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2021 FINANCIAL SECTOR ASSESSMENT PROGRAM REVIEW—BACKGROUND PAPER ON QUANTITATIVE ANALYSIS

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2021 FINANCIAL SECTOR ASSESSMENT PROGRAM REVIEW—BACKGROUND PAPER ON QUANTITATIVE ANALYSIS

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Glossary

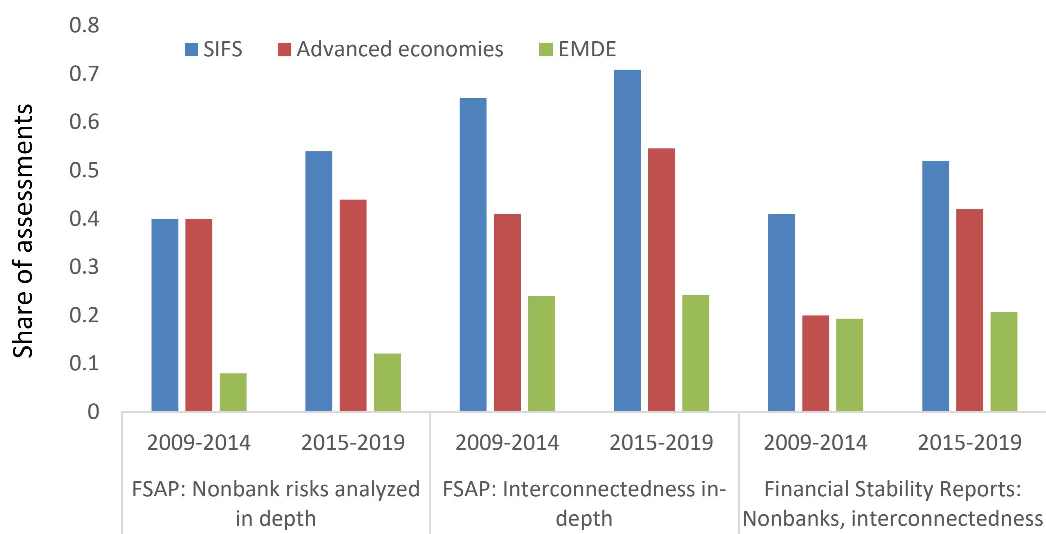
ABM	Agent-based models
BIS	Bank of International Settlement
BMA	Bayesian Model Averaging
BSA	Balance sheet analysis
CCP	Central counterparty
CDS	Credit default swap
CoVaR	Conditional Value at Risk
DSGE	Dynamic stochastic general equilibrium
DTI	Debt-to-income ratio
EMDEs	Emerging and developing economies
ESRB	European Systemic Risk Board
FMI	Financial market infrastructure
FSAP	Financial Sector Assessment Program
FSB	Financial Stability Board
FX	Foreign exchange
GaR	Growth-at-risk
GFC	Global financial crisis
GFM	Global macro-financial model
GFSR	Global Financial Stability Review
GPM	Global projection model
G-SIB	Global systemically important bank
G-SIFI	Global systemically important financial institution
GST	Global bank stress test
IAM	Integrated assessment model
IFRS9	International Financial Reporting Standard 9
IMF	International Monetary Fund
IOSCO	International Organization of Securities Commissions
ITD	Information Technology Department (of the IMF)
LCR	Liquidity coverage ratio
LDG	Loss-given-default
LTV	Loan-to-value
MCM	Monetary and Capital Markets Department
NBFI	Nonbank financial institution
NFC	Nonfinancial corporate
NGFS	Network for Greening the Financial System
NPL	Non-performing loan
NSFR	Net Stable Funding Ratio
PD	Probability of default
RCP	Representative concentration pathway
SIFI	Systemically important financial institution
SSM	Single Supervisory Mechanism
SSP	Shared Socioeconomic pathway
SVAR	Structural vector auto-regression
UN	United Nations
VAR	Vector auto-regression

INTRODUCTION

1. **This paper reviews quantitative tools of financial stability assessments under the Financial Sector Assessment Program (FSAP).** A key focus of FSAPs is on methodologies to gauge risks on a system-wide level and propose mitigating measures. Therefore, the paper concentrates on the main elements of the FSAP's macroprudential stress testing framework: (i) the interaction among solvency, liquidity, and contagion risks in the banking sector, (ii) the assessment of the health of nonbank financial institutions (NBFIs), their interactions with banks and their impact on financial markets, (iii) the assessment of the health of nonfinancial sectors and their links to the financial sector, and (iv) macroprudential policy analysis. The paper also reviews recent improvements in microprudential bank solvency stress testing—an important foundation for the macroprudential stress testing framework—and discusses new tools for emerging risks (climate change, fintech, and cyber). In each area, the paper explains the current toolkit, references more experimental work, and discusses the scope for improving the approaches used by staff. The paper also discusses challenges from data constraints, the adoption of quantitative tools by Article IV teams, and the potential for improvements in tool efficiency to allow for enhanced FSAP risk analysis with limited resources.

Figure 1. FSAP's Quantitative Tools Are Getting More Macroprudential

The quantitative work has been shifting towards analysis of NBFIs and interconnectedness, in line with similar trend in central banks' financial stability reports (FSRs).



Source: IMF staff based on FSAP Tracking System and information in central banks' financial stability reports.

2. **Since the 2014 FSAP Review, quantitative tools for risk analysis have adapted to evolving stability risks and vulnerabilities, including further analysis of systemic risk (Figure 1).** The 2014 FSAP Review suggested focusing more on systemic risks. In response, while analysis of banking system risks remains core in many FSAPs, Fund staff has expanded FSAP quantitative tools to include models to study vulnerabilities in nonfinancial sectors and NBFIs, and interconnectedness between banks, NBFIs, and nonfinancial sectors (Adrian, Morsink, and Schumacher, 2020). Some FSAPs have started to analyze links between solvency, liquidity,

and contagion risks. The Fund has also been making substantial efforts to account for the two-way feedback effects between the financial sector and the real economy. Moreover, Fund staff have developed a range of approaches, including growth-at-risk (GaR), structural vector autoregression (SVAR) models, dynamic stochastic general equilibrium (DSGE) models, and agent-based models (ABM) to model macrofinancial linkages. As the understanding of macroprudential policies deepened, some FSAPs started to focus more on the quantitative calibration of macroprudential tools.

3. Going forward, work will continue to enhance the macroprudential stress testing framework. The focus of the work will be guided by staff's assessment of the priority areas and the results of the FSAP Review's survey of stakeholders (Figure 2):

- ***Interaction between solvency, liquidity, and contagion risks.*** Staff is developing models that incorporate complex interactions between the risks to provide a better picture of systemic risk.

- ***Risks in nonbank financial sectors.*** To make NBFI risk analysis more macroprudential, staff plan to focus more on cross-sectoral interactions and impacts on markets, though data limitations will constrain progress in this area.

- ***Risks in nonfinancial sectors.*** Staff is developing models to analyze links between the health of nonfinancial sectors and the soundness of banks' balance sheets.

- ***Interconnectedness analysis.*** The scope of interconnectedness analysis could be expanded to include cross-financial segments and cross-sectoral linkages more fully.

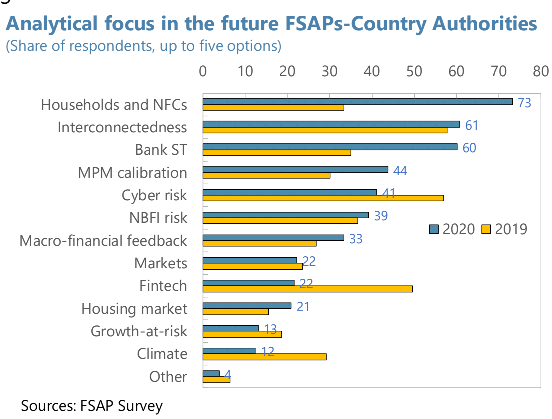
- ***Macro-financial interactions.*** GaR and DSGE models have been used in FSAPs mainly to build the macro scenarios underpinning the stress testing exercise, but they have not yet been used jointly with stress tests to measure feedback effects from financial distress to economic outcomes. More micro and structural approaches under development by staff (see Section on Macrofinancial Linkages) have the potential to integrate the results of stress tests—including at the institutional level—back to macro-financial developments.

- ***Macroprudential policy.*** Cyclical assessments and policy advice could rely more on the results of macroprudential stress tests, alongside early warning indicators of borrowers' vulnerabilities, such as debt-at-risk and debt-service-to-income ratios (DSTI), among others. Stress test results could inform the size of adequate buffers and be used to assess the impact of possible future measures ex-ante. Also, analytical tools using microdata could be considered more explicitly to calibrate borrower-based tools.

4. Heightened risks arising from the pandemic have increased authorities' interest in risk analysis, especially nonfinancial sector vulnerability analysis and bank stress testing. Unlike many past crises, the current shock did not originate in the financial system. Instead, the impact has thus far been felt mostly by other economic sectors. Corporate vulnerabilities have increased as firms have taken on more debt to cope with cash shortages amid extreme earning shocks. Underlying liquidity risks could morph into insolvencies, especially if the recovery is delayed, which could spill over to the financial sector. In this context, interest from authorities for FSAPs to include household and nonfinancial corporate (NFC) sector vulnerability assessments and bank stress tests has jumped in the update of the FSAP Review survey undertaken in the fall of 2020. With some national authorities having released macroprudential buffers, the interest in the quantitative calibration of macroprudential policy measures (MPMs) has also increased.

Figure 2. FSAP Analytical Focus—Survey Results

Demand for household and NFC analysis and bank stress tests have risen in the context of the COVID-19 crisis while interest in interconnectedness remains high.



Source: FSAP Survey and staff calculation.
MPM = macroprudential policy measure; ST: stress test

5. Enhancements to quantitative tools will be complemented by increased standardization and automation for core risk analysis where feasible. While expert staff judgment and engagement will continue to remain integral, some operational improvements could reduce costs of standard risk analysis tools without sacrificing their quality or cutting down an integral component of risk analysis. A good example is the development of the GaR tool (IMF, 2017b), which involved close collaboration with the Information Technology Department (ITD) and public dissemination on a popular software development site. Staff are working to standardize core risk analysis (especially bank stress tests, including satellite models—one of the most time-consuming parts of the FSAP stress testing exercise) for different data environments, which will be accompanied by detailed guidance notes and files/codes on a refreshed IMF webpage dedicated to the topic. More broadly, shifting quantitative analysis away from excel-based tools to program codes could increase efficiency and accuracy.

6. More effective use of quantitative tools will require alleviating data constraints. Quantitative risk analysis in FSAPs faces two types of data constraints: the availability (i.e., data gap) of and access to data. National authorities and international institutions have made substantial efforts to start collecting more data relevant for granular financial stability analysis, including across sectors and jurisdictions, following, for example, the G20 Data Gap Initiatives. In many cases, technical assistance from the IMF Statistics Department has supported the authorities in these efforts. However, certain data are still not adequately collected, including granular sectorized risk exposures across borders, cyberattacks, and data in emerging areas such as climate and fintech. In terms of access, virtually all national authorities now share with

FSAP teams—with stringent safeguards—their confidential supervisory data for bank stress tests. However, access to some data is still limited, including the Global Systemically Important Banks (G-SIBs) data collected by the Bank of International Settlement (BIS). Access and analysis using transaction and settlement data—namely activity-based data that encompasses all types of regulated and unregulated entities active in certain markets—is still rare, in part because of the technical challenge to handle such "Big (confidential) Data." On occasion, FSAP teams have conducted joint analyses with national authorities who have access to data, working with codes and information sharing platforms that do not require the FSAP team to have direct access to data.

7. **An operational approach to assessing financial stability risks from emerging risks, especially climate change and the concomitant need for adaptation in the financial sector, is a key priority**.[1] Climate change poses distinct challenges to financial stability analysis, reflecting very high uncertainty over its timing, likelihood, complex micro-level dependencies, and data availability. The staff envisage a three-stage approach to assessing these risks (see Section on Emerging Risks, Climate Change). First is a climate financial risk diagnostic to decide on the scope of the assessment and relevant climate physical and transition risks. The second is designing climate scenarios. And third is designing macro-financial scenarios and the integration of these economic scenarios into standard FSAP stress tests. The approach parallels that chosen by central banks, but key features for the Fund will be a focus also on risks over the three- to five-year FSAP horizon—by contrast with the mostly longer-term focus by other institutions—and close scrutiny of physical risks which may be relatively more relevant for many Fund members. Given the high degree of uncertainty, reverse stress testing approaches will be explored as a potential complementary perspective.

8. **Quantitative tools will also incorporate ongoing regulatory and accounting reforms**. Such reforms require adjustments to bank stress test tools. For example, in 2017, the Basel Committee on Banking Supervision (BCBS) introduced additional requirements to Basel III that limit the application of an internal ratings-based (IRB) approach to calculate risk-weighted assets. The adoption of international financial reporting standards 9 (IFRS 9) in many jurisdictions changed the ways loan-loss-provisions are estimated (called expected credit losses, ECLs) to calculate bank regulatory capital. The introduction changes the model and data structure for estimating bank credit risks, the core of a bank stress test.

9. **The staff use the scoping process to determine the approach to and methodologies for quantitative analysis in any given FSAP**. The process first identifies material risks and vulnerabilities for an FSAP to prioritize based on the preliminary Risk Assessment Matrix (see the background paper on scope SM/21/54). These risks and vulnerabilities guide the choice of quantitative approaches, combined with the availability and

[1] October 2020 Global Policy Agenda. Some FSAPs have already been assessing financial stability risks from physical risks (such as natural disasters) as a part of a macro scenario for bank and insurance stress tests in the past several years, with more sophisticated approaches being brought to bear recently (e.g., Philippines 2021). Other recent FSAPs have started to assess the implications of effects of transition risk, i.e., the risk of abrupt changes in public policy or technology.

structure of data and jurisdiction specific characteristics, including the supervisory framework and accounting rules.[2]

MACROPRUDENTIAL STRESS TESTING

10. IMF staff use macroprudential stress tests to assess systemic risk as part of the IMF's mandate to monitor financial stability in the membership. An IMF macroprudential stress test is a methodology to assess financial vulnerabilities that can trigger systemic risk and be used to support the recommendation of mitigating measures for the system. The main difference between a macroprudential and a microprudential stress test lies in the nature of the assessment and the consequences of the results.

- ***A microprudential stress test*** is a forward-looking supervisory tool that assesses the soundness of an individual bank's balance sheet. Key to the supervisory purpose is the ability of the bank "to pass or not to pass the test" and the subsequent bank-specific supervisory measures to increase capital and liquidity buffers when the bank does not pass the test.

- ***A macroprudential stress test*** is built on a similar framework to a microprudential stress test but focuses on systemic risk by incorporating amplification and contagion channels affecting the whole financial system. Examples include modeling interactions between solvency, liquidity, and contagion risks in the bank stress tests. Moreover, staff have expanded the FSAP analytical toolkit to include models to study risks in NBFIs, vulnerabilities of the nonfinancial sectors, and interconnectedness between banks and NBFIs and with the nonfinancial economic sectors. Work is underway to incorporate two-way feedback effects between the real economy and bank health through macro-financial channels (requiring also modeling bank balance sheets dynamically). The objective of the analysis is to recommend macroprudential measures to mitigate risks.

A. Improving Core Bank Solvency Stress Tests[3]

11. Staff continue to upgrade the bank solvency stress test toolbox currently used by FSAP teams. The focus of the upgrades is to enhance satellite models that translate macro-financial scenarios into banks' bank balance sheets and income statements and incorporate new methods to address changes in regulatory and accounting rules and new sources of risks. Table 1 summarizes ongoing upgrades.

[2] For example, while FSAPs always assess bank solvency risks, different methodologies may be used depending on the jurisdiction specific reporting format for credit risks (e.g., probability of default for banks when they are regulated using Internal-Rating Based approach, non-performing loan data or transition among loan classifications when banks are regulated following the Basel standardized approach, and lifetime probability of default when International Financial Reporting Standard (IFRS) 9 data are available).

[3] This paper focuses on improvements with regards bank solvency stress tests, as the methodologies for standard liquidity stress tests, including cash-flow based analysis and (modified) liquidity coverage ratio (LCR) and net stable funding ratio (NSFR) analyses, are now mature. The "frontier" of liquidity stress tests is the systemic liquidity analysis discussed separately in this paper.

Table 1. Bank Solvency Stress Test Model: Upgrades

Enhancements	Stress test model versions	
	Previous version	**Upgrades in progress**
New risks	Limited to financial risks	Climate change, and cyber-risk are incorporated as part of bank clients' distress analysis. Bank operational risks and counterparty risks are also modeled. Impact of fintech on banks' income.
Calculation of provisions	Approximation based on expected losses approach (often proxied by changes in probability of default × loss-given default).	Use of accounting (IFRS9) expected loss metrics as opposed to the regulatory one. Based on accounting definitions of 12 months and lifetime expected credit losses in line with changes in accounting requirements. Disentangling accounting and prudential layer and their interplay.
Satellite models	Econometric models, specifications chosen on an ad-hoc basis	Bayesian Model Averaging (BMA) models; based on more granular data
Risk-weights and hurdle rates	Based on Basel III	Among others: revisions to risk weights in the standardized approach, removing the use of internal risk models for certain asset classes, and a minimum leverage ratio.

Satellite Models

12. **Macro scenario stress testing requires satellite models to link macroeconomic and market factors to forecast key bank parameters.** Satellite models translate macro-financial scenarios into granular risk factors and project bank balance sheets and capital. The most important satellite models include those forecasting loan default rates (credit risk), net interest income, and capital requirements. Additional efforts are underway to model trading losses, fees and commission income, and operational losses.

13. **The satellite models capture relevant risk factors.** The modeling choices and calibration decisions usually consider the interactions among different risks and models.[4] The complexity of the models reflects data availability and the materiality of the portfolio. For example, models can be built at the loan, portfolio, bank, or country levels, among others. The explanatory variables in the models typically include a set of macroeconomic drivers (e.g., GDP growth, inflation, unemployment, income, output gap, policy rate, property prices, equity prices, yield curves), and a range of financial market indicators (e.g., foreign exchange (FX), equities, credit spreads, commodities, rates, FX volatilities, equities volatilities, and rates volatilities).

14. **Models are compared and validated based on a variety of performance measures.** A combination of criteria are used to inform the choice of satellite models: (i) in-sample forecast performance measures; (ii) out-of-sample forecast performance based on a truncated sample, measured by the root mean squared error (or similar measures) over the forecasting period; and (iii) the sign and significance of coefficient estimates. Expert judgment may be applied to the

[4] For example, models for default rates include loan interest rates to capture the dependence of credit risk on changing interest rate risk, in particular for portfolios with a significant share of variable interest rate loan contracts.

projected paths to assess how the banks' risk metrics have behaved historically relative to their macro environment against benchmark crisis episodes (e.g., the GFC or the European sovereign debt crisis).

15. One of the most important satellite models project loan default (credit) risk, typically with an econometric-based approach. Credit risk models project credit costs (i.e., newly required provisions) under a given scenario, which will reduce bank profits and capital. Credit costs are changes in the expected losses on loans. They are usually calculated as the changes of the probability of default (PDs) multiplied by the loss-given-default (LDG), as both PDs and LGDs deteriorate in downside scenarios. More specifically:

- ***Probability of default*** is assessed differently across jurisdictions depending on the structure of supervisory data, including changes in non-performing loan (NPL) ratios and the transition matrix of credit rating. Independent variables include local, regional, and global risk factors grouped by exposures to material geographies. The stress testing approach requires a robust econometric framework using traditional and non-traditional approaches to cope with technical challenges, including related the fundamental forecasting uncertainty with predicting tail events such as defaults and doing this using proxy data. Traditional approaches include linear regression techniques with adjustments to address the variance properties in the data, and more recently, quantile regressions to explore non-linear effects in the tail of the distribution, and Bayesian Model Averaging (BMA) approaches to address model uncertainty.[5] Non-traditional approaches, including machine learning, random forests, and neural networks, are also considered in some cases.
- ***Loss given default*** is more likely to be calibrated rather than estimated. If PDs are proxied by NPLs, the required provisioning rates by regulation and historically observed provision coverage rates could be used as proxies for LGDs. More generally, LGDs can also be calibrated based on experience summarized academic studies on credit risk modeling.

16. The Fund is making further efforts to project more granular pre-provision net revenue (PPNR). The objective here is to project components of PPNR, including trading losses, fees and commissions income, and others. Modeling these components of PPNR requires many separate sub-models for the stock of assets and liabilities, their contractual run-offs, pre-payments, new lending, defaulted assets, and broader profit and loss (P&L) items beyond net interest income such as fees and commissions. PPNR models also need to incorporate and project 'idiosyncratic risk' factors such as banks' pricing behavior, business strategy, and solvency and funding interactions, in contrast with credit and trading losses models that primarily reflect 'systemic drivers.'

[5] Throughout 2018/2019, the BMA methodology has been explored and employed for satellite model purposes in various FSAPs (e.g., Canada, Italy, Korea, France, and others). The corresponding methodology is documented in Gross and Población (2017). The BMA toolbox is currently under further development, considering the addition of other algorithms for model selection.

17. More granular data would be needed to improve the estimation of the impact on P&L from fair valued instruments. For example, valuation changes from a bond portfolio are often estimated, taking into account its duration, which is a linear approximation of the valuation change to an interest rate shock. However, a full valuation effect should also incorporate various non-linear effects that arise for large shocks. It would require additional data such as delta sensitivities by major index/counterparty, with a breakdown of long vs. short positions and cash vs. derivative positions. The scenario also needs to account for a break in the correlations between cash and derivative curves to stress the basis risk of hedged portfolios. When granular data are not available, a modified duration approach—a simple method that partially reflects non-linear effects—can provide reasonable proxy estimates.

18. Structural credit risk models can be effective when historical data is short or absent or when the structure of bank portfolios has recently shifted. In the absence of long-run historical data on banks' credit risk or a lack of data on events generating tail losses, econometric models tend to provide biased estimates of the true average loss rates. In such cases, a structural approach combining risk measures of borrowers (e.g., leverage, default rates) with estimates of behavioral and macroeconomic risk drivers (e.g., income, profitability, interest rates) can produce more reasonable estimates of losses.[6] Structural models typically rely on micro (or granular) data on borrowers (e.g., credit registry, household, and corporate surveys). Structural models more naturally permit counterfactual policy experiments, where some factors can be held constant. Other structural approach includes Merton-type credit risk models based on option pricing models, that use individual firms' balance sheet structure and their equity prices.

Changes in Regulatory and Accounting Rules

19. The FSAP stress testing approach is being modified to account for the major changes in accounting standards, such as the introduction of IFRS 9 in many jurisdictions (Gross, Laliotis, Leika, and Lukyantsau, 2000). Supervisory practice to calculate loan-loss-provisions (i.e., credit costs) to cover expected losses varies substantially across jurisdictions. Some, though not all, jurisdictions adopted IFRS 9 to calculate regulatory loan-loss-provisions and capital. For some jurisdictions, the IFRS9 could be tighter than prudential provision requirements. For some others, existing prudential requirements are more conservative. For the former, stress testing becomes more conservative by using accounting provisions. Moreover, IFRS 9 provisions are meant to cover lifetime expected loss of exposures, rather than one-year ahead losses under Basel rules. This makes accounting provisions more responsive to cyclical factors—consistent with the economic capital approach—and they may be larger than prudential impairments during a recession. In addition, both provisioning layers and their interplay need to be explicitly modeled to provide accurate estimates for banks' capital positions under an adverse scenario and help model banks' behavioral responses, including macro-financial amplification mechanisms.

[6] Some recent FSAPs (Finland, New Zealand, France, Switzerland) have applied a structural approach to the measurement of residential mortgage lending risk by risk bucket (for example, by LTV, DTI, and loan vintage).

20. The 2017 Basel rules represent the finalized Basel III framework, and these will be integrated into solvency stress test tools in the jurisdictions that adopt them. For instance, the BCBS introduced reforms on risk-weighted assets, which, among others, introduced a floor in 2017 on risk weights for banks using the internal-rating-based approach. This was in response to concerns over the appropriate use of this flexibility, including with excessive reduction of risk-weighted assets. The solvency stress test tools are being updated to reflect this reform for the jurisdictions that adopt these regulatory changes. The updates incorporate transitory arrangements, because some countries have different timelines to implement these reforms than the Basel timeline.

Simplified Tools

21. Staff have been developing simplified bank stress testing tools for supporting financial surveillance in Article IV consultations, including in response to the COVID-19 crisis. As indicated in the survey of country authorities, interest in household and corporate sector analysis and bank stress tests has increased in the context of the current crisis. Staff developed the Global Bank Stress Test (GST), which is a macro scenario stress testing tool using publicly available bank-level financial statements and covering 33 jurisdictions. In the Fall 2020 GFSR, the tool was modified to incorporate various COVID-19 related mitigation measures (such as loan guarantees) in the analysis. MCM has prepared a methodology note and which will be shared along with relevant codes so that desk economists can update the data and scenarios (and, if needed, models) to update stress test exercises. The GST is being expanded to include more countries using country-aggregate banking sector data (called the universal stress test, UST). Staff are also developing macro scenario stress testing tools for NFCs and households using firm-level and household survey data.

Linking Solvency, Liquidity, and Contagion Risks in Bank Stress Tests

22. The interaction of solvency and liquidity risks is an important driver of the severity of financial crises. Faced with a run on liabilities, solvent banks can be forced to liquidate assets, face losses, and risk becoming insolvent. The interlinkages between solvency and funding and market liquidity risks can reinforce each other, leading to “liquidity spirals” from margin calls and loss spirals. Many central banks and academics (Adrian and Shin, 2008, and Coen and others, 2019) recognize that stress tests should integrate such feedback loops because models focusing solely on solvency risks may significantly underestimate the overall impact of liquidity and contagion shocks and fire-sale episodes.[7] Loops have to reflect how capital losses lead to liquidity problems and contagion during stress episodes: banks with higher solvency risks are also likely to experience higher funding costs and tighter access to funding and trigger contagion to other banks. At the same time, funding withdrawals may force banks to liquidate assets at fire-sale prices, adversely impacting capital.

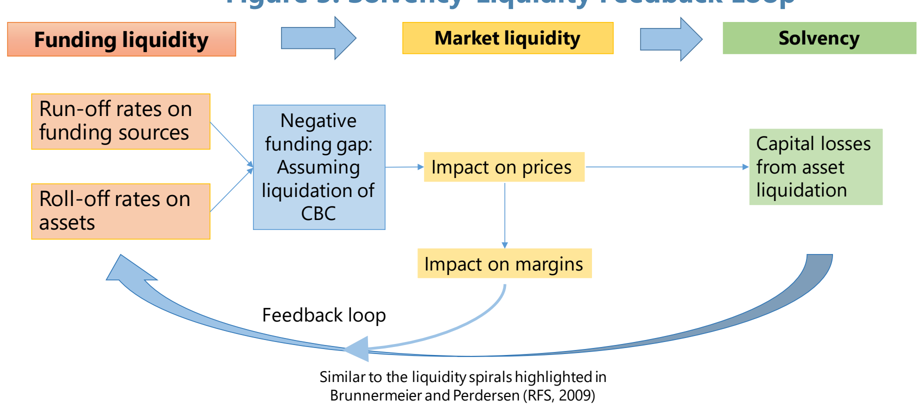
[7] Isolated liquidity and solvency shocks may not capture the systemic impact of the herding behavior of many banks. Such behavior may arise due to i) holdings of similar liquid assets across many institutions, ii) insufficient geographical/sectoral diversification of securities portfolios, and iii) the need to meet regulatory requirements in times of stress.

23. Some recent FSAPs have analyzed the interaction between solvency and liquidity risks. Bank solvency stress tests in recent FSAPs (e.g., 2018 Euro Area, 2018 France, and 2017 Japan) include the effects of higher wholesale funding costs due to deterioration of solvency position of banks in the stress scenario. Other FSAPs have incorporated the interaction between banks' solvency and contagion effects via the interbank network. In addition to a typical standalone contagion exercise, 2018 Brazil FSAP performed the contagion analysis as part of the bank solvency stress tests to gauge the additional impact on banks' capital due to credit losses associated with exposures to the defaulting banks.[8]

24. Building on those recent FSAPs, work is underway to further integrate the interaction between solvency and liquidity risks into FSAP bank stress testing (Figure 3). Models need to capture two-way interaction. First, solvency stress tests will identify banks with low capital adequacy in response to macro-financial shocks (1st round impact). These banks would then experience higher funding costs and liquidity shortages. Higher funding costs and losses from fire-selling liquid asset buffers would reduce the solvency ratio even more (2nd round effect). These effects are typically non-linear, and the amplification effects become disproportionally larger as banks' capital falls closer to the required minimum. To support the effort of analyzing the interaction between solvency and liquidity risks, staff have developed structural models that capture joint stress testing of solvency, liquidity, and their interactions (Cont, Kotlicki, and Valderrama, 2020, and Gross, Leika, and Valderrama, forthcoming), and Krznar and Matheson, 2017). Other models gauge the impact of haircuts on liquid assets using transaction-level data and apply them to analyze the impact on asset valuation and capital adequacy of banks (Han and Leika, 2019).

25. The next frontier in modeling the systemic risk associated with solvency-liquidity interactions is agent-based models. Thus far, models have not accounted for demand and supply conditions, market microstructure, redistribution of losses/gains, and liquidity gaps and surpluses among institutions. Agent-based models (such as Valderrama, forthcoming) could help incorporate these factors.

Figure 3. Solvency-Liquidity Feedback Loop



CBC = counter balancing capacity (i.e., liquid asset buffers).

[8] At the end of each year during the stress testing horizon, additional credit loss from the failure of other banks is calculated, and the level of capital after the contagion analysis would be the starting point for banks' solvency in the subsequent period for the solvency stress tests.

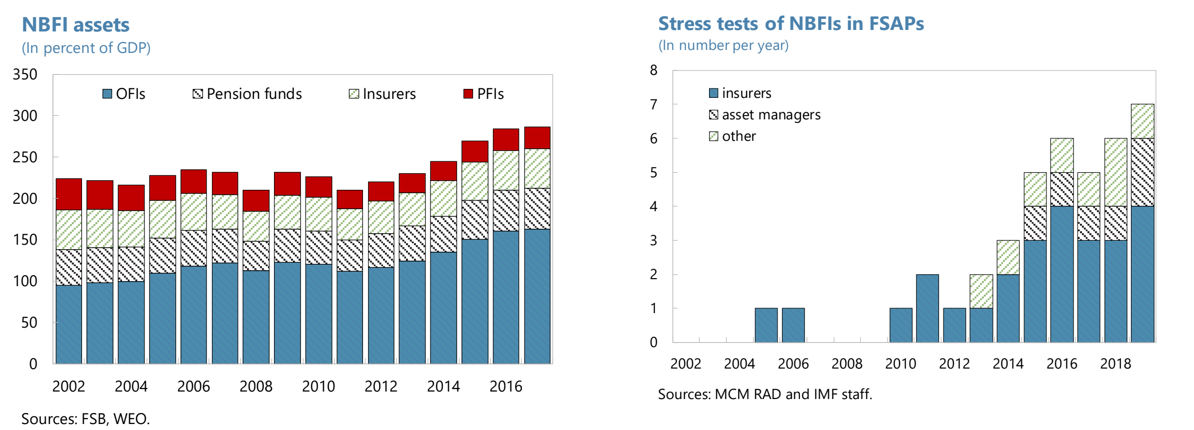
B. Risks in Nonbank Financial Sectors

26. The rapid growth of NBFIs after the GFC has seen them provide an increased contribution to systemic risk. NBFIs are institutions engaged in shadow banking activity or financial intermediation outside the traditional banking system (IMF, 2014b). They are diverse: notable examples include mortgage/leasing companies, asset managers, insurers, and pension funds. Their footprint has been growing in the global financial system over the past quarter-century (Figure 4, first panel). By contrast with banks, solvency distress of some NBFIs (e.g., investment funds and insurers) should in principle be contained by the fact that their investors and policyholders are usually expected to absorb losses contractually, unlike bank depositors.[9] However, shocks to their financial positions could generate systemic impacts for the financial system through their interconnectedness with other financial institutions and markets. NBFIs are interconnected with the system through their lending to banks (e.g., in the form of deposits or wholesale funding), borrowing from banks (e.g., credit lines activated on the onset of COVID-19 related market turbulence), NFCs (bonds), and households (mortgages), or market activities (e.g., repos, securities lending, credit derivatives, and insurance) and their impact on asset prices.

27. Risks to NBFIs have received increased attention in recent FSAPs. The first FSAP to include stress tests of NBFIs was Norway in 2005, which analyzed the insurance sector. Since then, more FSAP exercises have incorporated stress tests of NBFIs, culminating in seven out of eight FSAPs in 2019 (Figure 4, second panel). Some FSAPs undertook stress tests for insurers and investment funds and their impact on asset prices.

Figure 4. Systemic Risk and Nonbank Financial Institutions

NBFIs are growing in economic importance… *…and in risk analyses within the FSAP.*



[9] Moreover, (life) insurers do not typically "fail" suddenly because their liabilities are long-term, and policyholders cannot cancel contracts prematurely without large haircuts, unlike bank deposits. Many large life insurers also have "mutual" structures where policyholders are equity holders and are expected to absorb losses in the event of bankruptcy even when their insurance contracts offer "guaranteed" returns. As for investment funds, they are highly substitutable, i.e., investors can find other funds that offer similar services quickly. The default of an asset manager is unlikely to affect the industry-wide capacity to continue providing services.

Insurance Solvency Stress Tests

28. Solvency stress tests of insurers are the most common stress test of NBFIs in FSAP. Stress tests have been applied to life and general insurers, but more often to life insurers. These are more systemic because they build up large asset holdings through their business model.[10]

29. Whereas banks are most exposed to credit risk from loans, insurers—especially life insurers with large balance sheets—are most exposed to market risk from securities. FSAPs tend to analyze the market risk of insurers by examining the impact of a scenario that includes falling prices of stocks, real estate, and corporate bonds.[11] The effect of the scenario on capital is derived by applying discounts to the values of insurers' assets and by revaluing their policy liabilities at new interest rates. Risk-based capital requirements are also modeled by adjusting down the values of the assets in line with the scenario. Since asset values fall under the scenario, capital requirements, therefore, tend to relax.

30. Apart from market risk, FSAPs have also analyzed the interest rate risk of insurers, especially the potential effects of a "low-for-long" scenario. Given that many long-term insurance policies were issued when interest rates used to be higher, they were priced assuming high-interest rates, which now appear unrealistic. As their higher-yielding bond assets mature, the proceeds have to be invested in the lower-yielding bonds currently available, which lowers the average yield on the bond portfolio and slowly erodes net interest income.

31. Some FSAPs have used bottom-up sensitivity tests to investigate the impact of shocks on liabilities leading to larger insurance claims and expenses. For life insurers, these tests include losses that would arise if morbidity or mortality were to increase or decrease. In aging economies, longevity risks are the main threat to the sustainability of long-term insurance products. For non-life insurers, key threats include losses from natural disasters and, in some cases, cyber risk, often through standard business insurance (e.g., 2019 Singapore FSAP). Catastrophe risk insurance and re-insurance for natural disasters are critical for diversifying property-insurance related tail risks from severe cyclones and floods. These risks are likely to rise with climate change, but the solvency impact on insurers could be limited as contracts and premiums are usually revised every year.

32. Risk analysis of insurance in some FSAPs has explicitly considered interactions with banks. A good example is where banks and insurers (or other NBFIs) are part of the same financial conglomerate, or where banking groups own insurance subsidiaries so that spillovers to the insurance firm from its parent or affiliates are a source of risk. The 2018 Belgium FSAP stress-tested such bank-insurance conglomerate models.

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[10] General insurers tend not to build up large asset holdings because most of their contracts are short-term, reducing cumulative premium payments per contract.

[11] For bonds, the valuation change (market risk) reflects the change in credit risk.

Asset manager Liquidity Stress Test

33. Stress tests of asset managers tend to examine their knock-on effects on securities markets through liquidity stress. For most asset managers, solvency risk is not material because they are usually funded by equity (e.g., mutual and investment fund shares and exchange-traded-fund, ETF, shares), or they pass on all investment risks to their clients (IMF, 2015).[12] Exceptions are when the funds are leveraged directly by borrowing or by investing in complex instruments with embedded leverage. However, many are exposed to liquidity risk in the face of mismatches between their funding and investment. Most open-ended mutual and investment fund shares are redeemable on demand, so any rush to redemption could trigger a sell-off of the funds' assets, possibly at a large discount if the investment is illiquid. While stress facing a fund (or funds investing in certain asset classes) per se might not directly generate a systemic impact as funds are highly substitutable, it can trigger systemic market turbulence and distress of other financial institutions through their interconnectedness. In particular, if liquidity-crunched asset managers fire sale their assets, market liquidity could dry up market funding for banks, other NBFIs, and NFCs, and asset prices might decline excessively.

34. Several FSAPs undertook liquidity stress tests, and some attempted to measure the contribution to systemic risk from feedback effects through fire sales and contagion to banks.

- ***Redemption pressures***: Some FSAPs analyzed historical redemption behavior—at the level of individual funds or classes of funds depending on data availability—to calibrate a severe yet plausible scenario for redemptions.
- ***Fire sale pressures*****:** To gauge systemic impact, some FSAPs measured the amounts that asset managers would sell of each asset type by considering pro-rata and waterfall selling strategies in response to an industry-wide redemption scenario. Some have estimated elasticities separately for different types of assets, and they have varied the order in which asset managers sell their assets.
- ***Fire sale impact*****:** The most challenging part of systemic risk analysis of the asset management industry is to gauge the market price impact of the fire sales appropriately. The 2015 FSAP for the United States compared these hypothetical sales to dealer inventories, flagging asset classes with insufficient inventories. Other FSAPs compared these sales to investment funds' liquid assets (Luxembourg) or market turnover (2016 Sweden FSAP). The 2018 Brazil FSAP estimated the effect of sales on asset prices using elasticities, which, in turn, were estimated from market liquidity measures.
- ***Contagion effects*****:** The Luxembourg FSAP measured the impact on banks from liquidity stress to investment funds, as the funds keep substantial deposits in banks. The Brazil FSAP introduced second-round effects, where asset price falls lead to another round of redemptions and another fall in asset prices.

[12] Nevertheless, asset managers could be exposed to solvency risks if they have guaranteed returns to their investors.

35. **The severe market turbulence right after the onset of the COVID-19 crisis re-emphasized the need to strengthen systemic risk analysis of asset managers**. The liquidity mismatch issue resurfaced once again despite various reforms to monitor, manage, and mitigate liquidity risks with asset management products. In particular, the fund industry contributed to building up vulnerabilities in NFCs in the run-up to the pandemic, as many funds invested in higher-risk NFC bonds and papers with leverage. The resulting market freeze led to unprecedented central bank liquidity support in money and corporate bond markets in some jurisdictions. The link between the fund industry and banks strengthened after the market turbulence as many funds activated credit lines from banks. The pandemic experience underscores the continuously evolving nature of risks and vulnerabilities from the asset management industry and the need for adapting risk analysis accordingly.

Pension Fund Solvency Stress Tests

36. **Pension funds can contribute to systemic risk in some cases.** Pension funds in most countries are too small and disconnected from the financial system to be considered a significant source of systemic risk. Their assets and liabilities are also long-term, making them stable institutional investors. However, in some countries, pension funds have the potential to contribute to systemic risk, including in a context of low-for-long interest rates, and therefore have been the subject of FSAP stress tests (Mexico, Namibia, Netherlands). Life insurers often administer pension plans for employers or individuals and sell annuities to retirees, so the health of insurers and pension funds tend to be linked. Both defined contribution and defined benefit pension funds can contribute to systemic risk. Defined contribution pension funds pass on market risk to their active members and, therefore, bring similar systemic risks to those identified for asset managers above. The solvency of defined benefit pension funds is sometimes underwritten by a sponsor, which could be a company, association (of workers or firms), or the government. As such, capital shortfalls in the fund could generate a contingent liability for its sponsors. If an economy has many large defined benefit pension plans that invest in similar assets, then a fall in those asset prices could pose a systemic risk through the resulting simultaneous rise in contingent liabilities of the government and many firms. The solvency positions of unfunded (pay-as-you-go) pension plans are masked by the lack of balance sheet information and, therefore, cannot be stress-tested in an FSAP.

37. **Pension fund stress tests follow a similar methodology to those for insurers.** Stress tests of pension funds in FSAP follow the two approaches for insurers described above. They analyze the effects of a sudden drop in the prices of assets held by the pension funds, or they analyze the effect of a low yield environment on net interest income over several years.

Challenges and Work Going Forward

38. **Future FSAPs will focus more on assessing NBFIs' contribution to systemic risk**. Unlike banks, the "failure" of NBFIs per se may not necessarily threaten system-wide stability. For instance, (life) insurers tend to fall into insolvency only gradually, and policyholders mostly bear the losses. Losses to investment funds are also absorbed by their shareholders. However, NBFIs could be conduits of contagion and thus contribute to systemic risk. Therefore, the focus

should be on contagion and interconnectedness effects, especially on banks, including cross-sectoral interactions and impacts on markets.

39. Scenarios for stress testing insurance companies need to overcome special design challenges. A key question in stress testing insurers is how closely to align the adverse scenario to those used in the bank solvency stress tests. In particular, how should the adverse scenario treat government bond yields? These yields may rise under the adverse scenario to the extent that the jurisdiction experiences capital flight, but they may also fall if the central bank lowers domestic interest rates. The scenario assumed in the bank solvency stress test may provide a guide of which outcome is more likely. Aligning the adverse scenarios of the bank and insurer solvency stress tests also facilitates comparisons. However, stress tests also need to ensure that adverse scenarios are actually stressful. Insurers' liabilities are usually longer-term than their assets—while the reverse is typically true for banks—so the immediate valuation effects of shocks to government bond yields tend to go in opposite directions. Therefore, generating an additional scenario (or a battery of single-factor sensitivity shocks) focused on insurance companies is often needed to ensure stress tests are sufficiently prudent.

40. Moreover, more progress needs to be made to overcome remaining data constraints and the lack of globally agreed prudential rules for NBFIs. There are no Basel-like international standards on prudential requirements for NBFIs.[13] For instance, for insurers, there is no globally accepted definition of capital or financial soundness indicators (FSIs). Therefore, the FSAP will benefit greatly from 's project of the Statistics Department on a methodology for FSIs for the insurance sector. Data gaps for some NBFIs—such as hedge funds and new types of NBFIs that emerged for regulatory arbitrage (e.g., wealth management products in China)—remain large, limiting the scope to cover them in risk analysis.

41. Quantitative analysis of NBFIs could also contribute to macroprudential policy and crisis management discussion. As the footprint of NBFIs and market financing rises, macroprudential policies that only target banks and their borrowers could lose effectiveness. For instance, standard toolkits are likely to have little impact on containing the credit boom when NFCs borrow more from financial markets. Such concerns may call for developing macroprudential tools for NBFIs and markets and consideration of a liquidity provision framework in case of a crisis, as highlighted by the market turbulence experienced at the onset of the COVID-19 crisis. At the same time, there is a need for caution and to avoid rushing to

[13] The banking sector is subject to an international standard for the definition of capital, but NBFIs are not. This means that capital is calculated differently from one jurisdiction to the next. Solvency II in the European Union (EU) has provided standardized capital calculation and reporting templates that have made it possible to develop portable stress testing tools within the EU. International principles on broad NBFI issues have been set by the International Organization of Securities Commissions (IOSCO) and a separate standard for insurers (Insurance Core Principles, ICPs). However, compared to Basel rules, these principles are given at higher levels and do not specify the details of prudential requirements.

introduce prudential measures without fully understanding the systemic importance of certain vulnerabilities.[14]

C. Risks in Nonfinancial Sectors

42. Quantitative analysis of vulnerabilities in NFCs, households, and governments has grown, given the potential for spillovers to the financial sector. Experiences of recent decades have demonstrated that vulnerabilities of NFCs and/or households can impact financial stability. For example, NPLs associated with sharply increased corporate lending were the root causes of the Asian crisis in the late 1990s. More recently, bank weaknesses and high NPLs in Italy have been related to NFCs debt burden. Household vulnerabilities and unsound mortgage lending were the causes of the U.S. subprime market crisis, and the banking crises in Ireland and Spain. More generally, loans to NFCs and retail loans to households are often the largest portfolio items of banks, making analysis of vulnerabilities related to these exposures a crucial element of credit risk analysis in bank solvency stress tests, and of financial stability risk analysis more generally.[15] Sovereign-bank linkages came at the forefront of financial stability concerns at the time of the European sovereign debt crisis. Moreover, to the extent that distress in the nonfinancial sector reduces the valuation of securities issued by such entities, banks' liquidity risks could rise as the value of liquid asset buffer deteriorates.

43. FSAP risk analysis has been incorporating link between nonfinancial and financial sector distress to varying degrees. To the extent possible, the same macro scenario assumptions are applied to both bank and nonfinancial sector stress tests. NFC stress testing results are cross-checked with the prediction from credit risks models for banks' NFC exposures, where useful. Household sector analysis could be also cross-checked with banks' credit risk models. In a few cases, such analysis has helped with estimating the effects of borrower-based measures. The bank-sovereign nexus is usually fully incorporated in bank stress tests.

Nonfinancial Corporations

44. NFC leverage has risen in both advanced economies and emerging markets since the GFC. Borrowing by NFCs has increasingly been driven by global factors relative to firm-level characteristics (Herwadkar, 2017). This, in turn, has made firm balance sheets more sensitive to changes in the global price of risk (Moreno and Serena-Garralda, 2018). In some cases, NFC leverage has continued to rise even after the onset of the pandemic as many NFCs facing earnings and liquidity shocks increased borrowing. The borrowing demand has been in part supported by various public support measures to NFCs and a re-emergence of the search for

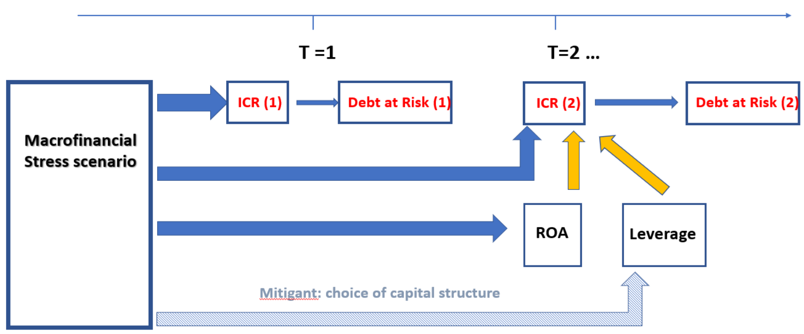
[14] For example, a sell-off in the corporate bond market may have a smaller overall impact on the real economy, depending on the investor base and link to the rest of the financial system. For instance, Giesecke and others (2014) studied 150 years history of corporate bond defaults and their macroeconomic impact in the United States, where the size of the market has been comparable to those of bank loans. While there were severe corporate default crises in which 20-50 percent of all outstanding bonds defaulted, they found that corporate bond crises had far fewer real effects than banking crises.

[15] For example, among EU banks included in the European Banking Authority's Transparency Exercise, loans and advance account for more than 60 percent of bank balance sheets, among which loans to nonfinancial corporations account for 27 percent and loans to households for 29 percent.

yield as major central banks have injected liquidity on a large-scale into market to mitigate the crisis.

45. Quantitative analysis of NFC vulnerabilities in FSAPs has typically focused on the interest coverage ratio (ICR), as summarized in Chow (2016). The analysis uses NFC financial statement data and defines distress as the risk of failing to repay any type of borrowing, including bank loans, payables, bonds, and international borrowings. The stress test estimates the impact of shocks to the interest rate, exchange rate, and profits (before interest and tax payments) on the ICR, defined as earnings divided by interest payments. The shocks could be applied one by one, similar to sensitivity tests, or in combination. Alternatively, the shocks could reflect a certain adverse macro scenario (IMF, 2016b, Figure 5). An ICR of below two is often considered as a sign of distress. Then, debt-at-risk (amounts of corporate debt issued by firms with an ICR of below pre-specified thresholds) measures the potential extent of corporate debt distress.

Figure 5. Macro-Scenario Corporate Stress Test using Interest Coverage Ratios



Source: IMF Staff.
ICR = interest coverage ratio; ROA = return on assets.

46. Another approach is to work with the PD. A firm's ICR is related to credit risk, but it is, in the first instance, a liquidity indicator rather than a solvency indicator. Regarding solvency risk, there are three approaches to assess corporate default risks: structural, empirical, and hybrid. Each approach has strengths and limitations. However, the current academic consensus is that the hybrid approach has the best predictive performance (Campbell and others, 2008).

- ***Structural approach***: This builds on Merton-type asset pricing models for corporate debt based on option pricing models, including the so-called contingent claims approach (CCA) developed by IMF staff (Gray and Malone, 2008) and Moody's KMV. It heavily relies on market-based indicators and is well suited for higher frequency monitoring. However, it is not applicable to firms without traded equity or bonds. Its forecasting performance tends to be weaker than other approaches.

- ***Empirical approach***: This is a reduced form empirical model that regresses the indicators of actual defaults on various firm characteristics, popular in the corporate finance literature. Historically, the literature focused on explaining cross-firm differences and included only firm-specific characteristics and indicators as explanatory variables. However, as the interest from the financial stability community rose, some authors developed models including macro-financial variables (Bruneau and others, 2012). The approach could cover a broader sample of firms than a structural approach but tends to be of lower frequency.

- ***Hybrid approach***: This approach is an empirical approach that includes some outputs from structural models—in particular, distance-to-default (Campbell and others 2008). The Bottom-up Default Analysis (BuDA) developed jointly by IMF staff and the National University of Singapore also adopts this approach (Credit Research Initiative, CRI, 2019a and 2019b). This type of model tends to show the best (out-of-sample) forecasting performance. Some FSAPs (e.g., 2017 Indonesia) have used BuDA.

47. NFC risk analysis is a useful input and complement to bank stress testing. FSAPs could treat NFC analysis as an independent exercise from bank stress tests as robustness checks of bank credit risk models or as substitutes for credit risk models. This is because NFC stress tests and banks' credit risk models for NFC exposures are closely related but different. First, the coverage of firms is different. NFC analysis could include listed and unlisted companies irrespective of whether these firms have bank loans or not. Bank stress tests only reflect the credit risk from firms that have bank loans. Second, the concept of the credit stress event, or "default," can be different. In the context of bank stress tests, the event considered is of loans being classified as nonperforming. In NFC analysis, credit stress can be conceptualized in many ways, including bankruptcy, default on any loans or bonds, or key metrics (such as the interest coverage ratio) falling below specific thresholds.

48. The COVID-19 crisis has highlighted the need to further integrate corporate sector analysis into bank stress tests going forward. Unlike previous NFC distress episodes, the variance of the impact of the pandemic shock across different economic sectors has been unusually high with continued uncertainty over the underlying solvency and liquidity positions of corporates, including once extraordinary pandemic-related policies are gradually withdrawn. In such cases, conducting (multi-year) macro scenario-based stress tests for NFCs and integrating them back to bank credit risk modeling could provide a more granular understanding of the potential financial stability impact of corporate stress. Tressel and Ding (forthcoming) establishes a framework for such analysis and complements the ICR-based analysis with additional indicators such as cash and equity buffers while being based on the same macro scenarios used for bank stress tests (e.g., GST). These stress indicators are mapped into aggregate bank PDs using the historical relationship between corporate defaults and these indicators, providing important potential input for bank credit risk modeling. Such corporate stress tests could also be useful inputs for bank stress tests when (historical) supervisory data are incomplete or of low quality.

Households

49. Several indicators have been used to assess household balance sheet vulnerabilities. The main source of household vulnerability is debt, especially mortgages. The measures of household indebtedness include (i) leverage such as the debt-to-income ratio (DTI) and the debt-to-asset ratio, and (ii) ability and willingness to repay measured respectively by the

DSTI and the LTV. The LTV ratio also affects loss-given-default (LGD) incurred by lenders. Risks of household debt tend to rise with lower bank lending standards. Understanding the characteristics of borrowers (such as income brackets) and the purpose of loans (primary residence vs. investments) is also helpful. Risks from household debt are mitigated when households have financial asset buffers that can be monitored by tracking saving ratios and financial asset allocations. Last, the assessments of residential real estate market prices and their potential overvaluation are essential to determine households' balance sheet vulnerabilities.

50. Microdata, such as household surveys, has been essential for assessing risks and calibrating borrower-based macroprudential tools. A lesson of the GFC is that vulnerabilities concentrated in a small segment of mortgages and their borrowers can harm the financial stability of the system. Focusing only on aggregate indicators could miss important sources of systemic risks, as the risky segments of the market would be masked. Various FSAP exercises have relied on the household survey to assess whether pockets of vulnerabilities are developing among categories of households. More recently, some FSAPs relied on household survey data to calibrate LTV and DSTI ratios for mortgages.

51. Some FSAPs undertook single factor stress tests of household balance sheets based on microdata. Examples include FSAPs for Italy, Luxembourg, the Netherlands, Ireland, and Brazil. The 2019 France FSAP and the 2017 Luxembourg FSAP analyzed households' vulnerabilities based on microdata, and both estimated a model of residential real estate prices. The 2019 Switzerland FSAP relied upon a structural model calibrated on microdata to estimate PDs and LGDs for mortgages.

52. Going forward, staff plan to increase the use of microdata and better integrate household vulnerability analysis into system-wide stress testing. Methodologies based on household microdata are important for (i) assessing the effects of downturn scenarios on household risk parameters, (ii) gauging the effects of policies including borrower-based measures such as LTVs, DSTIs, DTIs, and (iii) enhancing the assessment of household credit dynamics (mortgages, consumer credit). Staff is working on a household model framework to tackle these issues.[16] The framework will also consider second-round macro feedback effects and be integrated into bank stress tests where households' risk parameters will be modeled as a function of scenarios.

Public Sector

49. Most FSAP stress tests have treated sovereign risk as market risk from valuation changes in sovereign securities (Jobst and Oura, 2019). These stress tests face important challenges:

- ***Size of sovereign shocks***: Sovereign distress remains a relatively rare event in the post-World War II period for advanced economies and many emerging and developing economies. Historical data may not include sufficient distress events and generate too

[16] The framework is documented in Gross, M. and Población, J. (2017).

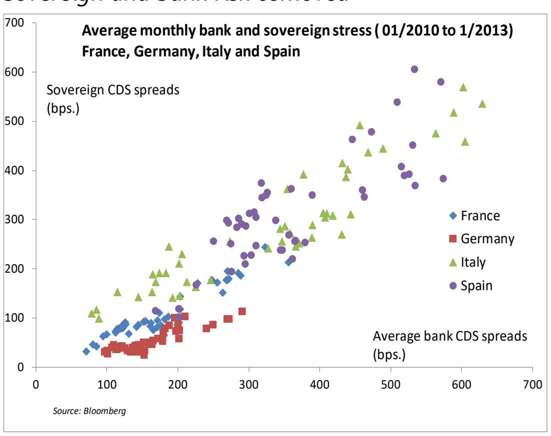
small shocks compared to what could potentially happen. Referencing cross-country experiences and using risk-sensitive market data (such as sovereign CDS spreads) when available could be useful.

- ***Treatment of sovereign exposures***: Basel capital rules have mechanisms to smooth out volatile, short-term effects to avoid introducing excessive pro-cyclicality. As a result, the same sovereign exposures could be valued or provisioned differently depending on how they are labeled. For instance, banks do not need to apply market valuation to securities in the held-to-maturity account (Jobst and Oura, 2019). However, such smoothing could reduce the effectiveness of macroprudential stress tests in the face of a sudden jump in sovereign risk. As a result, FSAP stress tests have often deviated from the strict application of regulatory standards and rules and have applied stressed market valuations of sovereign portfolios as deemed necessary for the risk analysis.

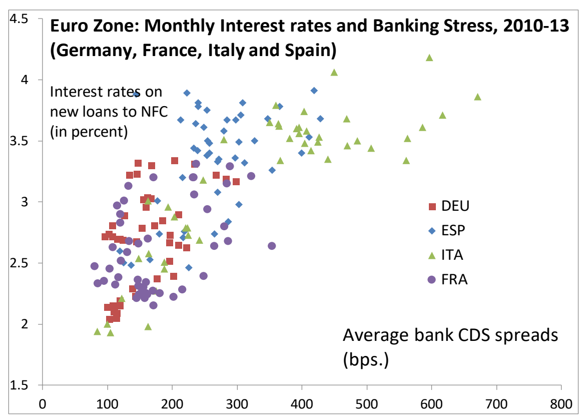
- ***Amplification and feedback mechanisms***: Sovereign distress could trigger a wide range of spillover effects on all the sectors of the real economy, making the overall impact highly uncertain. Designing an adequate macroeconomic scenario, therefore, is challenging. One might need to focus on a few channels that could be particularly relevant for the specific country.

Figure 6. Sovereign-Bank Nexus During the Euro Area Crisis

Sovereign and bank risk comoved



Impacting funding costs to the real economy



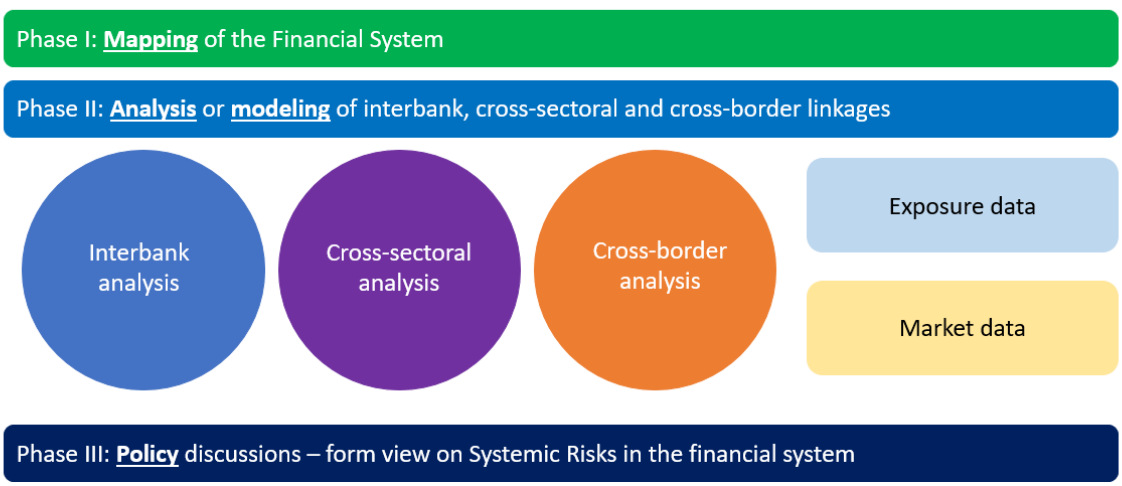
Source: Jobst and Oura, 2019

50. The pandemic could increase the relevance of sovereign risks for a broad range of economies, requiring new approaches to risk assessment. Many governments, including those in emerging and developing economies (EMDEs), have undertaken sizable deficit-financed fiscal expansions. The increased debt burden could increase sovereign risks in the years to come. As discussed by Jobst and Oura (2019), "sovereign distress" in EMDEs is more likely to be outright default than those experienced by advanced economies including explicit default on external debt, monetization of domestic debt, elevated bank loans to governments with evergreening, and accumulation of arrears among others. Indeed, the unprecedented unconventional monetary policy adopted by many EMDEs poses new challenges to assessing sovereign risks to financial stability in these jurisdictions. To assess these risks, FSAPs will need to consider alternative techniques, potentially such as incorporating sovereign default and its macroeconomic impact in scenarios and accounting explicitly for credit risks from government exposures.

D. Interconnectedness

51. Quantitative analysis of interconnectedness has expanded significantly since the 2014 FSAP Review. Reflecting data availability, FSAPs have focused on exposure-based interconnectedness in the domestic interbank market and cross-border bank lending, as well as price-based interconnectedness. More recently, improvements in data availability for sectoral financial accounts have allowed broader analysis of cross-sectoral and cross-border financial linkages. Interconnectedness analysis in FSAPs typically includes (i) mapping of the financial system, (ii) analysis or modeling of interbank, cross-sectoral, and cross-border linkages, and (iii) policy discussions (Figure 7).

Figure 7. Interconnectedness and Contagion Analysis in FSAP



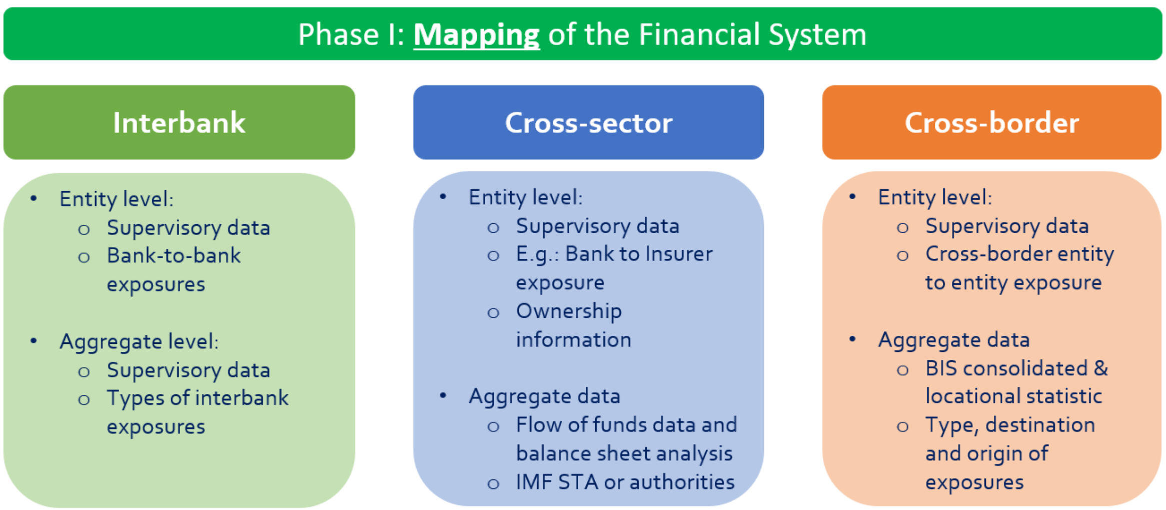
Source: Adapted from Bricco and Xu (2019).

52. Maps of financial system interlinkages help improve the understanding of shock amplification and spillovers (Figure 8):

- ***Interbank***: FSAP teams have used supervisory data to map different types of interbank exposures, such as loans, bonds, capital participation, and off-balance sheet exposures, and compared interbank with intra-group exposures (e.g., Spain).
- ***Cross-sectoral***: The balance sheet analysis approach (BSA) (IMF 2015) has been used to map cross-sectoral exposures based on the aggregated sectoral balance sheets of an economy (e.g., Romania), detailed supervisory data has been used to map the ownership structure within a country's financial system (e.g., Poland), and security-level data has been used to map cross-segment linkages in the financial system (e.g., France).

- ***Financial Market Infrastructures (FMIs)***: On occasion, authorities have shared FMI data, allowing the mapping of settlement and clearing linkages across a range of financial institutions. For example, the China FSAP used network analysis to map the linkage between FMIs and banks.
- ***Cross-border banking***: Many IMF assessments have used the consolidated and locational banking statistics from the Bank of International Settlements (BIS), which show cross-border financial flows intermediated by banks. The data allow mapping cross-border linkages between countries, analyzing the type, destination, and origin of these exposures, which also shed light on the business models of international banks (e.g., Spain).

Figure 8. Data Sources for Mapping Financial Systems



Source: Adapted from Bricco and Xu (2019).
Notes: BIS= Bank for International Settlements; STA=Statistics Department of the IMF.

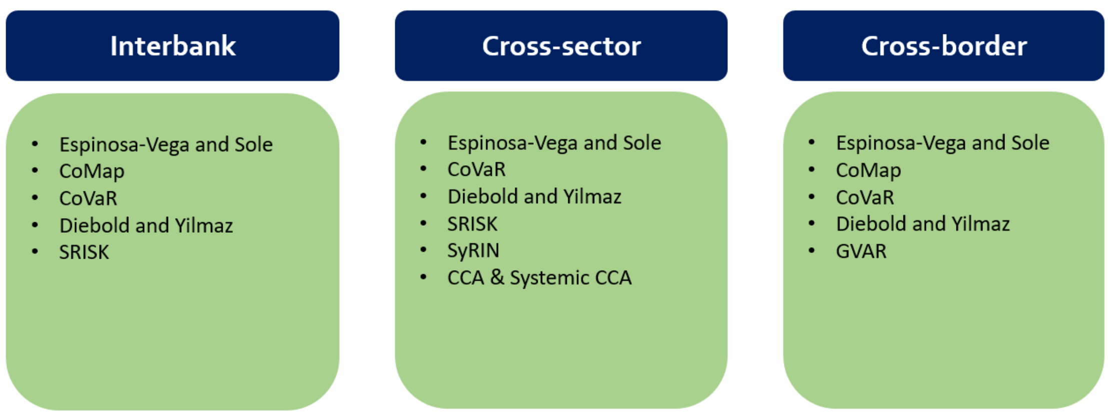
53. The modeling of interconnectedness has used a combination of exposure- and price-based approaches (see Figure 9, based on Bricco and Xu, 2019):

- ***Exposure-based approaches***: The Espinosa-Vega and Sole (2010) model has been used to analyze the impact of credit and funding shocks and their propagation across financial institutions (e.g., Luxembourg). The Contagion Mapping (CoMap) approach developed by Covi, Gorpe, and Kok (2019) was applied to a rich dataset of the euro area banking network in the Euro Area FSAP, allowing for bank-specific default thresholds. It was also added to the bank stress test to capture the impact of second-round effects through interbank contagion (Indonesia and Poland).

- ***Price-based approaches***: The Diebold and Yilmaz (2014) approach has been used by many FSAP teams to analyze interconnectedness based on equity prices and other market prices (e.g., Finland and Spain). The CoVaR (Conditional Value at Risk) method by Adrian and Brunnermeier (2016) was used in the New Zealand FSAP to assess the contribution of systemic risks stemming from the parent banks to New Zealand banks. The SRISK (Systemic Risk) approach by Acharya and coauthors (2012) and the SyRIN (Systemic Risk and Interconnectedness) approach by Cortes and others (2018) were applied in the United Kingdom FSAP to measure systemic risk in the banking and insurance sectors.

- ***Hybrid approach***: The contingent claims analysis (CCA) and the systemic CCA (Gray and Jobst, 2013) are built on both market and balance sheet data. CCA combined with vector auto-regression (VAR) and global VAR (GVAR, Dees and others, 2017) allow measuring various cross-sector and cross-border interlinkages such as bank-sovereign linkage assessed in Euro Area and the United States FSAPs. The Spain FSAP analyzed cross-border interconnectedness from macro-financial perspectives by considering the international transmission of credit shocks, following Xu (2012). A combined CCA-GVAR application was used in the Euro Area FSAP, involving individual banks, insurance, sovereigns, and economies, following Gross, Kok, and Zochowski (2016).

Figure 9. Interconnectedness Analysis: Approaches Used in FSAP

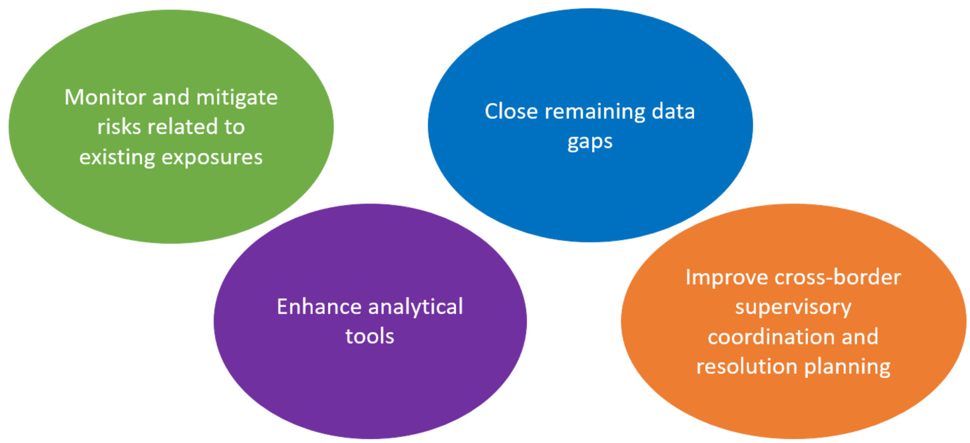


Source: Bricco and Xu (2019).

54. A combination of exposure- and price-based approaches provides a more comprehensive analysis of interconnectedness than either approach on its own. Exposure data alone do not reflect indirect linkages and potential amplification channels through market perceptions. Most price-data-based models are not structural and typically cannot pinpoint the channels of contagion. Therefore, applying both exposure- and market-based approaches has been the best strategy. Also, the results of interconnectedness and contagion analysis have been viewed in conjunction with different workstreams of financial stability analysis, including stress tests and nonbank and market analysis, to form a holistic view of risks and vulnerabilities in the financial system and interpreted with caution.

55. The results of the interconnectedness analysis have been used to formulate policy advice. FSAP recommendations based on interconnectedness and contagion analysis can be grouped into four main areas (Figure 10). The first is about strengthening monitoring of the linkages among financial institutions or between financial institutions and the real economy. The second is about closing major data constraints. The most common data constraints are related to cross-sectoral linkages at the entity level, for example, between banks and insurers and for conglomerates. The third is about enhancing analytical tools, often by expanding the coverage of cross-sectoral and cross-border linkages. The fourth about improving cooperation in cross-border supervision and resolution. Examples include the development of resolution plans for foreign subsidiaries and the enhancement of inter-agency and college collaboration and coordination.

Figure 10. Interconnectedness: Recommendations from Past FSAPs



Source: Adapted from Bricco and Xu (2019).

56. Broader coverage of institutions and activities would be desirable in future FSAPs. An example is institution-level interconnectedness analysis among all types of financial institutions (banks and NBFIs), including both direct and indirect (e.g., though common exposures) channels. The task is even harder when there are large institutions that are supervised only lightly or are entirely outside of financial supervisors' responsibility (such as nonfinancial corporations, NFCs). Also, a full interlinkage map is hard to construct in financial markets—securities, money market instruments, derivatives, and FX—where NFCs, government (agencies), and foreign institutions take part.

57. To strengthen interconnectedness analysis, it is critical to improve FSAP teams' data access. For example, FSAP teams do not have access to data on exposures across G-SIBs, data on financial conglomerates (which include banks and nonbanks), activity-based data collected by FMIs, or cross- and common-exposure data among banks and NBFIs. By contrast, some national authorities are using activity-based data (which cover transactions in certain markets by all types of participants) from clearing and depository institutions.[17]

E. Systemic Liquidity

58. Systemic liquidity analysis is closely linked to broader interconnectedness assessments. Systemic liquidity risk is the risk that multiple institutions simultaneously face liquidity difficulties. The key difference between institution-level and systemic liquidity risks is the amplification effect through interconnectedness in the whole financial system. It could

[17] A rapidly growing literature uses activity-based data to gauge contagion in credit default swap (CDS) markets (Paddrik and others 2016 and Levels and others, 2018) and interconnectedness through central counterparties (CCP, Huang and others, 2019).).

emerge in certain markets (e.g., repos) involving a broad range of participants and require activity-based analyses. A liquidity shock to some segments of the system could spill over to another (e.g., investment funds suffering from mass redemptions to banks where they keep their liquid deposit assets).

59. A liquidity stress in a part of the financial system could turn into systemic shock through different mechanisms, depending on the system's structure and main funding sources. Examples of systemic liquidity risk are:

- ***Market dislocation***: In financial systems that are primarily reliant on wholesale market instruments, systemic liquidity risks can arise when institutions face difficulties obtaining funding (funding risk) because of widespread dislocations of money and capital markets (IMF, 2011). The dislocation involves a wide range of institutions and financial instruments. The interaction of market and funding liquidity stresses could amplify the effects of a relatively small trigger to the overall liquidity stress of market participants (Brunnermeier and Pedersen, 2008, and Adrian and Shin, 2010) who may, in turn, fire-sell their assets and further depress the market.

- ***System-wide liquidity shortage***: In bank-dominated financial systems with little market funding, systemic liquidity risk could arise from maturity mismatch and a system-wide loss of deposits, either wholesale (e.g., government, corporate, and NBFI deposits) or retail. It could be triggered by common underlying drivers such as capital outflows, commodity price shocks, sovereign distress, or other issues that lead to a spike in risk aversion and liquidity need of various economic sectors.

60. Complete system-wide liquidity stress testing remains a challenge for staff and authorities. Despite strong interest, developing assessment tools has been challenging because of significant gaps in collating data cutting across different types of financial institutions and economic sectors. To conduct such a comprehensive stress test, one would need granular activity-based data, possibly through FMIs or by merging multiple databases collected by various financial regulatory agencies.[18] However, these data have been rarely made available to FSAPs or, in other cases, would involve such a large volume of confidential data processing that would be hard to accomplish without longer and more intensive engagement. The need to model participants' behavior in stress—similarly to in bank liquidity stress tests—is another outstanding challenge. Progress amongst national authorities here has also been slow, reflecting in part a need for significant collaboration across multiple regulatory agencies to integrate their extremely detailed databases.

61. Recent FSAPs have mapped the main aggregate financial linkages in the whole system as a step to understand the potential contours of systemic liquidity risks. Such mapping exercises can help identify key funding and liquidity markets, including the interconnections and the role played by different types of participants. The ideal data for such

[18] For example, Paddrik and others (2016) took the U.S. Comprehensive Capital Analysis and Review assumptions and examined its impact on CDS market participants through margin calls. Levels and others (2018) analyzed the impact of Brexit on the drivers of CDS transactions in the Netherlands.

efforts include granular information on who-to-whom exposures (e.g., the flow of funds by counterpart or balance sheet approach, BSA, data) and exposure data by instruments (Romania, Nigeria, Thailand, and Philippines FSAPs, for example).

62. Some FSAPs have undertaken more in-depth analysis and assessed systemic liquidity risk by connecting liquidity stress tests of main institutions and sectors. For instance, the 2017 Luxembourg FSAP conducted a detailed liquidity analysis of mutual funds, while the Article IV examined the link between banks and mutual funds through deposits. MCM has also developed a new tool to assess system-wide liquidity stress caused by balance of payment shocks in small open economies and their spillovers across economic sectors using the BSA data.[19] The 2020 Philippines FSAP applied the tool to assess the potential liquidity stress spillovers between banks and NFCs under loan moratorium programs introduced to counter COVID-19.

63. Given the critical role of behavioral assumptions, understanding the operational set-up of markets and regulation on key participants becomes particularly relevant. The propagation of liquidity stress depends heavily on participants' behavior, such as fire selling of assets and their pecking order, hoarding cash, discontinuing market-making, etc. Regulatory requirements are likely to drive parts of the behavior. The FMIs and their operational frameworks are likely to be different in each key market, which could affect their own resilience as well as their role in transmitting liquidity shocks across participants. Some supervisory reporting—such as contingent financing plans of financial institutions—could also help informing the choice of assumptions.

64. The crisis management framework and the backstopping capacity of the government could also affect participants' behavior and the impact of systemic liquidity stress. While typical liquidity stress tests do not incorporate central bank support, it would be more appropriate to judge system-wide resilience, including liquidity support, in case of systemic liquidity stress. Financial institutions should hold sufficient liquidity buffers to counter institution-specific shocks, but not necessarily under a system-wide distress. Moreover, the perimeter of systemic liquidity support—especially to NBFIs and certain markets—could affect liquidity stress test results. The availability of deposit insurance, government backstops to emergency liquidity facilities, and FMIs would also alter the likely behavior of agents in these markets.

65. The magnitude of the economic and financial disruption caused by systemic liquidity stress depends on the characteristics of the financial system. For example, stress could be successfully mitigated in jurisdictions with reserve currencies because the backstop capacity of the central banks is little constrained. As observed during the GFC and the early months of the COVID-19 crisis, major central banks managed to mitigate systemic liquidity stress successfully even though they needed to expand the perimeter of liquidity support to non-traditional counterparts and develop new instruments. The same does not necessarily apply

[19] See MCM COVID-19 note "System-wide Foreign Exchange Liquidity Stress Tests (with excel tool)" by Oura and Leika.

to small open economies without reserve currencies, especially when the sources of systemic liquidity shocks are from the balance of payment stress. Such economies would need external finance to mitigate systemic liquidity stress.

66. Developing more comprehensive systemic liquidity analysis tools in FSAPs is an important objective. The near-term effort will include targeted and manageable pilot exercises building on experience gained in past FSAPs. A comprehensive systemic liquidity stress test would include the liquidity stress tests of key institutions, incorporating any spillover effects through direct exposures and major liquidity markets. It should use both institution-level liquidity position data and activity-based market transaction and positioning data. Conducting such analysis at the contract and securities level could require substantial investments in big data processing capacity – options for collaboration with regulatory agencies in such processing and analysis could also be explored given the specific challenges here.

F. Macrofinancial Linkages

67. FSAP risk analysis addresses macrofinancial linkages in several ways. First, macrofinancial linkages are often embedded in the models used to build macro scenarios for stress testing. FSAPs usually draw on existing DSGE models available at the IMF or models developed by national authorities. Second, reduced-form models to quantify macro-financial linkages—such as GaR and structural VAR (SVAR), including macro-level economic and financial variables—are also deployed. Such models describe the extent of macro-financial linkages parsimoniously at the aggregate levels but are not linked to core stress testing exercises (though they could be used to build scenarios). Third, FSAPs also seek to assess so-called "second-round effects" and measure the impact of financial sector distress—the output of the bank-level solvency stress tests—back to economic growth. This analysis of feedback loops between financial and macro stress is at the frontier of current research at the Fund and major central banks. Staff are also working on agent-based models, which model tail risks away from rational behavior in DSGE models and can include both macro- and micro-level linkages, but these have not been yet used in FSAPs.

Macro-Level Macrofinancial Linkage Analysis

Growth-at-Risk (GaR)

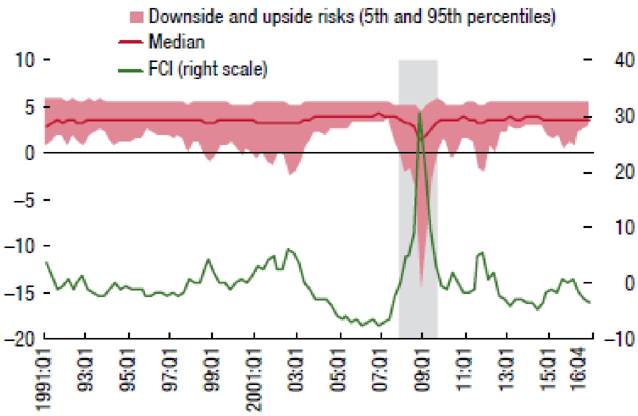
68. The GaR framework provides a high-level summary relationship between the real economy and financial conditions in an unlikely but plausible tail event.[20] It is based on the insight that macro-financial vulnerabilities can affect downside risks to economic growth differently from the median growth forecast. GaR forecasts the entire probability distribution of GDP growth conditional on a set of macrofinancial indicators. The non-linear relationship between GDP growth and financial conditions is estimated using quantile regression. For

[20] For technical details of GaR, see IMFGAR on GitHub. See Prasad and others (2019) for the application of GaR in IMF surveillance.

instance, in the United States in early 2007, the forecasted bottom five percentile growth rate started to deteriorate more noticeably than the median forecast (Figure 11).

Figure 11. Growth-at-Risk and the Global Financial Crisis

(One-year-ahead GDP growth rate density forecast; left scale = percent; right scale = standard deviations)

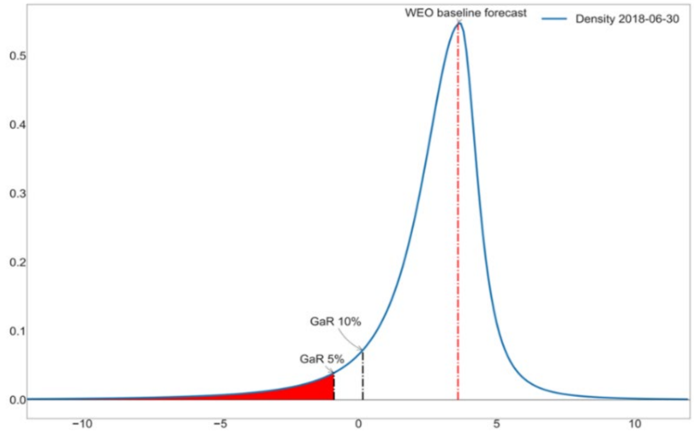


Source: IMF (2017b).
FCI = financial condition index.
The figure shows the time series of estimated, conditional 5th, 50th, and 95th quantiles of one-year ahead GDP growth. The median (red) line is the forecast of the 50th quantile of GDP growth made a year earlier. The shaded area in red shows the range between the 5th and 95th quantiles.

69. GaR estimation involves three steps. The first is to partition macro-financial indicators (such as credit spreads, interest rates, leverage, and external conditions) into distinct categories and extract common factors in each category using principal component analysis. The second step is to apply quantile regulations to measure the link between GDP growth and the common factors, to separate the strength of the link when the growth rate is close to median and at tails. The last step is to generate a full conditional distribution of GDP growth by fitting a distribution to the estimated conditional quantiles (Figure 12). Such a distribution enables an assessment of the upside and downside risks to growth as well as the probability of weak GDP growth at given future horizons.

70. Some recent FSAPs have used GaR to benchmark the severity of adverse scenarios in stress tests. Examples include Peru, Italy, France, Thailand, Canada, and Latvia. Historically, FSAPs relied primarily on the standard deviation of a two-year cumulative GDP growth rate to determine the severity of adverse scenarios. FSAP teams typically aimed at a two-standard-deviation shock, but the actual size varied as teams applied judgment to reflect the extent of vulnerabilities (i.e., bigger vulnerabilities, larger downturn). GaR provides a systematic, model-based approach to incorporating the extent of vulnerabilities in the severity of the adverse scenario. In particular, GaR will show more severe tail events when vulnerabilities are high.

Figure 12. One-Year Ahead Conditional GDP Density Forecast
(In percent)



Source: IMF staff calculations.
Note: WEO = World Economic Outlook.
The quantile regression results reflect the cumulative distribution of GDP growth—the bottom 5th percentile estimate means the likelihood of GDP growth rate being at that estimate or lower is five percent.

Dynamic Stochastic General Equilibrium (DSGE) Approach

71. DSGE models with financial sectors are widely used in macro-financial analyses to generate theoretically coherent and empirically-based dynamic interrelationships. These models encompass firms, households, financial institutions, the fiscal authority, and the central bank acting optimally in response to shocks in general equilibrium. Interpretable structural shocks—such as preference, technology, and risk premium shocks—drive the dynamics. Unlike reduced-form empirical macro models, there is no need to estimate structural shocks by imposing somewhat arbitrary assumptions on the order of spillovers among economic variables. DSGE models have many variants. Policymaking institutions often use the estimated New Keynesian DSGE models that incorporate a range of nominal and real rigidities. Since the GFC, researchers have been expanding the model with an array of macro-financial linkages and financial intermediation.

72. FSAPs have used DSGE models mostly for generating stress test scenarios. In most cases, teams used either the global macro-financial model (GFM) (Vitek, 2018) or IMF's Research Department's global projection model (GPM) (Carabenciov and others, 2013). GFM incorporates a variety of financial spillover channels while GPM mainly focuses on the trade channel. Given the role of the IMF as a multilateral policy institution, these models consider multiple countries and emphasize cross-border spillovers in contrast with the models used by national authorities. Such a feature is very important for FSAP for the home jurisdictions of global financial institutions.

73. The GFM is a New Keynesian DSGE model of the world economy. It covers 40 major advanced and emerging market economies—featuring extensive macro-financial linkages and diverse spillover transmission channels. It features a range of nominal and real rigidities, extensive macro-financial linkages, and diverse spillover transmission channels. These macro-financial linkages encompass bank and capital market-based financial intermediation, with financial accelerator mechanisms linked to the values of the housing and physical capital stocks. Spillovers are transmitted via international trade, financial, and commodity price linkages. These international financial linkages encompass cross-border balance sheet exposures and contagion effects. Policies are represented in the GFM by sets of monetary, fiscal, and macroprudential policy instrument rules. The parameterization of the model is based on a mix of calibration and estimation. It has been used to analyze macro-financial policy, risk, and spillover effects for these and other Fund surveillance products.

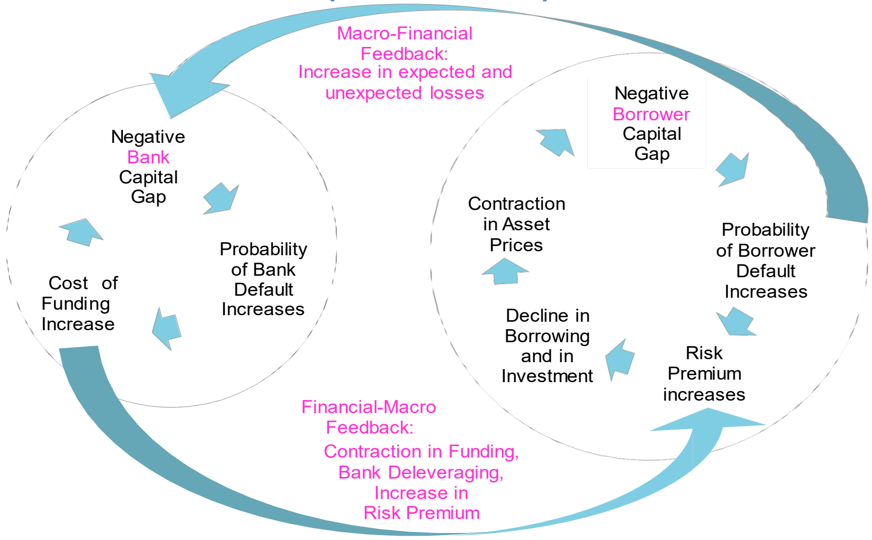
74. More recently, DSGE models have also been used for the analysis of macroprudential policies. Examples include the effects of borrower-based measures in housing markets—and the adequacy of risks and capitalization. DSGE models are particularly suited for counter-factual analyses for new policy instruments as their dynamics are driven by structural shocks that have a clear interpretation and offer a narrative behind historical realizations and future simulations of macro-financial variables.

75. In the 2017 Netherlands FSAP, a DSGE model with the financial sector was used to simulate how different loan-to-value (LTV) ratios affect the volatility of macroeconomic variables. The response of aggregate consumption and investment to positive and negative income shocks was compared when households face an 80, 90, and 100 percent LTV ratio. A higher LTV ratio moderately increases financial intermediation in tranquil times. But the negative effects of higher LTV ratios during downturns from increased defaults and lower consumption and investment outweigh the benefits. The adverse response is non-linear, and the costs of increasing the LTV ratio from 90 to 100 percent are much higher than increasing it from 80 to 90 percent.

76. Another DSGE model has been used to identify financial cycles and capital gaps that may trigger macroprudential measures (Lipinsky and Miescu, 2019).[21] The model estimates the deviations of bank and corporate capital from "desired" levels, where the desired levels of capital are determined to account for evolving risks. Actual capital accumulates only slowly, in line with bank and corporate income (Figure 13). The 2019 France FSAP used this approach to identify risks from the banking and corporate sector jointly and estimate capital needs.

[21] The model features extensive balance sheet linkages between the banks and corporates as well as non-standard financial shocks. The model extends Christiano, Motto, and Rostagno (2014) with a banking sector. Bank-corporate feedback effects were particularly important in France because the corporate sector has been leveraging up sharply with both bank loans and corporate bonds.

Figure 13. Macro-Financial Feedback Between Borrowers (Real Economy) and Lenders (Financial Sector)



Source: IMF staff.

Macro-Financial Analysis Linked to Stress Testing Exercises

Structural Vector Auto Regression (SVAR) and Semi-Structural Approach

77. Staff have also developed empirical approaches to integrate macro-financial feedback effects into bank-level stress tests. Catalán and Hoffmeister (2020) developed a credit response and externalities analysis model that integrates bank by bank stress tests into an otherwise standard macroeconomic SVAR model. Krznar and Matheson (2017) developed a semi-structural modeling framework that facilitates the analysis of both the direct effects of macroeconomic shocks on the solvency of individual banks and feedback effects that allow for the amplification and propagation of shocks that result from bank deleveraging and credit crunches. The main feedback channel of both models operates via bank credit. Capital losses from adverse macro-financial shocks prompt banks to cut lending and contract their balance sheets. The resulting credit crunch amplifies the initial macro shocks. They have been developed in the context of technical assistance and AIV surveillance and are yet to be applied in FSAPs.

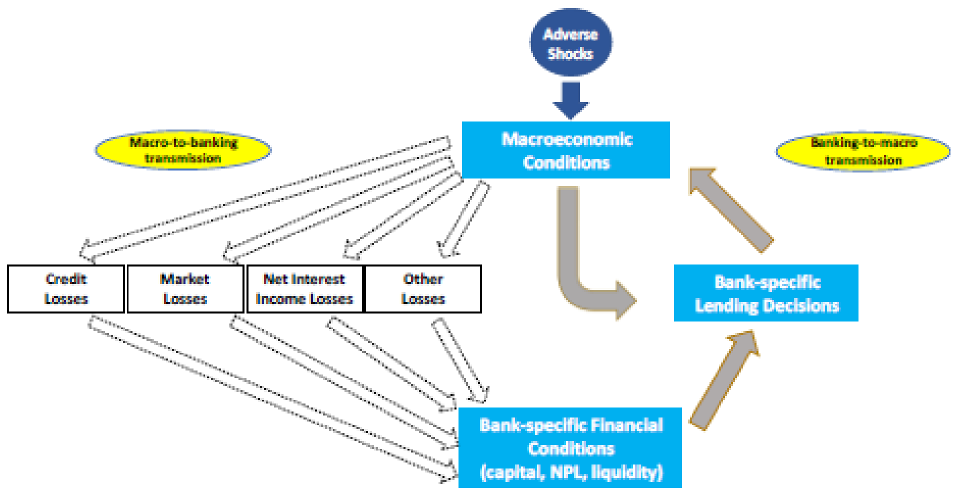
78. The models have several building blocks (Figure 14).

- ***Catalán and Hoffmeister (2020):*** The main macro block is estimated using an SVAR that includes endogenous macroeconomic variables and exogenous aggregate bank indicators. Then, a bank-by-bank satellite model block estimates the losses (credit, market, interest income, and others) in response to the changes in macroeconomic variables. The losses are put together to calculate key financial ratios (capital, liquidity, and non-performing loan ratios) for each bank, and the indicators are aggregated up for the whole banking sector. The aggregate bank indicators in the stress scenario are then put back into the macro block, and the process continues until micro-macro consistency is achieved.

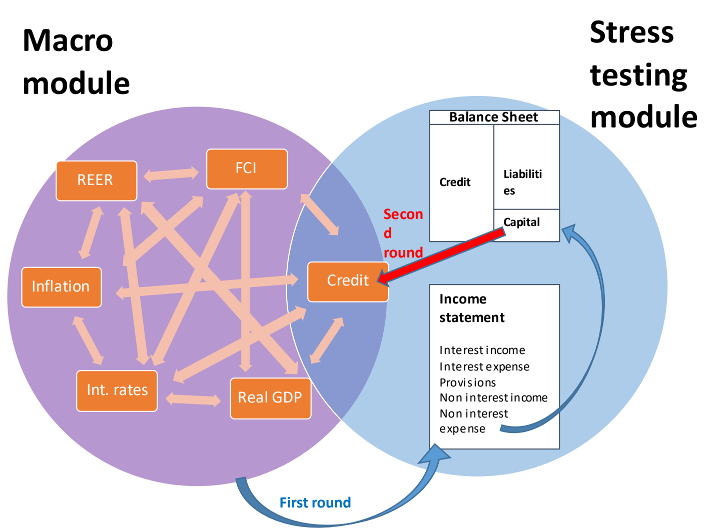
- **Krznar and Matheson (2017)** embed a standard stress-testing framework based on individual banks' data in a semi-structural macroeconomic model. The macro model characterizes an open economy where the relationships between the variables are determined by theoretical and empirical considerations. The stress testing module is a set of panel regression models that describe the behavior of the individual banks' income and expenses to key variables from the macro module. Panel credit equations link individual banks' capital (from the stress-testing module) to bank credit and output. The whole framework is estimated using Bayesian methods.

Figure 14. Macro-Financial Feedback Loops and Building Blocks

Catalán and Hoffmeister (2020)



Krznar and Matheson (2017)



NPL = nonperforming loans.

79. These approaches point to the limitations of applying static and quasi-static assumptions of bank balance sheet growth and exogenous scenarios in standard bank stress tests. The relative performance of banks under the test (i.e., the ranking of impact on capital ratios) changes depending on the balance sheet growth assumptions and incorporating macro-feedback effects. Banks that appear resilient (vulnerable) under a static balance sheet and exogenous scenarios could turn out to be vulnerable (resilient) when assessed through a dynamic balance sheet approach and incorporating macro-feedback effects and endogenous scenarios.

Agent-Based Models

80. Agent-based models (ABMs) are a promising new simulation-based approach to capture macro-financial linkages. ABMs are an alternative to econometric/empirical and dynamic equilibrium models used by some central banks (though not yet in FSAPs). ABMs are simulation-based models that allow modeling macro-financial system dynamics "from the bottom-up," based on individual agents, including firms, households, banks, central banks, and sovereigns. They involve heuristic behavioral rules, often with bounded rationality in contrast with rational expectation critical for equilibrium models.[22,23]

81. Stress tests have always had some elements of ABMs, as they assume certain behavior of individual financial institutions. Yet, compared to an ABM, a typical stress test model does not have sufficiently rich behavioral rules, comprehensive agent groups (besides banks), explicit financial contracts, financial markets, or regulatory constraints. In an ABM, the agents may include banks, nonbanks, central banks, sovereigns, households, and firms. Financial contracts represent interlinkages between institutions (e.g., common asset holdings, counterparty exposures, funding provision, and collateral channels). Markets are crucial to determine the price formation process and the fair valuation of instruments. Constraints include regulatory constraints (e.g., capital, liquidity ratios), market constraints (e.g., leverage ratios), and internal constraints (e.g., internal risk limits). Agent behavior drives the overall dynamics of the macro-financial system.[24]

82. Indeed, ABMs enable assessing complex interactions of many micro-elements of the financial system and evaluating their systemic impact, which is essential for macro-financial stress tests. In contrast with the mainstream macroeconomic approach with representative agents and equilibrium relationships, stress tests try to capture tail events, which usually entail sudden shifts in markets, so historical distributions may not adequately capture the non-linear dynamics under stress (Bookstaber, 2012). Financial instability assessment requires modeling behavioral assumptions and realistic constraints that explain out of equilibrium behavior. More specifically, a meaningful macro-financial stress test should include a granular agent-based economic system with financial sector focus, macro-financial feedback effects including dynamic balance sheets, and state dependence (i.e., non-linearities of some

[22] LeBaron and Tesfatsion (2008) observe that mainstream macroeconomic models miss important elements, e.g., subsistence needs, incomplete markets, imperfect competition, inside money (credit creation), strategic behavioral interactions; and, therefore, call for the exploration of ABMs. Tesfatsion (2006a and b) are two general framework papers exploring the role of agent-based economics next to traditional equilibrium-based economics, including definitions of complex and complex adaptive systems.

[23] Heuristics (Simon, 1955) are decision rules which ought to reflect agents' behavior who are cognitively limited and not able to understand the complexity of the world and to absorb and process all relevant information.

[24] For a general discussion in a stress test-oriented framework, see Aymanns and others. (2018).

kind). It is ideal to explicitly account for network interconnectedness between all agents in an economy as well.

83. The financial stability community has been developing agent-based stress testing models based on simplified balance sheet structures (BIS, 2015). It incorporates solvency-liquidity and macro feedback effects. The framework would allow policymakers to examine the capacity and willingness of the banking sector to support the economy under stressful conditions. The model incorporates behavioral responses of banks and nonbanks, examines the interaction of risks (credit risk, market risk, liquidity risk), endogenizes funding access (leverage), fire sales (portfolio rebalancing), and capital dynamics. When banks hit a constraint, they become destabilizing agents as they are forced to cut credit or sell undervalued assets triggering fire sales and curtailing financial intermediation. However, agent-based stress testing models are still experimental, and FSAPs have not yet used them for stress testing.

84. Staff are developing two prototype models to assess the macro-financial impact of a range of adverse scenarios in different banking sector structures. In the prototype model (Valderrama, forthcoming), simulations show that a temporary shock may morph into a long-lived shock eroding the solvency of the banking sector, depressing credit growth, and undermining economic growth. The analysis shows that attempts to regulate risk by tightening only bank regulatory requirements or restricting market access at the local level may be ineffective to contain systemic risk due to the linkages between the banking sector, the securities market, and the credit market. Instead, a system-wide perspective to prudential regulation, including banks and nonbanks, is needed.

85. A second prototype model is a larger-scale macro-financial ABM that features banks, households, firms, a sovereign, and a central bank. The purpose of the model is to assess the effects of both borrower-based and capital-based macroprudential policy measures in one model, which has a rich structure in terms of the bank loan granting process to households (for mortgages) and firms (for investment). The Eurace 2.0 model comprises an integrated balance sheet structure between micro agents within and across groups of agents (Gross, Hilberg, Hoog, and Kohlweyer, forthcoming).

G. Macroprudential Policy

86. FSAPs have made progress in using quantitative analysis to provide macroprudential policy advice. Most FSAP reports provide a comprehensive assessment of potential vulnerabilities, including broad-based vulnerabilities from rapid overall credit growth, sectoral vulnerabilities from the indebtedness of the household and corporate sectors, vulnerabilities from liquidity and FX mismatches, and structural vulnerabilities from interconnectedness, including between the bank and nonbank financial system. FSAPs can formulate macroprudential policy recommendations based on early warning and leverage indicators in the guidance note (Table 1 in IMF, 2014) and FSAP risk assessment incorporating existing risk mitigants. For instance, the 2018 France FSAP identified vulnerabilities in the corporate sector based on its analysis of interest coverage ratios (debt-at-risk) and recommended action to control these risks. It also argued that household sector vulnerabilities were more contained as a result of a shift towards fixed-rate mortgages and a leveling off of house prices.

87. Some FSAPs have more recently conducted a dedicated analysis to help guide the calibration or assess the impact of macroprudential tools. For example, the 2018 Romania FSAP used credit register data to identify thresholds for the sensitivity of borrowers' probability of default to DSTI, thereby guiding the calibration of a cap on DSTI. As discussed earlier, the 2017 Netherlands FSAP used a DSGE model to assess the macroeconomic impacts of a housing shock for different LTV ratios. And the 2018 Peru FSAP assessed the impact on bank lending of a tightening of capital buffers, using bank-level data in an event study around an increase in capital requirements.

88. The more explicit use of solvency and liquidity stress test methods to inform the assessment of the macroprudential stance may be explored in the future. To adequately inform macroprudential policy, the stress test scenario should be more severe when economic and financial conditions are more buoyant. Such test results can then inform buffer sizes (e.g., for the countercyclical capital buffer or sectoral buffers). Stress testing tools and models can also be used to conduct an ex-ante impact assessment of possible future measures. In addition, analytical tools using microdata can be considered more explicitly in the future to inform the calibration of borrower-based tools (such as LTV and DSTI). As the financial system continues to involve, tools will also need to be developed and refined to allow for a quantitative assessment of risks in the nonbank financial system and the calibration of policy responses in this increasingly important area.

H. Improving Efficiency

89. Improving the efficiency of core quantitative tools is critical to expanding risk analysis in FSAPs within the established resource envelope. Results of the survey of stakeholders suggest an expectation for more work on emerging risks, broader types of interconnectedness, and macro-financial linkages. At the same time, staff see a crucial need to continue core bank stress tests to support the value of independent FSAP assessments. Therefore, improving the efficiency of core risk assessment tools is critical for preserving the quality and breadth of FSAP risk assessment.

90. Over the past five years, the use of quantitative tools has expanded, while the overall FSAP cost has remained broadly flat. In addition to bank stress tests, more FSAPs have covered the risks from NBFIs and interconnectedness. The trend is similar to the scope of central banks' financial stability reports. However, the central banks have substantially increased resources allocated to financial stability analysis.

91. Going forward, staff will standardize core quantitative tools, which will improve efficiency. Staff are undertaking work to standardize core risk analysis for different data environments, accompanied by detailed guidance notes and files/codes on a refreshed webpage dedicated to the topic to support FSAP teams. Staff are also working to develop a tool to efficiently estimate various satellite models for stress tests and check their performance—one of the most time-consuming parts of building a stress testing framework. More broadly, shifting quantitative analysis away from excel-based tools to program codes could increase efficiency and accuracy and help validate stress testing frameworks.

92. Nonetheless, such efforts will be constrained by the need to tailor risk analysis to country-specific conditions. For one, bank-level supervisory reporting format differs substantially across jurisdictions, in part owing to the difference of accounting standards, bank business models, and main risks. Economies also adopt different supervisory approaches—such as on loan-loss provisions, collateral valuations and loan-to-value calculation, securities and derivatives valuation, and off-balance sheet items—and intrusiveness, which require adjustment for cross-county consistencies. While internationally active banks are subject to Basel III rules, some jurisdictions apply different rules for domestic banks, and many jurisdictions without global banks follow Basel II or I rules. A standardized tool should be flexible enough to handle these country-specific characteristics in key risks, transmission channels, regulations, and data.

93. Several projects are already underway to improve the efficiency of existing tools.

- ***Bank stress test tools***: MCM has been producing numerous internal guidance notes and mostly excel tools posted on the internal Knowledge Exchange site in addition to published policy notes and working papers. These internal notes and toolkits are now being updated and expected to be finalized in the next couple of years. Staff will collate these in an internal operational reference note for FSAP teams. There are also ongoing technical projects, including a tool to rapidly estimate satellite models using various techniques and a project to develop stress testing codes rather than spreadsheets. Staff is also operationalizing and planning to disseminate the simplified bank stress testing tools with publicly available data—the GST and the UST—which could also help financial surveillance in Article IVs.

- ***Stress test scenarios***: Recent FSAP stress test scenarios have been usually simulated by the GFM, but the maintenance and implementations of the model had been dispersed among a handful of MCM staff across divisions. The creation of the modeling unit in MCM and its role in implementing the model for FSAP scenario design should improve efficiency and also support the consistency of scenarios across FSAPs.

- ***Growth-at-Risk***: The GaR tool is unique for two reasons. First, the user-friendly package—Excel interface with underlying Python codes—was developed with close coordination of MCM and ITD. Second, the whole package is published in GitHub—the largest community for software developers—free of charge. Applying the same approach for other tools could improve the efficiency of the FSAP risk analysis process despite initial development costs.

- ***Corporate sector stress test tools***: As discussed in the NFC stress test section, a corporate risk assessment tool is under development to support FSAPs and bilateral based on Tressel and Ding (forthcoming). In addition, staff are able to access the BuDA tool to implement macro scenario corporate stress tests with little human resources.

94. External dissemination of FSAP quantitative tools will improve communication with national authorities. The publication of methodological notes will facilitate discussions with authorities.

EMERGING RISKS

95. Quantitative methods in FSAPs have been adapted to support analysis of emerging risks, and new approaches will continue to be developed in the future. Unlike the assessment of financial sector oversight and safety nets, there are no prescriptive global standards for quantitative risk assessment. Given the rapid evolution of data availability and statistical and quantitative techniques in the field, the financial stability community has considered broad best practice "principles," supporting a wide range of tools including those that may have been recently developed (BCBS, 2018 and IMF, 2012).[25] These approaches have been useful for many members of the Fund (see SM/21/53, background paper on traction), and staff would continue to develop new approaches to assess emerging risks.

A. Climate Change

96. Analyzing the financial stability implication of climate change raises key new analytic and data challenges for FSAPs. There is a need to obtain data and build a framework to assess which risks are material for members. And then to design plausible scenarios at different horizons. The choice of horizon is an important issue in financial stability analysis. Typical bank stress tests focus on the 3-5-year horizon. The climate science literature usually considers long-term "pathways" up to 2100 (see Box 1). Thus, a key feature of the staff's proposed approach for FSAPs is to assess both short- and long-term financial stability risks from climate change. And finally, to map macro-financial consequences of these into FSAP stress testing framework. The landscape here is complex and is summarized in the appendices.

97. Financial stability risks from climate-change-related events can be broadly categorized into physical and transition risks:

- ***Physical risks*** represent physical damages related to the direct and indirect consequences of climate change. They can materialize as extreme events (acute physical risk caused by natural disasters such as cyclones, floods) or via the effects of more slow-moving, long-term changes in climate patterns (chronic physical risk such as sea-level rise, and drought among others).
- ***Transition risks*** pertain to the consequences of changes in public policies and technology aimed at mitigating the effects of climate change and adjusting towards a lower-carbon economy. They are often modeled as higher carbon price scenarios aimed at mitigating rising temperatures.

[25] BCBS (2018) listed nine principles, including "stress testing framework should capture material and relevant risks and apply stress that are sufficiently severe" and "stress testing practices and finding should be communicated within and across jurisdictions." IMF (2012) listed seven principles, including "focus on tail risks" and "define appropriately the institutional perimeter for the tests."

Box 1. Long vs. Near-Term Scenarios for Analyzing Climate Risk

The Network for Greening the Financial System (NGFS)—an expanding international group of central banks and financial supervisors, currently comprising 75 members that the IMF has joined as an observer—is developing scenarios over an 80-year horizon (2020-2100). The scenarios are based on specific global temperature targets and the "Middle of the road" Shared Socioeconomic Pathway built by an international team of climate scientists, economists, and energy systems modelers. They are to be used in assessing the impact of climate policy and technology shocks (NGFS, 2020).

Some of the "representative" climate scenarios published by the NGFS in June 2020 have been used, inter alia, by Banque de France staff in their scenario analysis to assess the implications of climate-related transition risks for financial stability in France (Allen et al., 2020). The Bank of England also plans to adopt NGFS scenarios in its bottom-up "Biennial Exploratory Scenario (BES)" analysis of climate-related risks (Bank of England, 2019).

Staff from the Dutch Central Bank, on the other hand, analyzed the exposure of Dutch financial institutions to policy and technology-related transition risks over a 5-year risk horizon by adopting energy transition scenarios not explicitly tied to a temperature outcome (Vermeulen et al. 2018). Similarly, the European Systemic Risk Board (ESRB) adopted two interrelated exploratory scenario analyses to assess transition risks for the EU banking and insurance sectors over a 5-year horizon with no explicit link to a specific global temperature path (ESRB, 2020).

The two types of analysis can be seen as complementary to each other: the use of longer-term scenarios allows to better capture the impact of climate change itself and of the societal response to it along the pluri-decadal horizons over which they're expected to manifest themselves in full; the near-term perspective, on the other hand, allows to focus on the immediate dangers and challenges for financial stability and to draw more operational indications for action in the shorter term. The latter perspective is more closely aligned with the use of quantitative analysis in FSAPs, i.e., as a tool meant to gauge risks on a system-wide level and propose mitigating measures.

98. **FSAPs have been assessing the impact of climate-related natural disaster events on financial stability, including banks, for some time**. A textual analysis of 192 FSAP reports (up to 2019) found that 33 (17 percent) contained meaningful references to risk factors such as droughts, floods, and storms. Many of these are for small island states (such as the Bahamas, Jamaica, and Samoa), but some assessments for advanced economies (such as the United States, France, Belgium, Denmark, and Sweden) have also covered natural catastrophe risks as part of insurance stress testing. More recent FSAPs have developed new approaches to assessing climate change risk, e.g., transition risk in the 2019 Norway FSAP (Box 1) and physical risk in the 2021 Philippines FSAP.

99. **Significant effort and collaboration will be needed to develop stress testing tools for climate change risks and deploy them regularly in FSAPs.** This work will require close inter-departmental collaboration within Fund departments and with partners such as the World Bank, the United Nations (UN), and the NGFS (Box 2 describes the scenario design agenda of the NGFS). Technical details are discussed in the appendices.

Box 2. Transition Risk in the Norway FSAP 2020

In the pilot, three possible transmission channels for transition risk shocks to the financial system were explored:

- The impact of a substantial increase in domestic carbon pricing on banks' credit exposures, such as loans, via its effect on corporates' operating costs and profitability, under severe assumptions.
- The impact of a drastic increase in global carbon prices on the domestic economy on banks' loan losses via the fall in the revenues of domestic oil producers.
- The impact of a forced reduction in the production of domestic oil firms on their share prices and, in turn, on the net wealth of domestic shareholders (such as households or financial and nonfinancial corporates).

Results show that a sharp increase in carbon prices would have a significant but manageable impact on banks (IMF, 2020b and Grippa and Mann, 2020).

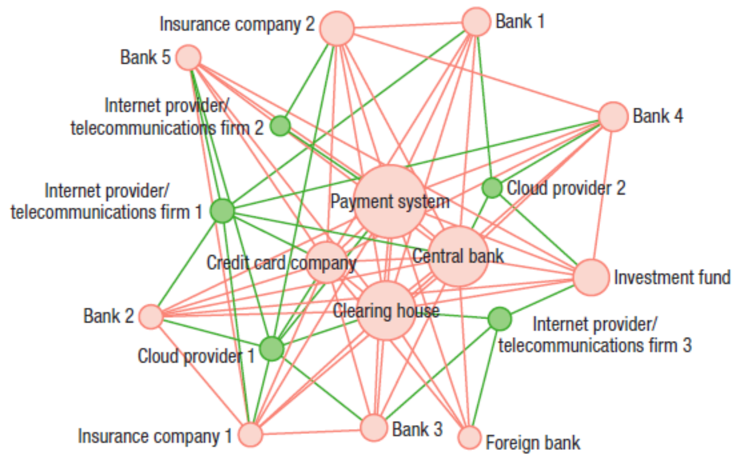
B. Cyber Risk

100. Cyber risk is a growing source of potential systemic risk to financial sectors.[26] Financial systems are particularly vulnerable to cyberattacks, given the increasing reliance on information and communication technology (ICT) systems. The "entry points" of attacks could be diverse, including in-house systems as well as the systems of the third-party vendors, contractors, clients, retail partners, or counterparties in trades. An attack on a handful of firms could spread to the whole financial system quickly both through the interconnection of the ICT as well as the inherent interconnectedness in the financial system through cross and common exposures, the collapse of key liquidity markets and FMIs, and correlated reputational risks. Cyberattacks can be systemic if they target several financial institutions simultaneously or a systemically important financial institution (SIFI), such as Global-SIFIs, central banks, and FMIs. Spillovers may also come indirectly from attacks to key ICT providers and physical infrastructures (such as utilities, Figure 15). Cyberattacks could also exacerbate an emerging financial crisis by propagating disinformation, undermining confidence, or disrupting safety nets (Healey and others, 2018). Direct and indirect cyberattacks to the financial system could stall key payments and settlement transactions, liquidity crunch to banks, and mass insurance claims from the policies that cover the cyber risk, among others.

101. Quantitative analysis of fintech and cyber risks has been limited, and further experimentation will be needed, also reflecting data constraints. Some FSAPs have gathered descriptive information on cybersecurity practices through interviews (Namibia) and on potential losses from cyberattacks through questionnaires (Poland). Bouveret (2019) explores potential loss estimates as research work, but not in FSAP's financial stability risk assessment.

[26] The term cyberattack is used here generically, and it includes Distributed Denial of Service attacks, website vandalism, data breaches, data manipulation, and theft of funds.

Figure 15. A Cyber Mapping Exercise: An Example



Source: IMF (2019b).
Notes: Supervised financial institutions are in pink and third-party technology providers (could be service and internet providers) are in green. The size of the circle on the diagram is proportional to the degree of centrality, the measure of interconnectedness, and the importance of an entity (i.e., the note of the network). The stylized scheme illustrates a network in which important and central institutions—for example, a payment system—depends on a single internet provider, making a technology firm a crucial piece of the system and revealing potential vulnerabilities.

102. The Euro Area FSAP conducted a cyber risk-motivated liquidity stress test of banks. The stress test simulated a scenario in which banks could not access their collateral at central counterparties for five business days.[27] It identified some vulnerabilities, especially at internationally active banks. This approach has shown that a stress tester can assess some aspects of cyber risk with the conventional stress test toolkits for liquidity, solvency, and interconnectedness. For example, a cyberattack on a bank could be the reason behind the funding stress simulated in a liquidity stress test or behind the initial bank failure in a network analysis of contagion risk. Similarly, conventional capital and liquidity buffers can also be considered sources of resilience against cyber risk.

103. The Singapore FSAP broadened the types of cyber risk analyses to assess financial stability. The authorities provided data on historical cyberattacks that the team analyzed over time and across firms. Banks provided cyber risk scenarios that they thought would be most impactful to themselves, as well as the associated loss estimates and management actions. These scenarios assisted the authorities in developing their inventory of scenarios. Selected scenarios were presented in a Cyber Risk Assessment Matrix, which is an application of the FSAP Risk Assessment Matrix concept to cyber risk. Insurers were asked to estimate the losses they would incur if their ten largest policyholders of affirmative and silent cyber coverage were to experience cyberattacks and thus claim on their insurance policies.[28] These losses were assessed

[27] The other scenario parameters, like deposit run-off rates, were chosen to match the traditional five-day liquidity stress tests. In particular, run-off rates were not increased for the cyber risk scenario.

[28] Some policies are explicitly targeted at insuring cyber risk (affirmative coverage). Cyberattacks could also lead to claims on other types of insurance policy, like fire insurance, which the insurer would have to pay (silent or non-affirmative coverage).

to be manageable after accounting for reinsurance recoveries, but insurers identified a need to restrict their implicit cyber coverage.

104. Data constraints on cyberattacks and losses remain a key challenge. Towards overcoming challenges from the data constraints, Goh and others (2020) discuss methods and data that can be used to analyze cyber risks in FSAP and country surveillance. Key indicators of cyber risk such as event frequency, distribution across sectors, and cybersecurity budgets can be tracked over time. Kamiya and others (2018) and Bouveret (2019) analyze historical data to estimate the likelihood and severity of cyberattacks, but to be applied in FSAP, they must overcome the sparsity of cyberattack data in any one individual country. To do so, Goh and others (2020) suggest applying existing models to data from the country of interest rather than attempting to re-estimate them using data from the given country. Another analytical approach recommended by IMF (2019b) is to develop a list of financial and nonfinancial institutions and the information technology links and financial exposures between them—namely, the cyber risk mapping exercise (Figure 9). Once data become available, one could estimate institution-level impact using the techniques from broader operational risk assessment tools. Under the Basel rule, banks are required to set aside capital to cover potential losses from operational risks, including cyber risks. Recent IMF papers (e.g., Bouveret, 2019) and FSAP (2019 Singapore) have taken these techniques. The challenge is to assess their systemic impact, incorporating potentially devastating contagion effects, including those from third-party IT service providers.

C. Fintech

105. Quantitative analysis of financial stability risks from fintech is still at an early stage. This reflects in part the still early stages of development of these technologies and that many of the nascent risks are operational in nature.[29] There is also a need to build a conceptual framework to understand the interplay between financial innovation, financial stability, and fintech policies reflecting efficiency-stability tradeoff. Full assessments will require the development of a framework to model the incentives for financial innovation and risk-taking by incumbents and entrants and the roles of market structure and government policies in balancing risk-return tradeoffs from innovation versus stability. Data gaps and rapidly changing landscape also hinder quantitative assessment.

106. Quantitative analyses of some aspects of fintech risks have been piloted in some recent FSAPs (2019 Singapore and 2019 Korea). The analysis aimed to understand the impact of fintech on financial stability both in the medium- and long term, addressing efficiency-stability tradeoffs, the impact of policy, and highlighting the role of market structure and uncertainty surrounding technology. The exercises estimated the potential non-interest income reduction for incumbent banks, conditional on the increased competition by new entrants. In the case of Singapore, it also estimated potential gains from fintech with the changes in the unit

[29] See, for example, "FinTech and market structure in financial services: Market developments and potential financial stability implications," FSB, 2019.

cost of financial intermediaries.[30] The analysis suggested that the unit cost of financial intermediation in Singapore has been around 1.5 to 2 percent for the past decade, similar to that of the United States, pointing both to the scope for eroding earnings and putting pressure on banks and to the potential gains from fintech development going forward in Singapore. In Korea, the income shock was introduced into the stress testing framework to illustrate the potential impact on bank capital.

DATA CONSTRAINTS

107. FSAP missions face two sources of data constraints: availability (i.e., gap) and access. Some data do not exist—especially data for interconnectedness, shadow banks, and emerging risks. When the financial sector landscape is rapidly changing—such as fintech and shadow banks—existing reporting formats are likely to be obsolete quickly. At the same time, not all data collected by country authorities or international organizations are accessible to FSAP due to their confidentiality. Accessibility depends critically on authorities' willingness to share them. For global data that include financial institutions from multiple jurisdictions, the Fund would need permission from all of them.

108. For conventional risks, data availability has improved notably since the GFC.

- ***G-20 Data Gap Initiatives***: The G20 Data Gaps Initiatives (G20 DGI) aim to close the data gap considered relevant after the GFC. It includes 1) monitoring risk in the financial sector (Financial Soundness Indicators, leverage and maturity mismatches, and complex structured products); 2) international network connections (G-SIFI data, international banking statistics, coordinated portfolio investment survey, international investment positions (IIPs), and cross-border activities of NBFIs; and 3) sectoral and other financial and economic datasets (sectoral financial accounts). As of 2020, while notable progress has been made in many areas, gaps remain with the data for systemic risks for insurers, sectoral accounts, currency composition of IIPs, and commercial property prices (FSB and IMF, 2020). There is also an ongoing discussion to extend the exercise beyond the end of the current initiative in 2021. In addition, the FSB now publishes an annual global report on NBFI.

- ***Activity-based data:*** Creations of new and centralized FMIs—such as CCPs—and the development of big data techniques leveraging digitalization of finance allow supervisors to monitor activity-based transactions and exposures that include all entities active in markets. Such data include shadow banks and NBFIs required to report or disclose little data (e.g., hedge funds). As a result, there is new and quickly expanding literature on financial stability analysis using data collected by FMIs (see the discussion on systemic liquidity in the interconnectedness section).

[30] Financial institutions channel sources of funds to users of funds by overcoming information asymmetries and managing the associated credit, liquidity, and other risks. They are rewarded for providing these financial services. Following academic research (Philippon, 2015), the total cost of financial intermediation in a country can be measured as the value-added of the financial sector that includes both labor wages and profits. The total quantity of intermediated assets by the financial sector includes all debt and equity contracts that are newly written and serviced in the economy.

109. FSAP access to confidential supervisory data from national authorities has improved over time, though with resource-intensive arrangements in several cases. For mandatory financial stability assessments, the share of jurisdictions providing access to confidential supervisory data for quantitative analysis has increased from 75 percent in the first assessments to 97 percent in the latest. However, for many jurisdictions—including European countries where the Single Supervisory Mechanism (SSM) supervises their banks—access has been allowed only in a specific physical location (a secure "data room"), increasing the FSAP team's costs of the bank stress test exercise. For voluntary financial stability assessments in the past five years, all jurisdictions have shared at least some confidential supervisory data, even though the breadth of access and quality of data varied across FSAPs.

110. Future FSAPs could deepen cross-border interconnectedness analysis with access to more granular data collected by the BIS. Many FSAPs have benefited from publicly available country-level BIS cross-border banking statistics to assess vulnerabilities from cross-border interconnectedness. Country-aggregate ultimate-borrower-basis data—the data that labels banks' nationality using their headquarters' location of incorporation—are publicly available. When national authorities permit, FSAPs have also benefitted from access to locational data—the data that labels banks' nationally using the physical location of their affiliates and therefore relevant especially for international financial centers. The institution-level G-SIB interconnectedness data—which are treated with utmost confidentiality including within the BIS—could further strengthen FSAP's cross-border contagion analysis.

111. The Fund typically has little access to activity-based data collected by FMIs, but some recent FSAP exercises have made notable exceptions. FMIs—many are private sector companies—typically share data with authorities that have supervisory power over them or a subset of data that involves institutions or assets supervised by a certain agency.[31] As a result, the Fund has rarely had access to these data, especially some FMIs that handle global transactions and therefore critical for monitoring cross-border market transactions, except for a few cases. Some Fund staff worked with counterpart authorities on the side of the FSAP to produce a research paper using FMI data. 2019 France FSAP attempted to create an interconnection map for banks, insurers, and investment funds using their respective security holding data. Nonetheless, the data had to be created from multiple sources under the supervision of different agencies; each of them has different confidentiality protocols and structures. This made data management extremely challenging, even when authorities are willing to conduct such exercises.

112. For emerging risks, data existence and access vary across the risks.

[31] For example, the Depository Trust & Clearing Corporation (DTCC) in the United States provides clearing and settlement services for equities, bonds, unit investment trusts, mortgage-backed securities, money market instruments, and over-the-counter derivatives—including CDS. During the height of the European sovereign debt crisis, the Bank of Italy monitored Italian sovereign CDS positions using the DTCC data, as most sovereign CDS were traded in the United States. Nonetheless, the bank could not access the data for other sovereigns except for the positions held by Italian institutions.

- ***Climate change***: There are relatively ample climate data and forecasts from climatology literature. Regarding the economic impact, the potential likelihood and impact of physical risk have long been a subject of catastrophe modeling developed by insurers.[32] However, the industry's estimates tend to focus on events in advanced economies with high insurance coverage and potential claims.[33] The underlying data and models are useful for developing stress testing tools for broader types of financial institutions.
- ***Cyber-risk***: Cyberattack databases are being constructed by national authorities and private sector platforms, though they may not be comprehensive. Financial supervisors may not have access to incidents for nonfinancial corporations, including companies that offer IT systems for financial institutions. Incident reports may not include monetary loss figures, and even when there are, information tends to be limited to legal costs. Access by FSAP missions may require a national security clearance, well beyond the level of confidentiality agreement FSAP typically handles.
- ***Fintech***: Fintech suffers the most from data gaps. Fintech firms and the technologies and services they offer are all new. The challenges are similar to those with shadow banks and even more severe. New technologies could quickly and completely transform the industry landscape with many new and unregulated-monitored entities and markets.

113. Data constraints for FSAP risk analysis could be improved by both assisting the authorities to develop new data and by increasing access to confidential data.

- ***Improving data existence***: IMF's statistics department, sometimes jointly with the IT department, has been actively providing technical assistance to develop many country-aggregate data in the context of the G20 Initiatives. FSSR for lower-income economies discusses financial data development in their diagnosis, and its TA roadmap usually includes data components.
- ***Improving access to data***: Staff welcomes Board's support for encouraging national supervisory agencies in their constituencies to share data with FSAP teams as standard practice. In particular, electronic remote access to data could substantially improve efficiency and save costs for FSAP risk analyses.
- ***Exploring alternative approaches***: An alternative approach to managing data access challenges is to develop codes to implement the analysis and ask counterparty authority to run it and receive the results. So far, the core risk analysis tools are built in Excel—the main workhorse of the IMF country team's macroeconomic forecast. Excel is also suited for disseminating tools to the diverse membership of the IMF. However, it requires direct access to the data. While a code-based approach would make FSAP-like risk analysis less accessible by Article IV teams, the potential benefit for circumventing data access constraints could be sufficiently large.

[32] For example, see Lloyd's 2014 Catastrophe Modeling and Climate Change.

[33] For instance, Lloyd's maintains a set of mandatory Realistic Disaster Scenarios to stress test both individual syndicates and the market as a whole. Most of these events take place in the US, Europe, and Japan, where disaster insurance coverage is high.

SUPPORTING FINANCIAL SURVEILLANCE IN ARTICLE IV

114. FSAP quantitative tools can help strengthen macrofinancial analysis in Article IV consultations. Article IV reports have used a variety of vulnerability indicators, balance sheet analysis, and, more recently, Growth-at-Risk tools.

- ***Vulnerability indicators.*** Indicators used in FSAPs have been used to analyze the links between the financial cycle and the business cycle. In particular, the credit-to-GDP gap, defined as a deviation of credit from the simple HP trend or a trend estimated using a semi-structural model, has been used to inform the recommendations on system-wide macro-prudential tools such as the countercyclical capital buffer.

- ***Growth at risk***. Some Article IV teams have used the GaR as a forward-looking tool for the assessment of downside risks to growth and the identification of vulnerabilities that can trigger systemic risk.

115. Going forward, staff plan to provide a broader menu of FSAP quantitative tools to help strengthen financial surveillance in Article IV consultations. Depending on the financial vulnerabilities of their country, desk economists could choose the priority area and the corresponding quantitative tools.

- ***Simple stress testing tools.*** The standardized GST and UST tools using publicly available data would allow Article IV teams to carry forward the bank solvency analysis. The system-wide FX liquidity stress testing tool uses BSA data and links system-wide liquidity shortages from balance of payment shocks to bank liquidity stress test analysis. The tool could enrich the reserve adequacy discussion in Article IVs.

- ***NFC and household vulnerability assessment tools.*** The new macro scenario stress testing tools developed by Tressel and Ding (forthcoming) for NFCs could help Article IV teams to strengthen their NFC vulnerability assessment, especially in the context of COVID-19. MCM is also developing multiple household vulnerability assessment tools, and some are explicitly lined to calibrate borrower-based MPMs.

- ***Tools to analyze macro-feedback effects and inform macroprudential policy advice.*** The macro-financial linkages models that are currently under development could be used in Article IV surveillance to capture the two-way macro-financial feedback effects. Some of these models can also help inform the calibration of broad-based macroprudential tools.

- ***Stress testing results and other policies.*** Some elements of FSAP stress testing can also inform policies not covered by an FSAP but relevant in the context of Article IV surveillance. For example, liquidity stress tests can be used to calibrate the reserve requirement as a prudential tool rather than a monetary policy tool when adequate. Foreign currency liquidity stress tests could be used to inform the adequacy of international reserves and assessment of exchange rate misalignment. Borrower-based MPMs could be informed by household and corporate sector analysis, and cyclical capital measures could be calibrated using the macro-financial feedback effect models that incorporate bank stress tests. The analysis of the sovereign-bank nexus in the solvency stress test could be used to inform the public debt sustainability analysis. The stress tests for climate risk could trigger policy advice on demographic, industrial, labor policies to limit the ultimate financial stability impact of climate change.

Appendix I. Approach to Assessing Climate Change Risk in FSAPs

1. **Three stages.** We envisage a three-stage approach to assessing climate risk in FSAPs. First, we will begin with a diagnostic and assessment of what are the principal sources of risk facing individual jurisdictions that may arise from climate change. Second, risks identified in the previous first step will then be linked to specific scenarios of the evolution of physical and transition climate risks. Third, to map climate scenarios into the resiliency of banks, two approaches could be used depending on the level of data granularity and the scope of the analyses.[1] In some cases, a macro approach would be to map climate risk scenarios from stage 2 into corresponding macro-financial scenarios and use them in standard stress testing methodologies based on financial institution data to assess the implications of climate risks for the banking system's resiliency. If granular data is available, a micro approach focusing on borrower-level assessments could be considered. This would involve a comprehensive analysis of the impact of climate and macro scenarios on the performance of corporates, households, and the public sector, building up to bank-level stress tests. While the staff will seek to build a common general framework for climate risk scenario analysis, the approach in each FSAP will be country-specific, depending on data granularity.

2. **Climate risk scenario analysis is not a standard stress test.** It is important to note that climate risk scenario analysis is not a standard stress test where bank resilience is assessed based on fail-or-pass criteria and the hurdle rates. In contrast, the objective of the climate risk scenario analysis is to assess pressures on capital to gauge the magnitude of the challenge facing the banking system and the concomitant need and opportunity for adaptation. This would also spread the awareness of the challenge and the need to develop tools to manage the risk by banks and supervisors and potentially drive gradual early adjustment by banks.

3. **Challenges**. Developing credible climate scenarios, given the unprecedented uncertainty, is difficult. This will require drawing on external expertise to develop paths for physical and transition risks and associated macro-financial scenarios. On top of these fundamental uncertainties, the sectoral and geographical granularity of the impact of shocks is likely more pronounced in the case of climate as opposed to standard macro-financial shock analysis.[2]

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[1] Ideally, granular data needed would include information on banks' exposures to companies/households stratified by geography (e.g., flood plain) and carbon intensity (e.g., lending to utilities generating power from fossil fuels).

[2] Climate risk is a long-term phenomenon where the benefits of policy actions today will emerge towards the end of the 21st century. This is well beyond the typical stress testing horizon for banks. There is a high degree of uncertainty in climate science models and associated policy scenarios, partly because the risk is "black swan"—something that never happened before but could happen in the future. The difference across scenarios may appear mostly at the far tail, e.g., once in 250- or 500-years events that are commonly used in the insurance sector but not in the banking sector, which tends to be the focus of most systemic risk analysis. Lastly, unlike typical macro-financial risk factors, climate change is expected to have a differentiated impact across industries and locations. As such, economic and credit risk models with multiple industries linked to detailed analyses of nonfinancial corporations and geographical characteristics will be needed to conduct a more accurate assessment.

Stage 1—Climate Financial Risk Diagnostic

4. **A diagnostic of the exposure of a member to specific climate risks is the place to start**. MCM will build a heatmap to help FSAP teams in deciding on the scope of the assessment and relevant physical and transition risks. Climate risks span physical risks (stemming from exposure to extreme weather-related events and the effects of more slow-moving, long-term changes in climate patterns) and transition risks (from the impact on balance sheets of changes in public policies, technology, market sentiment, and consumer preferences linked to climate change mitigation and to the transition to a lower-carbon economy). Exposures to these risks are different across countries and financial systems. FSAP teams will need to develop a climate risk assessment matrix (C-RAM). The C-RAM would identify specific and material climate risks and their likely channel of impact and would be informed by the global climate risk assessment in the G-RAM.

5. **The heatmap would pull together data from identified datasets to provide an operational assessment of the potential exposure of each country to different climate risks.** We expect that the FSAP teams going forward will increasingly be able to apply the climate risk stress testing methodologies (stage 2 and 3) for climate risks that appear material. It will also be important to consider spillovers of climate risk from other countries as relevant (e.g., higher imported energy prices due to higher carbon taxation in trading partners or a materialization of hazards in a country where banks have exposure). The heatmap could also inform bilateral surveillance work by AIV teams.

Stage 2—Designing Climate Scenarios

6. **While there is much debate over the relevant horizon, climate change is generally considered a long-term challenge**. For physical risk, designing climate scenarios entails mapping scenarios for emissions and global temperature pathways into projections of climate-related events typically over a 50-80-year horizon. For transition risk, climate scenarios consider the endogenous impact of policies to mitigate climate change, technological change, and consumer preference shifts as a function of emissions and temperature scenarios. Regarding emissions and temperature pathways, the climate community relies on standard scenarios agreed upon within international groupings which span the period 2020-2100. These Representative Concentration and Shared Socioeconomic Pathways (RCPs and SSPs) are the basis for scenarios developed for financial stability analysis and policy formulation by the NGFS.

7. **Climate change risks could, in principle, prove material for the financial sector within the 3-to-5-year horizon typically considered by stress testing exercises in FSAPs.** Key channels differ depending on the nature of risks and judgment about how the likelihoods of natural disasters will change because of climate change and how (and with what probability) transition risks could materialize. These uncertainties motivate the possibility that physical or transition risks could arise within the 5-year horizon of FSAPs. Moreover, the increasing likelihood of the realization of long-term costs (including from stranded assets) could feed back into shorter-term horizons via a reassessment of market valuation of companies and thus banks

and potentially into forward-looking assessments of credit losses for very long-term investments.

8. Staff, therefore, propose to build a climate risk stress testing methodology for FSAPs that will consider both medium-term and longer-term climate risk scenarios. This reflects that financial sector resilience could be undermined by both the uncertainties and delays with reallocating financial resources across sectors in the face of climate change and the transition to a low carbon economy. The elements feeding into the specifics of climate scenario design are developed further below.

Physical Risk

- Acute physical risks could be simulated as the occurrence of immediate extreme weather events based on either projected or historical distributions (the former would be the preferred approach as feasible). As a first step, we would generate such scenarios by looking into the historical distribution of disasters and losses. However, limiting the analysis to that of historically observed shocks could fail to incorporate ahistoric tail risks.[3]

- Climate change will likely change weather-related natural disaster risks over the next 50-80 years, especially in the scenario with faster global warming. The scenario analysis to assess physical risks should ideally use the future projected distribution of disasters, compare the range of results with the currently observed historic disaster distribution, and apply the near-term and long-term future disaster distribution to assess damages, losses, and their impact on the economy and balance sheets of financial institutions over the near and long term (i.e., the approach to scenario design for the near and long term is broadly similar). While losses may potentially not be large in expected value terms over the near term, the projected distribution of hazards over the long term could be used in calibrating a severe climate-related shock over the near term to account for uncertainty over the magnitude of the shock.[4]

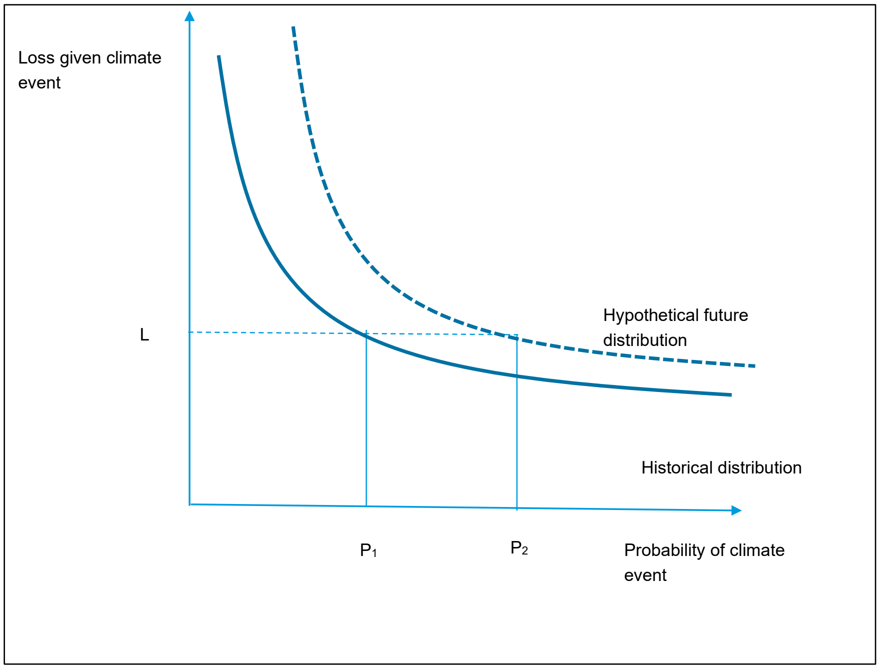
- Projecting future distributions of extreme weather events and damages, however, will require additional resources and external expertise. If modeling the future distribution of natural hazards is not feasible, staff could go further into the tail of events in the historical distribution to mimic the climate shock as illustrated in the Text Figure. We will explore developing rules of thumb for making such a mapping in as generalized a fashion as feasible.

[3] As an illustration, catastrophe insurance models (CAT models) often consider tail events with a once in 250-500-year probability, which may in effect have not been observed in recorded history. Moreover, these scenarios are disaster scenarios, not climate change scenarios per se.

[4] This is the approach taken in the 2021 Philippines FSAP.

Appendix 1. Figure 1. Impact of Climate Change on the Likelihood and Damages from Extreme Weather Events

The example below shows one of the possible combinaiton of future likelihood of extreme weather events and their damages under a climate scenario compared to current combination. In this case, climate change increases both the likelihood and damanges of weather events.



Source: IMF staff.

Transition Risk

- The progression to a low-carbon economy is typically thought of as a long-term process. As carbon policies are gradually introduced, technologies and consumer preferences evolve, the overall sectoral structure of the economies' energy matrix will shift. But there is significant uncertainty regarding the path and probability distribution of emissions and temperatures over time for a given RCP scenario (Text Figure). This means that there is a distribution of trajectories of carbon prices for any given RCP scenario[5] such that there is uncertainty over the likely trajectory of carbon prices in any temperature scenario. As such, there is a reasonable probability that carbon prices may need to be raised earlier and at a faster pace to higher levels than considered under median global scenarios.

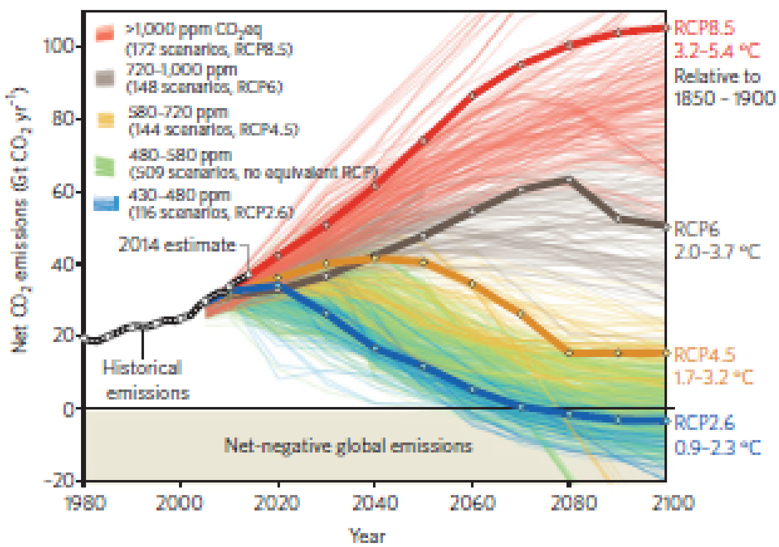
- Accordingly, different central banks in the NGFS have adopted a range of approaches to simulating the evolution of carbon prices (Table 2 and Annex). These typically consider variations of lower temperature increase paths with higher carbon price trajectories and

[5] While policies supporting a transition to a low-carbon economy can take different forms (e.g., subsidies to renewable energy production, caps on fossil-fuel-based power generation, etc.), the assumed shock is often represented by a (sharp) increase in carbon prices. This is a convenient, powerful, and relatively manageable assumption that allows to effectively and parsimoniously characterize and model a decarbonization scenario, which is also extensively used in the scenario design for transition risk by central banks.

vice versa. Essentially, the different paths trade-off transition versus physical risk (the slower the transition, the greater the odds of increased physical risk). The staff propose to leverage initially the NGFS scenarios in the climate risk stress testing framework to assess financial stability risks over the traditional three-to-five-year horizon in FSAP work. The NGFS scenarios include a range of carbon tax increases, from no increase in carbon taxes to $100 in 2025. We would also explore NGFS scenarios over the long term to analyze the opportunities from higher carbon prices over the next 30 years and moving to a low-carbon economy. We will also consider alternatives for a higher carbon price trajectory—relative to the NGFS scenarios—for sensitivity analysis. Some initial work on mapping the NGFS scenarios into shorter-term horizons can be carried out now, but further work on the sensitivity of transition scenarios and examining alternative paths will require additional resources.

Appendix I. Figure 2. Carbon Dioxide Emission Pathways until 2100

The projected pathways of CO_2 emission—the main component of greenhouse gasses—and corresponding global temperature at 2100 compared to 1850-1900 (pre-industrial period) average vary substantially depending on climate scenarios.



Source: Fuss and others (2014). RCP = representative concentration pathway from IPCC's fifth assessment report (AR5, IPCC, 2014), ppm = parts per million. Dark colored pathways corresponds to the four RCPs from IPCC's AR5. CO_2 emissions in gigaton per year.

Sudden Transitions

- While climate change is a long-term process, stress testing exercises may consider up-front shocks to carbon prices to illustrate pressure points in the financial system. One approach used by some central banks is to consider the sensitivity of financial system capital to a large up-front change in carbon prices. [6] Alternatively, the impact of

[6] See Vermeulen, Robert, Edo Schets, Melanie Lohuis, Barbara Kölbl, David-Jan Jansen, and Willem Heeringa, "An Energy Transition Risk Stress Test for the Financial System of the Netherlands", De Nederlandsche Bank Occasional Studies 16–7, 2018; and European Systemic Risk Board, "Positively green: Measuring climate change risks to financial stability", June 2020.

transition risk could materialize abruptly if there is a technological breakthrough or if consumers, firms, or financial markets suddenly change their expectations regarding how future policies, technologies, or physical risks may impact asset valuations. In such a "Minsky moment," [7] agents could reassess the value of carbon-producing sectors based on the present discounted value of the impact of prospective carbon price policies, sectoral technology shocks, and physical risks linked to specific temperatures and emissions pathways. In such a case, the climate scenarios would be simulated as a one-off shock affecting macro-financial variables and industry-specific (or even firm-specific) asset valuations. Overall, the staff will explore methodologies for parameterizing reasonable values for such one-off shocks arising from sudden transitions.

Stage 3—Mapping Climate Scenarios into Financial Stability

9. Financial stability analysis of climate risk requires a mapping from temperature paths, physical risk distributions, and materialization of transition risks to impacts on the macroeconomy and bank capital. Projections of climate events and their damages and the impact of transition risks would be used as input in macro-financial models in the third step to estimate the impact of the materialization of physical and transition risks on economic or sectoral growth and other macro and financial variables. Once macro-financial scenarios are built, the standard FSAP stress testing approach for credit and market risks would be applied to assess the risks and the impact on bank capital.

10. The scope and depth of the analysis that maps climate scenarios into the banking sector's health will be determined by the granularity of data and available models. There are two general approaches. The macro approach focuses on macro-financial transmission channels of climate scenarios and assesses the impact of macro scenarios on the banking sector (possibly using data on the distribution of financial exposures by industry or regions). The micro approach builds on geographical exposures of the financial sector, detailed sectoral analysis, industry and firm-level data, data on balance sheets of households and the government, and collateral values to link them to the earnings of financial institutions. As NGFS' scenario guideline points out, a more micro approach will provide a more accurate assessment because the effects of physical and transition risk will vary across different sectors and firms. However, it requires granular bank exposure data, macro models that account for differentiated shocks across industries, as well as the analysis of the corporate and household sectors integrated with bank stress tests. Depending on specific climate risk and data granularity, a combination of the macro and micro approaches could also be considered (including the impact of macrofinancial scenarios on sectors' financial statements). In practice, FSAPs may fall in a spectrum between these two approaches depending on the availability of data and models, though we anticipate

[7] This concept—introduced by Mark Carney in his 2015 speech on "The Tragedy of Horizons"—refers to the possibility of newly enforced and more stringent environmental regulations producing or reinforcing financial failures in credit markets, or abrupt reallocations of assets from brown to green activities motivated by market repricing of risks and/or attempts to limit reputational risks and litigations (see also "The Green Swan - Central Banking and Financial Stability in the Age of Climate Change," BIS January 2020). The current generalized mispricing of climate risks in financial assets, as evidenced by research (including in the GFSR), and low interest rate environment adds to the plausibility of such a scenario.

that in the short term, the macro approach may be the more feasible option, also given the current resource constraints.

Appendix I. Table 1. Assumptions on Carbon Price Paths for Transition Risk Scenarios

	Up-front Shock (if applicable)	Level of assumed carbon prices in scenario (2020 US$/ton CO2) 2020	2025	2030	2050
Institution					
NGFS					
Orderly		0	103	132	350
Disroderly		2	10	17	841
Hothouse		7	7	7	11
Bank of France					
Orderly transition		0	50	75	180
Delayed transition		0	0	0	700
Sudden transition		0	0	170	900
Bank of Canada					
2°C (consistent) scenario		0	80	190	600
2°C (delayed action) scenario (abrupt transition)		0	0	0	800
Nationally determined contributions		0	20	70	190
ECB					
Orderly		7	60	114	360
Disroderly		7	54	68	845
Hothouse		7	14	14	16
ESRB					
Sudden transition	USD 100 per tonne carbon price shock	100			
Dutch National Bank					
Sudden transition	USD 100 per tonne carbon price shock	100			
WEO					
Adverse (average) 1/		7	19	27	101

1/ Assumes the baseline is the NGFS hothouse scenario.

Macro Approach

11. There are several modeling approaches that vary in their complexity to account for cross-industry and geographical differences when mapping climate scenarios into macro-financial shocks.

- ***Standard macro-financial models***. Standard macro-financial models used in the IMF (or by FSAP counterpart authorities) with relatively less cross-industry detail could be extended to incorporate features that would allow simulation of the impact of climate shocks on macro and financial variables. Staff in the Research Department are developing extensions of the Funds multi-country models with climate features that could be used to support FSAPs once ready. In the meantime, staff are exploring using models provided by external vendors, also used by the NGFS, and a small macro model developed in-house in MCM. For assessing physical risks, empirical findings from disaster/climate economic models could help calibrate the adequate shocks (such as productivity and capital depreciation shocks). For transition risks, these models could incorporate the economy-wide effects of the carbon tax, technology and preference shocks, and modeling opportunities from transition risk (the rise of green industry).

- ***Macro models used in combination with models with cross-industry differences***. The impact of physical and transition risks will likely vary by industry and geography. Physical risks are more likely to affect the agricultural, real estate, and mortgage sectors, while the transition risk would weigh on brown industries and benefit green industries. Macro models will be used in combination with CGE models (such as the GTAP model maintained by the Research Department), which are well known for their richness in incorporating cross-industry differences and will be explored for generating a greater degree of sectorization in the scenario design. Also, for physical risks, there are distinct models to analyze disaster impact across industries (e.g., those separating the infrastructure sector from the sectors that produce final goods and services), which could be used as an input to macro models.

Micro Approach

12. **The micro approach would directly examine the financial performance of affected sectors, to which banks are exposed**. This approach has a very high requirement for granularity of data and industry-specific knowledge. More specifically, implementing this approach would require micro-data on the (industry and geographical) characteristics of the financial institutions' underlying sectoral exposures and the assessment of borrowers' capacity to pay, incorporating cross-industry effects. Models using micro-data (e.g., cash flow models) would be used to estimate the vulnerability of sectors (in terms of earnings and their volatilities) to physical or transition risks. The vulnerability analysis would be used to revalue the financial institutions' exposures related to the affected sectors, based, for example, on incorporating long-term losses into the valuation of assets they hold. Given this complexity and resource constraints, this approach is likely to be feasible in only a few FSAPs where the relevant central banks have themselves been developing the needed data and modeling.

Additional Background

13. **This Annex lays out a general approach to climate risks analysis in FSAPs**. The application of the approach will necessarily be country specific and reflecting also available data and modeling tools. The staff will need to experiment and learn from experience in this new and challenging area in the period ahead. Further details of the approach that could inform the specific work of FSAP and country teams will be developed in an MCM paper on the issue planned for later this year. Some important operational areas that staff will reflect on as the work advances include:

- **Collaboration**. The work on incorporating climate risks analysis into FSAPs will require close collaboration with country teams, functional departments, the World Bank and the NGFS. Among opportunities here are work on (i) judging the materiality of different climate risks for individual country cases, (ii) scenario design including projecting different hazards and estimating their damages and losses, (iii) carbon price paths, (iv) implications for scenario design of the use of carbon tax proceeds, (v) modeling approaches (including modeling opportunities from climate change, considering the coverage of all member countries since not all countries are covered by widely used models), and (vi) the challenge of physical climate risk for financial stability in smaller members. We see particular scope for collaboration with the World Bank on the assessment of materiality of risks and deeper analysis of physical risks, leveraging the Banks expertise in catastrophe insurance and financing.

- **Data needs**. Climate change analysis requires novel and very granular data. The staff will coordinate closely internally, and also with the World Bank, NGFS partners, and outside vendors to seek synergies and cost efficiencies on access to needed data.

- **Beyond banks**. While this note focuses on climate risk scenario analysis for banks, the methodology could be applied to other financial sectors such as insurance companies and mutual funds. For both insurance companies and mutual companies, stage 1, 2 and part of the stage 3 that pertains to macro scenarios would be the same while scenario analysis methodology for each sector would be different.

- **Beyond FSAPs**. We hope that this framework for climate risk scenario analysis will also be of value to members through our capacity development work including in support of FSSRs. Resources permitting, there could be an important opportunity to provide assessments of physical risk facing financial systems in fragile states).

Appendix II. Approaches to Climate Risk Scenario Analysis by Selected Central Banks and Institutions

	Bank of England	Central Bank of Denmark	Bank of Canada
"Stress Testing" Approach: bottom up vs top down	Bottom up	Top down	Top down
"Stress testing" objective	Size the exposures to climate related risks (impairment charge; how banks will adjust their business model; identify data gaps; develop management of climate-related financial risks	Size mortgage exposure book to the risk of higher sea levels	This is a scenarios analysis only
Scope	Banks, insurers	Bank mortgage book	NA
Climate risks covered	Transition (early and late policy action scenarios) and physical risks (no policy action)	Physical risk (rising sea levels)	Transition risk
Climate Scenarios	3 scenarios provided by BoE (from NGFS): early, late, no policy action (carbon price, tech change, consumer preferences, emissions, temperature; frequency and severity of climate events; productivity)	Two scenarios (from IPCC): no policy action, reduction of emissions	4 scenarios (from IPCC): no action, NDCs, 2C (consistent), 2C (delayed action)
Macro Scenarios	Provided by BoE consistent with climate scenarios (at the required sectoral and geographic granularity)	NA	CGE to map climate scenarios to macro variables
Data granularity	Corporate exposures, household exposures (assessment done by banks)	Household mortgages by geo. Location	18 regions, 33 sectors
Stress testing horizon	30 years (60 years for physical risk)	80 years	30 years
Reporting frequency	Every 5 years	NA	Every 5 years
Static versus dynamic balance sheet	Static (dynamic responses captured through a qualitative questionnaire))	NA	NA

	Bank of France	Dutch National Bank	ESRB	ECB
"Stress Testing" Approach: bottom up vs top down	Bottom up	Top down	Top down; similar to DNB	Top down
"Stress testing" objective	Assessing vulnerabilities to climate risk, raising awareness among firms of climate risk and encoring them to develop risk management tools	Assess total losses and, for banks, capital shortfalls	For banks assess mark-to-market losses, credit losses in the banking book and an increase in credit risk capital charges	NA
Scope	Banks, insurers	Banks, insurers, pension funds	Banks, insurers	Banks (but worldwide firms)
Climate risks covered	Transition and physical risk	Transition risk	Transition risk	Transition and physical risk
Climate Scenarios	3 scenarios provided by BdF (from NGFS/IPCC): orderly, delayed, sudden transition + "business as usual" for physical risk	4 scenarios/shocks: consumer confidence, tech. shock, carbon price shock, combination of shocks	3 scenarios: no action, abrupt policy response, positive tech. breakthrough	4 scenarios (from NGFS/IPCC): orderly, disorderly transition (two scenarios), hot house world; projections for 427 on physical risk
Macro Scenarios	NIGEM (macro impact), CGE (sectoral impact), other models for financial varbs	Macroeconometric model (NIGEM) to map climate scenario into macrofinancial varbs	Macroeconometric model (NIGEM) to map climate scenario into macrofinancial varbs	Impact on macro variables from NGFS
Data granularity	55 sector in CGE model (assessment done by banks)	Bond and equity holdings (at the level of individual securities); banks' corporate loan exposures disaggregated by risk classes and industries	Bond and equity holdings (at the level of individual securities); banks' corporate loan exposures disaggregated by risk classes and industries	Bond and equity holdings (at the level of individual securities); banks' corporate loan exposures (at the level of individual firms), country-level assessment for HHs
Stress testing horizon	30 years	5 years	5 years	30 years
Reporting frequency	Every 5 years	1 year	1 year	1 year
Static versus dynamic balance	Static (2020-25) and Dynamic (2025-50)	Static	Dynamic	Static and Dynamic (10 years)

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