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Introduction and Overview

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As we looked back on the 10th anniversary of the financial crisis, and in particular the 10-year anniversary of the 2009 US bank stress test, we thought it a good time to assemble both a retrospective and current state of financial stress testing.

Stress testing, although hardly new, was applied like never before during the Global Financial Crisis (GFC), which is roughly dated 2007–2009, although it stretched out in Europe. At a time of substantial market turmoil and significant uncertainty about the health of individual banks and thus the banking system, assessing banks' resilience against a specific and clear macroeconomic and market scenario turned out to be a very useful mechanism for providing transparency into which banks needed capital (and how much) and which did not. Sufficiently rich disclosure was needed to allow the market to assess the credibility of the results.

With the success of crisis or wartime stress testing, this approach also became the tool of choice in peacetime by regulators and bank risk managers alike. Of course, we did not expect when we started this project that 2020 would bring a new but different crisis, namely, the COVID-19 pandemic. The chapters were all in their final draft form when the pandemic hit, but the tools, methods, ideas, and approaches described in this handbook are being used widely to help manage the current crisis. The banking system is undoubtedly better prepared than it would otherwise have been, and the stress tests conducted during 2020 bore this out. Future innovations in stress test design might help regulators to have an even better grasp of the system-wide effects of such monumental crises.

The aim of the *Handbook of Financial Stress Testing* is to provide policymakers, practitioners, scholars, and students with a comprehensive resource, a common point of reference into cutting-edge work on stress testing. We asked experts and leading scholars from a variety of jurisdictions, professional backgrounds, and disciplines to contribute a critical reflection on stress testing from their particular vantage point. It has been a real challenge to put together a volume of this ambition. We are proud to say that this has resulted in a rich collection of insights about the past, present, and possible future of stress testing, with direct practical benefit for those working in this field.

This handbook would not have been possible without the generosity of the International Monetary Fund (IMF), which organized a conference in October 2019, "Rethinking Financial Stability: The FSAP at 20."[1] The FSAP is arguably the grandfather of stress testing programs, so it was only fitting for the first of this 2-day conference to be devoted to

[1] FSAP: Financial Sector Assessment Program. Conference information can be found at www.imf.org/en/News/Seminars/Conferences/2019/09/20/rethinking-financial-stability-the-fsap-at-20.

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contributions from the *Handbook of Financial Stress Testing*. The conference provided a valuable venue for the authors of this handbook to engage in exchange and dialogue, which helped create a joint effort with a coherent trajectory. Adrian, Morsink, and Schumacher also contributed a chapter on the latest thinking on stress testing at the IMF—so we are doubly thankful.

The *Handbook of Financial Stress Testing* is organized into five parts:

I. History and Objectives
II. Inputs and Outputs
III. Microprudential Stress Testing
IV. A Macroprudential Perspective on the Financial System
V. Macroprudential Stress Testing

The first part, History and Objectives, starts with a discussion of the objectives and challenges of stress testing by Herring and Schuermann. They expand on the crisis response motivation and present some of the basic ideas that are explored in more depth throughout the handbook, including the distinction of the discipline into microprudential (resilience of banks) and macroprudential (resilience of banking and financial systems), disclosure regimes, and challenges confronted (e.g., the focus on capital rather than liquidity). They present six fundamental choices in structuring a stress testing exercise: (1) the design of stress scenarios; (2) the risk exposures to be stressed; (3) the range of institutions to be tested, the length of the scenario, and the intervals over which shocks are measured; (4) the development of models to map shocks into outcomes and impacts on individual bank financials and on the banking system; (5) the choice of criteria to determine whether banks pass or fail the stress test; and (6) the decision about what to disclose to the public.

Das, Dent, and Segoviano discuss the historical evolution of stress testing and identify areas where more integrated approaches are needed. They highlight the need to better capture all enterprise risk, as well as the amplification of shocks through the banking and nonbanking systems. Improving data and information technology (IT) infrastructure would support increased automation of stress test development and analysis and thereby reduce the resource burden for stress-tested institutions. Finally, Anderson, Brazier, Haldane, Nahai-Williamson, and Radia from the Bank of England provide a retrospective on why banks failed the stress test and how the discipline has evolved over the subsequent decade, as well as how we build on these foundations to complete the agenda set out a decade ago. Further development of system-wide stress tests for macroprudential policymaking is needed, the authors argue, but such stress tests would need to involve a deeper study of the "empirical and theoretical foundations for modeling of institutions' behavior" and incorporation of a broader set of markets. They further emphasize that such stress tests should start taking the evolving and global nature of financial markets into account, as well as their feedbacks with the real economy. To guard against complacency, exploratory scenarios could be used to capture unexplored tail risks in stress tests that do not have any historical precedent.

Part II of this handbook, Inputs and Outputs, expands on some of the important ingredients and outputs of stress testing. The first two chapters provide insight into the scenario design challenges from a system perspective that a regulator would need to address, whether with a micro- or a macroprudential objective. Gross, Henry, and Rancoita present a summary of recent developments in the field of macrofinancial scenario design. Various areas are

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in need of refinement, including properly designing countercyclical scenarios, capturing state-dependent nonlinearities, calibrating the appropriate horizon for market-risk shocks, and avoiding double-counting of shocks in a system-wide stress test. In particular, scenarios should not double-count the initial and higher-order shocks. Flood, Jones, Pritsker, and Siddique explore the challenges that come with a heterogeneous banking system: the less homogeneous, the more complex the risk surface, the more complex the scenario design problem. They propose variants of reverse stress testing and apply their approach to data from 28 large bank holding companies in the US, which reveals significant heterogeneity.

Hopper provides the scenario design perspective for a financial institution, highlighting that a well-designed stress scenario depends on a well-developed risk identification process: if you don't know your risks, it's hard to know what to stress. Hopper points out that more complex financial institutions will likely face complex interrelationships across business activities and thus risks. This makes capturing the full risk profile with just one scenario quite challenging, calling for the need for multiple scenarios.

Stress tests use a mixture of public and private data. Banks' internal stress tests and most supervisory or regulatory stress tests make use of private or proprietary data not available to market participants. However, market data can be very informative, and Engle lays out what we have learned by using information, especially from equity markets, to provide insights into bank and banking system resilience to shocks. Engle makes use of the SRISK measure, based on dynamically estimated market betas, to showcase the advantages of these market-based approaches: they are easy to perform (so it is easy to try many scenarios), they are flexible in their severity, and it is straightforward to conduct sensitivity analysis around the stress estimates. Sarin and Summers express the importance of developing stress tests that integrate both market and book capital. They note that it is "puzzling that [current] bank stress tests entirely eschew market information about financial stability because the regulatory capital ratios that they rely on are known to be a static and easily arbitraged measure of the bank's true capital position." Yet, stress tests that rely solely on market measures of financial sector health are imperfect because they can be driven by noise and are procyclical. Sarin and Summers therefore argue that "stress tests should take into account both market and regulatory indicia of bank health, rather than being mechanically tied to market performance alone."

Ullersma and Van Lelyveld survey the opportunities that the increasingly ubiquitous granular data of the financial system offer for stress testing. Highly granular (transaction-level) data allow a regulator to tailor the data aggregation to the needs of each of its competence domains. System-wide stress tests, for instance, typically require disaggregated data, whereas macro analyses can often be conducted with aggregate statistics. They also discuss the logistical challenges associated with using more granular data, such as adopting solid data-governance processes, having the right skills and tools within the central bank to work with and interpret the data, and ensuring data quality and consistency across the financial system.

A key feature of stress testing is information production; the stress test should tell us something new about the risk profile of a bank or a banking system. But what should one disclose, how much should be disclosed, and who should disclose? Goldstein and Leitner provide a rich discussion of these issues and point out that in addition to the obvious benefits of a rich disclosure regime, there are also costs. The benefits are clear: more information to

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the market to allow investors and other agents to arrive at a better understanding of the risk profile of banks subjected to stress testing—in short, it promotes market discipline. The costs are less obvious, but they include the possible crowding out of other sources of information (regulators have access to private information about banks, so their disclosure must be especially valuable), and it could invite gaming by banks. Judge wraps up Part II with a discussion of the benefits of stress testing during times of war. She argues that after a financial crisis has taken hold, stress tests can offer useful guidance about the location of weaknesses impeding market functioning, enabling more tailored government interventions. Stress tests can provide market participants with credible information that underlying problems have been or will be addressed, thereby facilitating market functioning. However, given that regulators will rationally be hesitant to produce, much less disclose, information that could exacerbate the very crisis regulators are seeking to contain, crisis-time stress testing is only viable if regulators also have the tools needed to address any bad news the testing may reveal.

Part III launches into a discussion of microprudential stress testing for a variety of financial institutions. Cope, Hsu, Lively, Morgan, Schuermann, and Sekeris present a detailed map of stress testing for commercial, investment, and custody banks, covering the range of businesses, products, and services that are provided by banks. Because "modern" stress testing was developed for and by banks, the methodology has influenced the approach to stress testing in other parts of financial services. Longerstaey provides a discussion of stress testing for asset managers, bearing in mind that they manage assets on behalf of their clients. Put differently, asset management is a balance-sheet-light business model, and as such, the financial risk is borne by the clients, which presents its own challenges. Peters delves into the stress testing challenges and approaches for insurers, which typically face a broader set of risks than banks but have a less fragile funding structure. All of these approaches make clear that models are central to any and all stress testing, and with the proliferation of and dependence on models comes model risk. Canabarro explains how formal model risk management has become an important feature of post-GFC risk management broadly and stress testing in particular. After all, it is hard enough to forecast performance in ordinary market conditions, let alone under rare stress conditions.

Next, Clark, who oversaw the development and implementation of the stress testing program at the Federal Reserve, provides the supervisory perspective on stress testing, noting that "[t]he use of stress testing in supervision is a valuable tool in a business where good tools are scarce, and its prominence has created large benefits for supervisors, banks, and the stability of the financial system." Powerful and popular as stress testing has become, Cumming rounds out Part III with a rich discussion of the strengths but also the weaknesses of this now widely used tool. To name just two of those remaining challenges: joint capital and liquidity stress testing (this volume focuses almost exclusively on capital stress testing, a reflection of the state of practice) and the more comprehensive inclusion of nonfinancial risks.

Part IV moves away from stress tests of individual institutions and pivots to the systemwide concerns that stress tests seek—or could seek—to address. Fernandez Dionis and Mosser provide an overview of the structure of the financial system, stressing that banks are just one of the many agents operating in that system. Their discussion of the intense interconnectedness of the various elements of the financial system (banks, asset managers,

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exchanges, central counterparties, etc.) provides a rationale for the development and use of stress tests that are more systemic—or more macroprudential—in orientation. Building on such thinking, Goodhart discusses how stress tests can aid regulators in developing "holistic bank regulation." He writes that "such tests, both at the micro and systemic level, should, in theory, be able to take account of relative capital, liquidity, and profitability concerns, all together in a single package." Currently, however, "regulators tend to have tunnel vision when introducing, or amending, financial regulation. They consider each proposal in isolation, without attempting to see how it might fit, holistically, into the broader canvas of the whole set of financial regulations affecting banks."

Geanakoplos points out that leverage is a fundamental driver of financial instability. Any understanding of financial stability, he argues, needs to explore the system's sensitivity to changes (usually increases) in leverage, and stress tests can help do that. English presents a discussion of monetary policy and financial stability. He highlights how the two interact and how stress tests can—for example, through the choice of stress scenarios—help inform (and should be informed by) these two policy perspectives. Finally, Berner, Cecchetti, and Schoenholtz focus on stress test practices from a network perspective, highlighting central counterparties (CCPs) as an example of a critical network hub. Because these networks are highly interconnected, shocks propagate quickly and widely and can even be amplified along the way. Such networks tend to be opaque, and thus designing and executing a cogent stress test is challenging. The authors suggest using market-based risk indicators such as CoVaR and SRISK as measures of systemic (network) vulnerabilities.

Part V covers macroprudential stress tests, which serve to assess systemic risk in interconnected financial systems and to design and evaluate macroprudential policies to mitigate this risk. Bassett and Rappoport present a way in which microprudential stress tests, such as those run by the Federal Reserve Board, can be extended to become more macroprudential. They show how contagious spillovers, specifically funding spillovers, can be modeled as an add-on to such microprudential stress tests, using a reduced-form relation between banks' funding cost, bank capital, and economic activity. Hałaj and Traclet discuss how contagion mechanisms are incorporated in bank stress test models of the Bank of Canada. Their chapter introduces the Macro-Financial Risk Assessment Framework (MFRAF) and the Bank Dynamic Balance Sheet (BDBS) model of the Bank of Canada. MFRAF captures three second-round effects (i.e., the interaction of liquidity and solvency risk, overlapping portfolio contagion, and exposure loss contagion) but does not capture how banks adjust their balance sheets in response to shocks and regulatory constraints under a profit-oriented optimization objective. The BDBS model does just that. It uses optimal portfolio choice theory to model how banks might adjust the balance sheet (i.e., their assets, funding, and equity) in response to shocks to maximize the risk-adjusted return on capital while adhering to regulatory constraints (i.e., risk-weighted capital ratio, leverage ratio, and liquidity coverage ratio). The chapter insightfully puts their work in a broader discussion of the challenges ahead to improve systemic stress tests.

Adrian, Morsink, and Schumacher provide a comprehensive overview of stress testing at the IMF. They not only present an overview of the historical evolution of stress testing at the IMF but also discuss how the IMF's stress tests are currently conducted and what the remaining challenges are to improve the value of stress tests for policymaking in addressing emerging risks. So far, both micro- and macroprudential policies have been informed mainly

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by microprudential stress tests, but increasingly, macroprudential stress tests are used to calibrate macroprudential policies. Challenges remain, such as the need to better capture behavioral responses driving contagious spillovers, incorporating physical and transition risks from climate change for the financial system, and measuring systemic risk emerging from novel financial technologies (e.g., fintech) and cybersecurity breaches. The authors conclude that the degree to which these challenges can be met in part depends on the availability of suitable data.

Bousquet, Henry, and Żochowski set out how a top-down macroprudential stress test can be developed for the euro area, building on microprudential stress tests that have already been developed for various subsets of the financial system. They call for a top-down approach with macroprudential policymaking to be able to capture system-wide interactions within the banking sector as well as cross-feedbacks with other parts of the financial system, such as insurers, other financial institutions (e.g., money market funds), and central clearing parties. The authors argue that agent-based models are well suited to model interactions among financial intermediaries in a systemic stress test, as long as they strike the right balance between policy interpretability and real-world complexity. Whether system-wide modeling is possible, they emphasize, hinges on obtaining more granular firm-specific data, especially on nonbanks. Next, Thurner offers a complex systems perspective on macroprudential regulation. The science of complex systems—the science of self-organized, networked dynamical systems—can contribute to the understanding of the origins of systemic risk and how it extends current stress testing technology by systematically focusing on the interconnections of financial contracts and their implications for systemic risk. To illustrate that approach, he argues that a systemic risk tax levied on new financial contracts that would increase systemic risk reduces this risk in a self-organized manner without efficiency losses or additional economic burdens to the financial system.

Finally, Benjamin, Haddow, and Jacobs offer a thought-provoking piece on stress testing a central bank's own balance sheet. They set out how a central bank can use forward-looking stress tests as a tool for its own risk management. A central bank's risk exposure stems from its contingent balance sheet expansions associated with its role as a backstop of the financial system. Put differently, central banks, by design, have to expose themselves to wrong-way risk. Central bank stress tests specify the severely adverse scenarios for which the central bank has to stand ready to deliver its policy goals of monetary and financial stability. The authors stress that the severity of adverse shocks is endogenous because these are affected by mitigatory interventions of the central bank. Therefore, it will be critical to incorporate "the feedback effects of central bank actions through the broader system of banks, nonbanks, and markets that compose the financial system." Macroprudential stress tests that include central banks, the authors conclude, should therefore be developed.

The handbook concludes with a forward-looking discussion by Farmer, Kleinnijenhuis, and Wetzer. Finance is characterized by rapid change and exploding complexity, creating serious supervisory and regulatory challenges. Technological advances, including in model development and big data, enable the development of truly system-wide stress tests that can help supervisors and regulators to meet those challenges. The authors sketch what it would take to develop and implement a stress test of the full financial macrocosm, what such stress tests might look like, and how such tests can help enable more dynamic financial regulatory policy.

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