CHAPTER 3

Stress Tests as a Systemic Risk Assessment Tool

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Turning stress tests into a useful tool for assessing system-wide risk requires (1) incorporating general equilibrium dimensions, so that the outcome of the test depends not only on the size of the shock and the initial buffers of individual institutions but also on their responses to the shock and their interactions with each other and with other economic agents; and (2) focusing on the resilience of the system as a whole. Progress has been made toward the first goal: several models are now available that capture behavioral responses and feedback effects. But building models that measure correctly systemic risk and the contribution of individual institutions to it has proved more difficult. Further progress in this area would entail using a variety of analytical approaches and scenarios, integrating nonbank financial entities, and exploring the use of agent-based models. As well, stress tests should not be used in isolation, but be treated as complements to other tools and—crucially—be combined with microprudential perspectives.

1. INTRODUCTION

The importance of systemic risk originating in a country's financial sector—in other words, the risk of a shock that disrupts the functioning of the financial sector to such an extent as to have major consequences on the rest of the economy—was dramatically highlighted during the global financial crisis. To be sure, the notion that a stock market crash or a banking crisis can have knock-on effects on the real economy is not new: economic history has plenty of examples of both. But the global financial crisis underscored three new elements. First, the degree of systemic risk is not just a function of the magnitude of vulnerabilities facing individual sectors but also of the interconnections between them, as well as between financial firms, nonfinancial firms, and consumers, both domestically and across borders. Second, even the failure of individual firms can create systemic risk if these are too big or too interconnected to fail. And third, traditional policy frameworks that rely only on monetary, fiscal, and microprudential policies are not sufficient to contain systemic risk. In the words of the previous US Federal Reserve Chairman Ben Bernanke, regulators and policymakers need a "broader field of vision" (Bernanke 2008). One of the early lessons from the crisis was thus the need to adapt and broaden the "traditional" risk-monitoring toolkit to capture systemic risk better.

Stress testing has long been one of the key tools for assessing risks and resilience in financial institutions. The global financial crisis sparked a renewed interest in stress tests, which have now become a prominent—and in some cases statutory—feature of the regulatory regimes in many jurisdictions. Stress testing, once an arcane subject, has become a household term. But how well suited are stress tests in assessing systemic risk in the financial sector? How far has this "broader field of vision" been adopted in the current stress testing models? And where do we go from here?

These are the central questions this chapter is trying to address. Section 2 provides a brief primer on stress testing and how it has evolved over time. Section 3 discusses the challenge of adapting stress testing models to the task of assessing systemic risk and provides a critical evaluation of the

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progress made so far. And Section 4 outlines the key priorities in order to complete this task.

One important caveat is in order. This chapter is not a comprehensive overview of stress testing practices around the world. It does not provide advice on how to run "better" stress tests overall. The focus is solely on the use of stress tests for systemic risk assessment. Several important aspects of stress testing, like scenario selection and design, data quality, shock calibration, communication of results, or policy follow-up, are not covered. Fortunately, there is no shortage of studies covering these other aspects of stress tests.

2. "PLAUSIBLE, SEVERE, AND RELEVANT": THE ORIGINS OF STRESS TESTS FOR BANKS

Stress testing is not a recent invention. Originally used in engineering, stress analysis is a technique for testing a structure or system beyond normal operating capacity, often to the breaking point, to confirm specifications are met, determine breaking limits, or examine modes of failure. Asset managers and financial institutions, as well as their supervisors, have also realized the benefit of submitting portfolios or entire balance sheets to numerical simulations of hypothetical shocks to selected variables, like various asset prices, and assessing the impact on profits, capital, or the ability of regulated institutions to continue meeting their obligations, including observing regulatory requirements.

One of the early adopters of stress tests in the early 1990s was J.P. Morgan, whose RiskMetrics methodology used value-at-risk to measure market risk: in other words, the potential loss over a specific time period from movements in asset prices with a certain probability (see Zangari 1996). Regulators caught up after a while, and the Basel II capital framework required banks to perform stress tests for market risk and, in some cases, credit risk. These tests had to be "plausible, severe, and relevant" to help the bank evaluate its capacity to absorb losses and identify steps it can take to reduce risk and conserve capital (BCBS 2005).

Early stress testing models were relatively simple. They assumed a hypothetical shock—for instance, on credit quality or asset prices—and calculated the associated losses, making simplistic assumptions about the behavior of the bank (on profit distribution, credit expansion or deleveraging, and so on). They focused on the solvency of the individual bank, that is, on the impact of the shock on the bank's capital. Liquidity risk was treated separately from solvency, if at all, and interactions among banks were generally ignored.

These stress tests had a microprudential focus. Their objective was to assess the capacity of an individual institution to absorb losses under adverse conditions, that is, its ability to avoid failure and continue to function and to meet regulatory requirements. This was consistent with the dominant approach to financial regulation at the time, which was focused on safeguarding the safety and soundness of individual institutions. And this, it was thought, would ensure the stability of the financial system as a whole.

3. A NEW GENERATION OF STRESS TESTS

Even as bank regulators were putting the finishing touches on the Basel II framework, many understood that ensuring the safety and soundness of each individual institution was neither necessary nor sufficient to ensure that the financial system as a whole would remain stable and continue to function. As Andrew Crockett, then General Manager of the Bank for International Settlements, put it: the microprudential approach to financial regulation may "strive for too much and deliver too little" (Crockett 2000). It may strive for too much because the occasional failure of individual institutions is not the problem, if other institutions are capable of stepping in and providing intermediation services. Trying to avoid such outcomes risks providing "excessive protection." And it may deliver too little because it does not take into account *how* each individual institution pursues compliance with capital regulation. When, for example, a regulator pushes a troubled bank to restore its capital ratio, the regulator does not care whether the bank increases capital or shrinks assets. But if a substantial proportion of the banking system shrinks assets simultaneously to meet capital requirements, the damage to the economy may be considerable. Unless regulators take into account the collective behavior of institutions in response to a shock (or to regulatory requirements), they may fail to minimize the probability of distress for the system as a whole and the associated economic costs—in short, systemic risk.

Moving from the traditional microprudential stress tests toward a new generation of stress tests that, in Andrew Crockett's words, would "marry the microprudential and macroprudential dimensions of financial stability" involves two challenges:

- Introducing *general equilibrium dimensions*. This does not require that the economy or the financial system are at equilibrium at any given time, it just means that the stress tests are designed so that the outcome depends not only on the size and nature of the initial shock and the buffers of individual financial institutions, but also on the behavioral responses of these institutions as the shock unfolds, and on the interactions of these institutions with each other and with other economic agents (borrowers, funding providers, depositors, and economic policymakers).
- Shifting the focus of the stress tests from individual institutions to the *resilience of the system as a whole*, in other words, on its ability to continue functioning and providing financial intermediation services to the economy.

How much progress have stress testers made in tackling these challenges?

On the basis of a review of the experience of central banks, supervisory institutions, macroprudential authorities, and the IMF with stress testing models (Demekas 2015), the answer is: quite a lot, but we are not there yet. The stress testing community has made significant progress in tackling the first of the two challenges but much less in dealing with the second.

A number of models that incorporate some general equilibrium dimensions into stress tests are now available and widely used. They fall into two broad categories, each with its own strengths and pitfalls.

- Balance-sheet-based models that, as the name implies, use individual bank balance sheet data to assess the impact of an exogenous shock on asset quality, income, and ultimately capital (for solvency tests) or various measures of liquidity (for liquidity tests). The results are then aggregated to give an idea of the vulnerability of the system as a whole. In this approach—by far the most common across central banks and supervisory agencies around the world—any general equilibrium dimensions the stress tester intends to capture, whether solvency-liquidity interactions, behavioral responses, or macro feedback effects, are built in the model.
  - This benefit, however, comes at a price. First, these models can only capture general equilibrium effects that are explicitly incorporated in the framework. Second, analytical and computational complexity and data requirements increase very rapidly as more features are added to the models. This renders them slow, cumbersome, and costly to construct and run. Third, since they rely on bank balance sheet data, they depend crucially on the availability and quality of these data. Fourth, the microfoundations of these models are weak: instead of an integrated framework of optimizing economic agents, most of these models use ad hoc mechanisms and rules-of-thumb to incorporate dynamic effects and behavioral responses. Arguably, this is a price worth paying for introducing, in a practical way, general equilibrium dimensions in the traditional balance-sheet-based stress testing models. Moreover, one could point out that these behavioral rules of thumb are not arbitrary but derived from observations of past behavior. Nevertheless, this is an important handicap of these models, especially in times of crisis, when observed behavioral patterns break down and economic agents learn and adapt, often on the basis of imperfect information. And lastly, these models cannot capture the propagation of risks through market contagion, credibility effects, and so on.
- Models using (mostly) market data to infer the probability of distress or default of individual institutions can in theory capture *all* sources of vulnerability and contagion, including the risk of self-fulfilling runs triggered by investor sentiment that may not necessarily reflect weak fundamentals. Another advantage of these models is computational simplicity: combined with the availability of very high frequency market data, this makes them ideal for high frequency monitoring of bank resilience to a variable set of risks.
  - An obvious weakness of these models is their reliance on market data, which are noisy and may overestimate or underestimate risks. Bank default risk indicators estimated from these data may thus be excessively volatile and may not provide a sound basis for bank management or supervisory action. Another pitfall is that by extracting information from market data and constructing a summary metric of bank soundness, market-price-based models do not allow the stress tester to differentiate between the various factors that contribute to the bottom line (initial shock, risk interdependence, common exposures, cross-institution contagion, or market sentiment). Instead, all these factors are lumped into the implied probability of default or distress generated by the model. This had led some critics to dismiss these models as "black boxes."

In contrast to the progress made toward incorporating general equilibrium dimensions into the traditional microprudential stress testing framework, relatively little has been done to tackle the second challenge. Few stress testing models focus on—and measure correctly—the resilience of the financial system as a whole and its ability to continue providing financial intermediation services under stress. This reflects two fundamental problems: the *aggregation problem* and the *robustness problem*.

- The *aggregation problem* reflects the fact that the sum of individual banks' losses or capital shortfalls in the event of a shock is not a good proxy of system-wide risk. Given the different ways in which banks are interconnected, the individual losses are not additive. Correctly aggregating individual losses requires some knowledge of the dependence structure between individual bank balance sheets. And this dependence structure is nonlinear and tends to vary with the degree of systemic stress—that is, to increase at times of stress.
- The *robustness problem* expresses the notion that a single stress scenario, however severe, does not provide enough information about the resilience of the system to other shocks with the same probability. A theoretically more correct approach would be to look simultaneously at all risk factors affecting the system; estimate a multidimensional region with a given probability mass—say 95 or 99 percent; and calculate the maximum loss of the system for all

scenarios falling in this region.[1] This would measure the resilience of the system to *all* plausible scenarios with a probability of at least 95 or 99 percent. But this approach is very hard to implement and has not so far been used in stress tests conducted by a major central bank.

Both problems have long been recognized but are tough to crack. Some market-price-based models do not face the aggregation problem: models like Adrian and Brunnermeier's CoVar (Adrian and Brunnermeier 2016) or Segoviano and Goodhart's distress dependence (Segoviano and Goodhart 2010) start by estimating systemic risk and then derive the individual bank's contribution to it. One issue, however, with these models is that they do not translate these risk metrics into something that can be readily compared to the regulatory capital or liquidity requirements. Since these are ultimately the main tools microprudential or macroprudential regulators can use to mitigate risk, both at the individual bank and at the systemic level, a model without this element is unlikely to be of much practical value to policymakers. As regards the robustness problem, despite some promising theoretical approaches,[2] no satisfactory practical solution has been widely accepted yet.

[1] Estimating the maximum loss for a multidimensional region of a given probability mass has an undesirable property known as the dimensional dependence of maximum loss. As an example, start with a bond portfolio with risk factors consisting of two yield curves in 10 currencies. One risk manager models the yield curve using seven maturity buckets and another using 15 maturity buckets. Both choose a plausibility region of 95 percent. It has been shown (Breuer 2008) that the second risk manager will calculate a maximum loss that is 1.4 times higher than that calculated by the first risk manager, although both look at the same portfolio and the same plausibility level. Addressing this technical pitfall requires using a slightly different statistical concept of plausibility (Breuer and others 2009).

[2] One such approach is proposed in Webber and Willison (2011). Instead of estimating system-wide losses under a stress scenario, distributing those losses among individual banks, and then comparing the outcome to starting bank capital, this approach recasts the problem entirely from the policymaker's perspective. The policymaker is interested in setting individual bank capital at a level that ensures systemic solvency over a given time horizon at a certain level of probability. Given the trade-off between stability and efficiency, this is set up as a constrained optimization problem, where bank capital requirements are minimized subject to a specified probabilistic systemic stability target. Another promising theoretical approach that tackles both the aggregation and the robustness problem is outlined in Pritsker 2014. The key innovation here is a definition of systemic stability that is directly related to the level of regulatory capital of each bank: the "system assets in distress" (SAD) measure is defined as the sum of each bank's intermediation capacity, in turn defined as a function of its total assets and capital times a vector of risk factors. A continuous measure of systemic risk is then given as the probability that SAD exceeds a prespecified level θ ($p(SAD > \theta)$) for a given time horizon. The model then sets up a constrained stress maximization problem to estimate the amount of capital needed for each bank so as to satisfy the constraint that $p(SAD > \theta) \leq \alpha$, where θ is the regulator's systemic risk target. The constrained stress maximization uses Monte Carlo simulations to estimate nonparametrically the probability density function of SAD so as to take into account distress dependence *and* cover all possible realizations of the risk factors at a certain probability level.

4. THE WAY FORWARD

How do we move toward making stress tests more effective tools for systemic risk assessment? What follows is not a systematic research agenda, but a set of practical suggestions for stress testing practitioners that, in the author's view, can yield improvements or address obvious pitfalls and, in this way, move the dial on system-wide stress tests.

Use a Variety of Models

Given the limitations of the existing stress testing frameworks, it is surprising to see several central banks and regulatory agencies relying on a single model. This makes the outcome of the stress test hostage to the limitations of a single analytical framework.

Instead, a variety of models should be used for system-wide stress testing. The challenge in this case would be to interpret and synthesize the results of the different models into a coherent and persuasive narrative. Should the different results be combined or averaged according to a strict rule? Should qualitative judgment be used in weighing different—and potentially contradictory—results? These are not easy questions. But this is a challenge well worth tackling, as it would enhance the insights into systemic risk and the quality of the ensuing conversation about financial stability, both within the supervisory agency and with the banks.

Run More—and Smarter—Stress Scenarios

Most stress testing exercises are limited to one or two macroeconomic stress scenarios (for instance, an "adverse" and a "severe" recession scenario). This approach has a major pitfall: resilience to a shock of a given probability does not imply resilience to *all* shocks with the same probability (the robustness problem). It also ignores the increasingly important cross-border nature of risk: banks and other financial institutions are increasingly interlinked across borders, and may be vulnerable to shocks that originate in—or propagate through—a foreign country or market. The outcome of a single stress scenario focused on a domestic recession may thus be misleading.

The obvious remedy is to use a multitude of extreme but plausible scenarios for the stress tests. This would provide a better sense of the resilience of the system and of individual institutions to a range of shocks than a single scenario. Using multiple scenarios (as well as a variety of models) would also have another big advantage: it would minimize the scope for individual institutions to "game the test," that is, make portfolio choices geared toward passing the specific stress test—a risk that was recognized early on (Office of Financial Research 2012; Bank of England 2013).

In addition to the *number*, a related issue is the *type* of scenarios used in stress tests. In most cases, the main stress scenario is an adverse macroeconomic shock exogenous to

the financial sector. But in many actual financial crises, the shock originates entirely inside the financial system and is then followed by a recession. A well-known study of 43 banking crises in 30 countries (Alfaro and Drehmann 2009) shows that only about half were preceded by adverse macroeconomic conditions.

Effective system-wide stress tests should therefore involve a higher number and a wider range of "smart" stress scenarios. This is not a new idea, but implementation is demanding. It requires an in-depth understanding of the risks affecting the financial system, including cross-border dimensions. It would also complicate the task of synthesizing and communicating the results—especially when accompanied by a variety of models—and would cost more. It is these challenges that have held back many supervisors from moving in this direction. However, given the significant pitfalls of limiting the number of scenarios to just one or two, it may be time to reconsider the cost-benefit balance of the current approach.

Expand Coverage to Nonbank Financial Entities

Microprudential stress tests have been traditionally applied to banks because these were the predominant agents of financial intermediation. Recent trends have undermined this fact. The line between banks and nonbanks has been blurred. The nonbanking industry has expanded greatly in size and importance in the last two decades and the global financial crisis has demonstrated that banks and nonbanks are deeply interconnected and risks move easily between the two. Therefore, from a systemic perspective, stress tests should cover both banks and nonbanks, with the choice of which nonbank entities to incorporate into the stress testing framework depending on country circumstances. Priority should be given to sectors that are closely connected with banks through ownership or financial linkages—typically insurance companies. Asset management companies, mutual funds, and sometimes pension funds are also sometimes important providers of liquidity to banks, and could be affected by—or be a propagation channel for—a systemic shock.

Explore Agent-Based Models

Stress testing models—like all traditional economic and financial models based on neoclassical microfoundations—face a fundamental problem: they assume homogeneous agents (individuals or institutions) that always behave rationally in ways that can be modeled based on past experience, and that policy decisions influence this behavior in the same way for all market participants. These assumptions miss some critical points about financial crises, notably:

- The fact that that market participants, both in the financial and the nonfinancial sectors, are heterogeneous and often make less-than-rational decisions, especially under stress
- The emergence of new dynamics under stress, when relationships among financial institutions can change suddenly[3]
- The fact that the response of regulated institutions to policy signals is state-contingent (for example, raising the regulatory capital requirements put in place in normal times to ensure banks have sufficient capital buffers may have no positive effect on systemic stability at times of crisis [Klinger and Teplý 2014])

Agent-based models can capture many of these aspects, and may be better suited for analyzing situations of financial stress.[4] An agent-based model postulates autonomous, heterogeneous agents with bounded rationality, and specifies heuristic rules that dictate how they will act based on various factors. These rules can vary across different types of agents (for instance banks, depositors, providers of wholesale funding) and allow for less-than-optimal behavior. The model determines the "topology," that is, the mechanism through which agents can interact (for example, how they form networks), and can explore various types of shocks, both exogenous and endogenous (such as changes in agent behavior, topology rules, and so on). Agent-based models are increasingly being used for macro-financial modeling, and relatively simpler versions have been used to explore the impact of stress scenarios on bank solvency, liquidity, and contagion.[5] Agent-based models are complex, and implementing them would require a shift in the approaches traditionally taken by (and the skills traditionally required of) stress testers. Nevertheless, the limited experience so far suggests that they can provide unique insights into the aspects that matter most in a crisis: the behavioral responses of banks and the interactions between banks, market participants, and policymakers.

Embed Stress Tests into the Financial Stability Policy Framework

The recent explosion of interest in stress testing is creating a risk. Policymakers, market participants, and the broader public may focus excessive attention on stress tests, form exaggerated expectations, take stress test results out of context, and give them much greater weight than they merit in guiding policy action. This risk is evident in the way stress test results tend to dominate the public debate on the health of the banks in the United States following adoption of the Dodd-Frank Act, as well as in Europe following a string of highly publicized

[3] For example, the endogenous network literature has explored how network formation changes depending on the environment—see Deb 2012.

[4] This point was argued compellingly by Bookstaber (2012).

[5] A well-known example is the Complexity Research Initiative for Systemic Instabilities, building a large-scale macro-financial agent-based model for the European economy. A relatively simpler version is used by Chan-Lau (2014) to explore the impact of financial regulation on bank solvency, liquidity, and contagion under stress scenarios. This paper also contains a brief literature survey on the use of agent-based models for macro-financial modeling.

tests originally by the European Banking Authority and now the European Central Bank. Immediate remedial action by bank management and supervisors is automatically expected—or indeed required—of banks "failing" the test.

This was less of an issue with the traditional microprudential stress tests. Those tests were an input into the assessment of the soundness of individual institutions. Their results were not made public and rarely triggered automatic remedial action; they were instead used to inform the ongoing conversation between the regulated entity and the regulator. But the unprecedented attention focused on recent system-wide stress tests in advanced economies seems at times to overshadow, rather than inform, the conversation about financial stability among policymakers, regulators, individual institutions, market participants, and the public.

This risk has been noted before. In setting out best-practice principles for stress testing, the IMF put it this way (IMF 2012):

> Regardless of how extensive the coverage of risk factors, how refined the analytical models, how severe the shocks incorporated in the stress tests, and how careful the communications strategy, there is always the risk that the 'unthinkable' will materialize. […] No matter how hard the stress tester tries, stress tests always have margins of error. Their results will almost always turn out to be optimistic or pessimistic ex post. In addition, there will always be model risk, imperfect data, or underestimation of the severity of the shock. One should therefore set stress test results in a broader context.

So the call to embed stress tests firmly in the financial stability framework is essentially a call for caution and humility. Stress testing is just one of the many tools available to assess systemic vulnerabilities and resilience. They should be treated as complements to other tools, such as early warning indicators, and—crucially—should be combined with microprudential perspectives.

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