sovereign securities as less safe (i.e., Level 2 assets in LCR) and subject to limits (up to 40 percent of HQLA) and valuation haircuts (15 percent). Such features do not appear desirable when the critical sources of systemic liquidity risk are capital outflows and dollar funding shocks. It may be worth changing the definition of HQLA if national authorities introduce FX LCR. Moreover, some central banks prohibit banks from holding any foreign securities for fear of investing in risky ones. Such rules could be modified to allow investing in international-reserve-qualifying global safe assets.

- **Reserve requirements**. Currency structure is a subtle feature of reserve requirements and usually does not attract much attention. However, it matters significantly for the resilience of banks against FX liquidity stress. Many EMDEs set FX reserve requirements. If banks are required to satisfy them by

[23] The U.S. Federal Reserve Board’s (FRB) Central Bank Swap Arrangement, established during the GFC, was extended to the central banks of Australia, Brazil, Canada, Denmark, Japan, Mexico, New Zealand, Norway, Singapore, South Korea, Sweden, Switzerland, and the United Kingdom and the European Central Bank. The FRB sets caps on the overall swap amount for non-reserve currency issuers. Separately, the FRB established bilateral swap arrangements with Canada (US$2 billion) and Mexico (US$3 billion) under the North American Framework Agreement in 1994 (see FRB). Still, upon the emergence of the Mexican peso crisis in the mid-1990s, the United States coordinated a rescue package of US$50 billion, including funding from private banks, the IMF, and the Bank for International Settlements.

[24] Basel's minimum microprudential LCR and NSFR requirements are set only for overall liquidity. National authorities can voluntarily enhance the requirements by currency (e.g., the domestic currency and all other currencies) as a part of minimum domestic requirements, bank-specific pillar 2 measures, or systemwide macroprudential measures.

building FX reserves at the central bank, they could be drawn down when banks face FX liquidity stress. FX reserves could also be part of HQLA in FX LCR in some jurisdictions where certain preconditions are met.[25] Nonetheless, as discussed in Box 2, some countries ask banks to comply with FX reserve requirements with LC reserve deposits. If there is FX LCR, such reserves will not be part of FX HQLA even though the reserves are earmarked for FX customer deposits. In such cases, the central bank may need to change the reserve requirement to be filled in FX. In particular, if FX LCR is imposed simultaneously, the combination of reserve requirement and FX LCR could burden banks to hold too much liquidity without aligning the details of the two measures.

Box 3. Structure of HQLA and Reserve Requirements

In many EMs, the structure of HQLA is closely related to the details of reserve requirements.[1, 2] When short-term money markets (including treasury bills) are underdeveloped, central banks often manage liquidity in the financial system using reserve requirements and central bank papers. Both create central banks' liabilities to banks, which are, in turn, banks' liquid assets. In dollarized economies, the details of FX reserve requirements affect the HQLA and central bank balance sheet structure. Examples include:

- **Armenia**. This highly dollarized economy with a fixed exchange rate regime has a history of significant external shocks and severe depreciation pressures. However, even reserve requirements for FX deposits are filled in domestic currency. To build more FX liquidity buffer in the system, the 2018 FSAP (IMF 2018) recommended considering the FX deposit reserve requirement as a prudential rather than a monetary policy tool and starting filling it in FX.

- **Philippines**. After the 1997 Asian financial crisis, the country tightened prudential regulation for banks to limit exposures to FX and FX liquidity risks. For instance, banks are required to limit their open FX positions to US$50 million (as of end-2019) irrespective of bank size, contrasting with the more common regulation that sets limits relative to bank capital. Moreover, banks must obtain a separate license to create a "foreign currency deposit unit" that handles FX-denominated transactions. The unit has to satisfy certain FX liquidity requirements on its own, as the central bank recognizes the limitation of its FX liquidity support capacity. As of 2021, the FX liquidity requirement was abolished, as the country adopted Basel III LCR.

- **Türkiye**. In the early 2010s, the central bank of Türkiye introduced the so-called reserve options mechanism (ROM, see Alper and others 2013). It allows banks to fill their reserve requirement for domestic currency deposits in FX and gold, but not vice versa. So, it is a policy that encourages banks to self-insure themselves against FX liquidity shock. At the same time, it elevates the potential contagion effects from banks to the central bank. Moreover, the policy boosts gross GIR but not NIR—the share of banks' FX deposits over total central bank foreign assets stood at about 57 percent as of end-2019 and has been nearly 70 percent several times since 2017.[3] The quality of international reserves deteriorated even more during the COVID-19 crisis, and the NIR has been negative as of fall 2021.

1/ According to the IMF survey of monetary operations and instruments database (MOID), 83 out of 125 respondent central banks had FX reserve requirements as of 2018. Objectives of FX reserve requirements include monetary policy, liquidity management, and prudential (financial stability). As of end-2017, 38 countries had liquidity requirements by currency, including FX LCR (IMF macroprudential policy database).
2/ More generally, the central banks' liquidity policy affects HQLA levels and structures in AEs as well. Most notably, asset purchase program expands central banks' balance sheet size with higher security holdings on the asset side and bank reserve deposits on the liability side. However, reserve requirements are less relevant as liquidity policy tools in AEs.
3/ Based on the analytical central bank balance sheet published by the Türkiye's central bank.

[25] See IMF technical assistance handbook on reserve requirement.

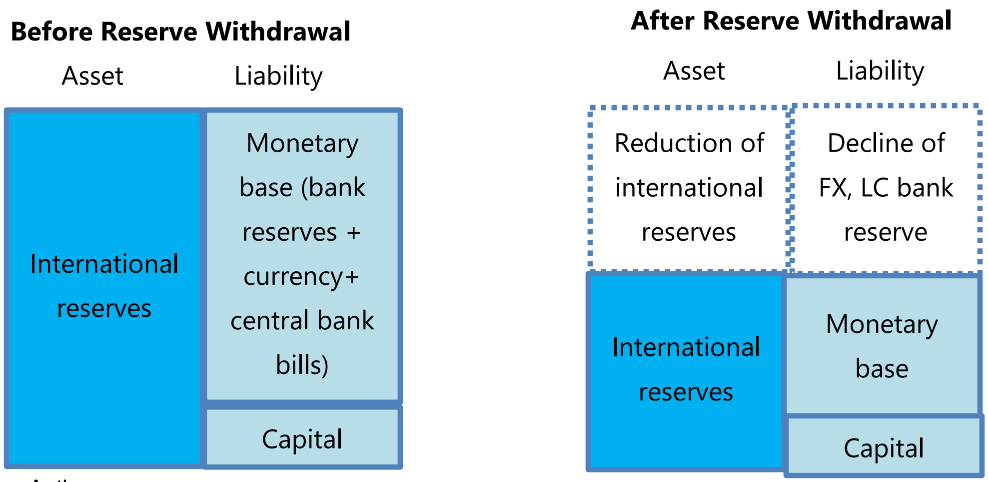
Moreover, they may need to expand the scope of financial stability surveillance to include NBFIs and non-financial sectors as needed. There have been several market stress events caused by non-financial market participants, such as corporate bond market stress caused by highly-leveraged real estate developers (e.g., Evergrande). The failures of Enron—a U.S. energy company—in 2001 and German fintech company Wirecard in 2020 were both related to their fraudulent financial reporting and led to question the strength of financial market supervisors, financial reporting system, and the quality of their auditors (Arthur Andersen and Ernst & Young). Typically stable sectors, such as U.K. pension funds, suffered from a sudden jump in margin calls due to the sharp valuation loss of gilts in October 2022.

The systemwide liquidity stress testing tool can deepen these policy dialogues. As discussed in the results section, it can quantify the potential amount for liquidity support or temporary reduction of FX LCR and reserve requirements. If ex-post support measures are undesirably high, regulators could identify which prudential measures should be tightened by how much and measures to enhance LOLR firepower. The tool can also identify key sectors and their behaviors to enhance surveillance. Bank behaviors and contingency financing plans could be identified in the supervisory process. Resolution planning and living will also be informative. In some cases, NBFIs and non-financial sectors could be systemically important. Then the scope of macroprudential risk monitoring and power should be expanded to include them. For example, the illustrative example in the previous section points out that the pecking order of asset liquidation can change the domestic liquidity spillover substantially. Especially, it is critical to mobilize liquid foreign assets held by NFCs to maintain financial stability, because they have about one-third of the nation's liquid foreign assets following the central bank. In such cases, the macroprudential authority might need to extend their risk monitoring to include some large NFCs and understand why they have such a balance sheet structure and what are their contingent plans facing liquidity shocks.

Such dialogue could also contribute to IPF discussion in some cases. In particular, BOP-related systemic FX liquidity stress entails monetary, liquidity, and external stability issues and policy tools. For instance, potential conflict between the need for liquidity support and monetary and exchange rate stability emerges acutely for those with a fixed exchange rate system where the size of the central bank liability and balance sheet is tied to international reserves (Figure 9). If banks withdraw excess reserves, it will reduce international reserves and central bank balance sheet size. When the exchange rate system does not allow sterilization and other operations to expand central bank money, the contraction of international reserves leads to monetary tightening. It is necessary to defend the exchange rate but at the cost of financial stability. Even with flexible exchange rates, the potential tradeoffs between exchange rate stability from capital outflows and financial stability often lead EMDE central banks to tighten policy rates procyclically to avoid currency crises first (Jacome and others 2011). However, there are exceptions, as observed during the COVID-19 crisis.

Figure 9. **Central Bank Liquidity Provision under the Currency Board Regime**

(A simplified case for a central bank that is required to back 100 percent of its liability in international reserves)



Source: Author.

Note: FX = foreign exchange; LC = local currency. Assuming no sterilization operation.

Conclusion

This paper proposes a simple Excel-based systemwide liquidity stress testing tool to assess the vulnerability of a financial system and economy against systemic liquidity risks. Developing reliable systemic liquidity stress testing models that encompass varieties of financial institutions and economic sectors has been challenging because of data constraints and the significance of behavioral factors. This tool simplified the analysis by focusing on economic-sector-aggregate data and behavior.

As such, the tool has several limitations. Since it relies on sector-aggregated data, it assumes away amplification mechanisms at micro levels, such as cash hoarding at institution levels, which prevents liquidity sharing from cash-rich firms to liquidity-constrained firms. Moreover, granular supervisory or FMI-collected transaction data are necessary for assessing collateral channels for secured funding like repo, the effects of encumbered assets, liquidity needs from off-balance sheet items (like credit lines), and margin calls from derivatives transactions, among others. These channels are particularly relevant in AEs with developed money markets and complex NBFI sectors but need a more advanced modeling strategy. At the same time, some countries do not have sufficiently granular BSA data. In such cases, we need to work with proxy data using the central bank and (aggregate) bank balance sheets, government financial statistics, BOP, international investment position, and external debt data.

However, the core concept of this simple tool is also applicable to more advanced analysis. Granular analysis and institution-level behavioral modeling are desirable for assessing systemic liquidity risks more accurately when data are available. Still, the principles offered in this paper remain valid. First, aggregate liquidity shocks spill over to various economic sectors as agents facing liquidity stress transfer it across sectors and instruments because their liquid assets are somebody else's funding. Second, test results depend critically on agents' behavior—especially the pecking order of liquid asset use. Many existing experiments of systemic liquidity analyses assume pro-rata liquidation of all assets, which is justifiable from the asset holder's perspective. However, the pecking order generates a too big difference in cross-sector contagion effects to ignore. In addition, prudential policies can influence key behaviors to be more favorable for financial stability. Therefore, a more advanced version of the tool should continue examining multiple behavioral assumptions. Third, the same should apply to macro-financial assumptions. Acute liquidity events usually last only for a short period, partly because central banks take some measures most of the time.[26] Still, the short-term volatility could be severely underestimated with a standard VaR approach that relies on recent history or past crises.[27]

This paper consciously focused on developing a simple tool and avoided assessing the second-round effects from asset fire sales to focus on building a "roughly right" stress testing tool that is robust to model uncertainty. It is possible to extend the tool to add such channels. But it may not provide reliable estimates without extensive and delicate empirical analyses, especially given that the first-round effects are already subject to notable model and parameter uncertainties. Typically, existing liquidity analysis tools incorporate the second-round effects by estimating the price-quantity relationship based on academic asset pricing literature that offers various models and functional forms. However, estimating reliable coefficients in practice is challenging because the model needs to capture the relationship during extreme tail events (i.e., liquidity crisis). There are several econometric techniques to estimate such dependence in tails, such as quantile regression or copula modeling approach. But we need to keep in mind that "unprecedented" dependence materialized in many never-happened-before liquidity crises. It is the author's personal view that we should aim to build a "robust" stress testing approach incorporating model and parameter uncertainty of the second-round effects by applying a range of potential models/coefficients instead of trying to nail down specific values too narrowly. As Andrew Haldane—Executive Director of Financial Stability at the Bank of England at that time—said in 2009 (Haldane, 2009), during the GFC, there are enormous risks with relying on one type of model when there is model uncertainty. It appears to make more sense to pursue "roughly right" stress testing tools that are more robust to model risks instead of a model that works perfectly under a specific hypothetical environment but fails miserably in another environment.

A "roughly right" stress testing tool can still inform prudential policies, a crisis management framework, and priorities to improve risk analyses and data. Exercises that examine multiple behavioral and parameter assumptions can separate key assumptions that could change the results substantially from those with moderate impact (see 2022 Mexico FSAP exercise). Once critical behavioral patterns are identified, risk monitoring, prudential tools, and crisis management tools could be set to incentivize agents to act in supporting financial stability. Also, such exercises could set priorities for closing the data gap. The stress testing literature tends to focus on improving analytical tools where data are available or easier to expand (e.g., banks, investment funds, bank-investment fund interlinkages). However, if the high-level vulnerability assessment with a tool this paper indicates key risks are from some NBFIs, NFCs, or markets where data are limited, then more resources should be allocated to develop data and tools that allow missing, likely-to-be critical assessments.

[26] Market volatilities could be "unthinkable" in a space without central bank to be the LOLR or security and market regulators that can stop trading as we see in cryptcurrency markets (e.g., the collapse of stablecoin Luna in May 2022 that lost about 90 percent of its value vis-à-vis US dollar, even though the coin was backed up with bitcoin reserves.)

[27] During the GFC, some markets and investors experienced a 25 standard deviation shock for multiple days—a 25-standard deviation event should occur only once in every 13.7 billion years assuming standard normal distribution (Haldane, 2009).

Annex I. Selected FX Liquidity Support Measures during the Global Financial Crisis

Trading FX in the spot market (excluding peg countries)

- Türkiye, CB starts intermediating interbank FX operations. (2008)
- Türkiye, CB halts its daily purchase of dollars and shifts to daily dollar sales. (2008)
- Chile, CB suspends reserve accumulation program. (2008)
- Chile, CB initiates a daily FX sale auction program. (2009)
- Colombia, CB provides FX based on a rule (giving market participants the option to buy FX from CB when the volatility goes above a threshold). (2008)
- Mexico, CB offers rule-based daily FX auctions with a minimum price floor. (2009)

Changes in reserve requirements

- Indonesia, CB reduces FX reserve requirement. (2008)
- Romania, CB reduces FX reserve requirement. (2009)
- Serbia, CB reduces FX reserve requirement and further changes currency structure of required reserves. (2008)
- Türkiye, CB reduces FX reserve requirement. (2008)
- Ukraine, CB relaxes FX reserve requirement. (2009)
- Argentina, CB relaxes FX reserve requirement. (2008)
- Chile, CB relaxes FX reserve requirement to be met in any FX, not just USD. (2008)
- Mexico, CB begins to pay monthly interest on dollar bank deposits. (2008)
- Peru, CB eliminates reserve requirements on long-term international bank loans. (2008)
- Peru, CB reduces marginal reserve requirement on FX deposits. (2008)

Lending using FX swaps

- Hong Kong SAR, CB offers FX swaps to banks. (2008)
- India, CB offers temporary FX swaps to overseas branches of Indian banks. (2008)
- India, CB offers temporary FX swaps to Indian banks with overseas offices. Allow banks to get domestic liquidity from CB to be used for swaps. (2008)
- Indonesia, CB extends FX swap tenors. (2008)
- Korea, government provides liquidity in FX swaps market. (2008)
- Korea, CB introduces a competitive auction FX swap facility. (2008)
- Hungary, CB offers FX swaps daily. (2008)
- Hungary, CB offers fixed price euro/Swiss franc swap. (2008)
- Hungary, CB offers six-month euro/Forint swaps and three-month floating-price euro/Forint swaps. (2009)
- Poland, CB introduces FX swaps. (2008)
- Serbia, CB offers local currency liquidity and FX swaps for foreign banks' subsidiaries committed to maintaining their exposures to the country (2008).
- Chile, CB offers FX swap program and extends its maturity later. (2008)

Lending in FX to banks	
	• Korea, government grants a temporary three-year guarantee on banks' FX borrowings. (2008) • Philippines, CB starts to offer USD repo. (2008) • Vietnam, CB expands eligible collaterals for its FX lending operations to include the country's recently issued USD sovereign debt. (2009) • Russia, government provides its FX reserve to the state-owned development bank (VEB) to on-lend banks and corporates. (2008) • Türkiye, CB increases the limit on its GX lending window and cuts the rates. (2008) • Türkiye, CB extends the maturity for FX repo between banks and vis-à-vis CB. (2009) • Argentina, CB offers to auction options for banks to borrow dollars to help trade finance. (2009) • Brazil, CB sells one-month dollar liquidity lines. (2008) • Brazil, government allows Brazilian banks to borrow reserves (collateralized) for on-lending to exporters. (2008) • Brazil, CB auctions FX loans, taking Brazilian sovereign global bonds as collateral. (2008) The eligible collaterals are expanded later. (2009) • Brazil, CB offers a dollar repo targeted at exporters. (2008)
Support for non-banks	
	• India, CB offers collateralized FX lending to oil refinery companies. (2009) • Indonesia, government creates a new export financing agency to provide FX liquidity via guarantees, insurance, or lending (2009). • Korea, government and CB provide funding to exporters. (2008) • Korea, CB expands collateral for FX loans given to banks, including export bills from all enterprises to facilitate export financing from banks. (2008) • Hungary, government provides FX to state-owned development banks to boost lending to companies. (2009) • Russia, government provides its FX reserve to the state-owned development bank (VEB) to on-lend banks and corporates. (2008) • Brazil, CB offers one-year dollar loans to companies. (2008)
Changes in capital account restrictions	
	• India, CB allows banks to borrow FX from overseas branches. (2008) • India, CB raises refinancing limit on bank export credit. (2008) • India, CB raises interest rate ceilings on FX export credit. (2009) • Indonesia, state-owned firms are required to repatriate export proceeds. (2008) • Korea, CB eliminates limits on bank purchases of USD in offshore non-deliverable forward markets. (2008) • Philippines, CB relaxes some FX documentation rules to allow easier access to dollars. (2009) • Ukraine, CB relaxes limits on foreign borrowings by banks. (2008) • Argentina, imposes a three-day waiting period for investors buying local securities for sale abroad for dollars. (2008)
Regulatory forbearance/amendment	
	• Nigeria, CB lowers limits on net open FX position. (2008, ’09, ’10) • Philippines, CB lowers the limit on FX liquidity holdings over FX liability. (2008) • Philippines, CB relaxes the marked-to-market requirement for foreign currency deposit units to reduce their dollar demands. (2008)

Swap/lending arrangements with other central banks	
	• China, with Japan and Korea. (2008) • Hong Kong SAR with the Netherlands. (2009) • Estonia with Sweden. (2009) • Hungary with the ECB. (2008) • Iceland with Denmark, Norway, Sweden and Finland. (2008) • Indonesia with China. (2009) • Latvia with Sweden and Denmark. (2008) • Poland with Switzerland and the ECB. (2008) • Brazil, Korea, Mexico with the U.S. (2008-February 2010) Among AEs, Australia, Canada, the ECB, Japan, Singapore, Norway, New Zealand, Denmark, Sweden, Switzerland, and the U.K. also had swap arrangements with the U.S. Most of these expired in February 2010, except for Canada, Japan, the ECB, Switzerland, and the U.K., where the arrangement was extended to 2014.
Other	
	• Brazil, government eliminates certain taxes on FX transactions. (2008) • Chile, government shifts FX deposits from foreign banks to domestic banks and coordinates with CB in auctioning USD CDs to local banks. (2008)

Sources: Author's extract from background database for Ishi, Stone, and Yehoue (2009), based on central bank websites, Factiva and IMF country reports; Moreno (2010); and Druck, Hofman and Lu (2013).
Note: AE = advanced economy; CB = central bank; ECB = European Central Bank.

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