Contents

The Concept and Practice of Stress Testing .......... 1
  A Change in Focus ......................................................... 1
  Barriers to Success .......................................................... 1
  Firmwide Stress Testing: The New Standard .............. 2
Firmwide Scenario Model Approaches ................. 2
  The Silo Approach .......................................................... 3
  The Firmwide Risk Model Approach ............................. 3
  Multiple Model Approaches ........................................ 4
Firmwide Risk Capital Measures ....................... 4
  Risk Measures and Stress Scenarios .............................. 5
  A Risk Reserve Approach: A Practical Illustration ........ 6
The Regulatory Stress Scenario Approach .......... 7
  Bank-Specific Approach: A Total Balance Sheet View ... 7
  Bank-Specific Approaches to Stress Testing: Scenarios and Models ........................................ 10
  Systemic View: Financial System Analysis and Financial Contagion ........................................ 11
The Future of Firmwide Stress Testing .............. 12
  Assessing and Managing Model Risk ......................... 12
Conclusion ................................................................. 13
References: ................................................................. 13
The Concept and Practice of Stress Testing

The concept and practice of stress testing has been around for many years. While traditional stress testing methodologies are still valid for firmwide scenario analysis and stress testing, special techniques and attentions are needed to successfully achieve the goal of firmwide capital adequacy in forward-looking stress scenarios.

During the 2007 financial crisis, many financial institutions were not sufficiently prepared for the ensuing liquidity crunch and capital drains. Perhaps if banks had worked through different economic scenarios prior to the crisis, they would have been in a better position to weather the storm. Inadequate preparation for crisis can lead to systemic risk and severe economic and political turmoil.

With the lessons learned from the 2007 financial crisis, regulators now require that banks use both quantitative and qualitative methodologies to ensure that robust, forward-looking capital-planning processes are used to account for the unique risks facing their respective organizations. For example, the SCAP (Supervisory Capital Assessment Program) exercise started in the United States in 2009. Now its successor, CCAR (Comprehensive Capital Analysis and Review), has become a major focus of the top 25 banks in the United States. CCAR initially required bank holding companies with consolidated assets of $50 billion or more to submit annual capital plans to the Federal Reserve for review. However, smaller banks are also joining the group; the DFAST (Dodd-Frank Act Stress Testing) regulation requires US banking organizations with consolidated assets of $10 billion or more to conduct stress tests.

Other regulators throughout the world are participating in this expansion of firmwide stress testing so that a broader range of banks must participate. For example, Europe has introduced the European Banking Authority (EBA) stress testing requirements. As a result, a bank may also face a country-specific firmwide stress test regulation (such as the Prudential Regulation Authority in the UK); in this case, prescribed macroeconomic scenarios overlap to some extent with the EBA-prescribed macroeconomic scenarios. Firmwide stress test regulations are also extending beyond Europe into the emerging markets - for example, with the Reserve Bank of India stress testing guidelines.

A Change in Focus

Initially, regulators emphasized credit losses and revenue, and thus they stressed just a few macroeconomic risk factors (similar to what was done with SCAP in the United States in 2009 and 2010). Today, regulators want to understand not only the effect of stress scenarios on credit performance and revenue, but also how the test results affect a broader array of measures, including liquidity and full balance sheet projections. In other words, regulators want stress testing to be an integral part of a bank's capital plan.

But for financial institutions, assessing the influence of stress scenarios across these different measures has created many challenges. Stress testing has become a systematic way to examine and identify an institution’s overall financial vulnerability. And for many banks, it’s not easy to implement a total balance sheet-based, firmwide stress testing process.

Barriers to Success

The total balance sheet-based, firmwide stress testing exercise requires adherence to sound data management principles. But for many banks, accessing, collecting and quality checking data to support stress testing remains a challenge – especially when criteria for stress testing scenarios change so that banks need to aggregate new or improved data. Banks also struggle with integrating risk financial measures into stress scenarios when creating their capital plan.

These requirements are part of most regulatory stress testing regimes and require banks to quantitatively project assets, liabilities, income, losses and capital across a range of macroeconomic scenarios. The stress testing functions (or steps) involved in the end-to-end stress testing process typically run in independent, departmental silos; moving to a firmwide stress testing process that involves a tightly integrated, cross-departmental approach isn’t easy for banks. At the same time, the heightened collaboration required affects how banks manage risk overall, as the approach brings together many disparate elements under a common approach.

To overcome these issues, what’s needed is a solid, but iterative firmwide stress testing process that is constantly improving and being invested in. This process should not only allow a bank to gauge its capacity to meet regulatory capital requirements such
as CCAR and EBA, but also significantly improve its ability to identify and prevent potential issues that may affect its revenue, liquidity, market growth and earnings.

Firmwide Stress Testing: The New Standard

Banks have long used scenario analysis and run stress tests for each bank risk, such as market and credit risks. But use of firmwide stress testing, which aims to predict a bank’s complete income and balance sheet statement under various stress scenarios, has picked up recently with the introduction of the CCAR and EBA stress tests. Firmwide stress testing also necessitates a collaboration between a bank’s risk experts (who are responsible for generating earnings and loss impact under stress as specific income line statements) and a bank’s financial balance sheet and capital management experts (who are responsible for analyzing the bank’s available capital and planning future capital needs).

In addition to analyzing the sufficiency of bank capital under firmwide stress conditions, banks can also analyze the sufficiency of their liquidity buffer under the stress. Since liquidity risk is usually a consequential risk, it is also natural to analyze bank capital and liquidity sufficiency jointly under the stress scenarios.

In this paper, we first discuss two commonly used firmwide scenario model approaches:

• A silo approach where analysis is done on each risk type and then results are aggregated.

• A comprehensive, firmwide risk model approach.

Both approaches are based on a bottom-up view of firmwide risk with scenarios for firmwide risk factors. Their differences stem from using siloed risk systems to achieve a firmwide risk view or using a firmwide risk model approach.

Second, this paper discusses firmwide risk capital measures such as estimating firmwide risk capital need and firmwide scenario analysis with a focus on testing capital sufficiency.

This kind of firmwide analysis extends the classical risk reserve approach to risk capital, which is traditionally used by banks, by focusing on the risk capacity, such as capital and earnings, as opposed to just the risk exposure. The risk exposure can be calculated using a statistical risk measure applied to many scenarios (for example, using value at risk). The risk exposure can also be calculated from a single stress scenario. The approach is frequently used in the bank’s ICAAP (Internal Capital Adequacy Assessment Process).

The third topic of this paper is the specific regulatory, firmwide stress testing process used in CCAR and EBA. The regulatory stress testing is different than the firmwide risk capital approach. In particular, the regulatory stress testing process is focused on maintaining minimum capital ratios under stress and ensuring that banks remain financially viable even under stress. The risk exposure, coming from losses and earnings reductions, is estimated under regulatory prescribed macroeconomic scenarios. Since the regulatory stress scenario is focused on sufficient capital ratios under stress, it also requires stressed estimation of required capital. Because regulatory stress testing uses high-level macroeconomic scenarios, the use of models is critical to the materialization of the high-level macroeconomic scenario.

The paper ends with a discussion of the future of firmwide stress testing and stress testing regulation.

Firmwide Scenario Model Approaches

In practice, it may be impossible to isolate risk effects into categories like market and credit risk (for example, by creating artificial subportfolios that allow for compartmentalized risk analysis) and then use a dependence model to integrate all of the risks back together. Indeed, most risk types have complex interrelationships that stem from dependence on many of the core risk factors as well as customer behavior. But by using a joint modeling of core risk factors for the risk types, institutions can better understand the consequences of each adverse scenario for risk factors across risk types and lines of business. They can then use their enhanced understanding to proactively manage these scenarios.

In a bottom-up approach to firmwide scenario analysis, the risk systems carry out calculations on the scenarios that are generated from a joint distribution of the key risk factors. This approach is useful not only for estimating firmwide risk levels but also for firmwide stress testing, as it relies on aggregating risk values per scenario. Hence, this model approach is commonly used for the firmwide stress testing.
In bottom-up, firmwide scenario model approaches, a bank can use either:

- A silo approach per risk type and then aggregate the results.
- A comprehensive, firmwide risk model approach.

In contrast, classic, firmwide risk aggregation models do not rely on joint, correlated scenarios. They take a top-down approach to determining firmwide risk levels using a specified codependency between risk types. The risk aggregation process involves aggregating compartmentalized risk measures into more comprehensive, firmwide risk measures.

Of course, the firmwide scenario model can also be a combination of the two. The following sections will discuss both of these firmwide scenario model approaches in detail.

The Silo Approach

In the silo approach, each silo risk system is responsible for predicting a certain risk’s profit and loss under given scenario(s). For example,

- The market risk system(s) generates the market risk profit and loss under the scenario(s).
- The asset and liability management system(s) generates the net interest income projection under the scenario(s).
- The credit risk system(s) generates credit loss under the scenario(s).

The portfolio-level net earnings for a given scenario are the sum of net interest income earnings less market and credit risk loss. Consequently, the specific market, credit and profitability risk techniques are still important for the firmwide risk. In practice, banks can add more of their earnings and loss contributions to the income statement to obtain a more complete view (for example, non-interest income and expenses such as fees and risks other than market and credit risks, such as operational risk).

The core of the silo approach is that the scenario-by-scenario results are aggregated across silo risk systems so that one distribution or an aggregated scenario result is generated for firmwide risk analysis. In this approach, the firmwide scenarios can be generated outside of the silo risk systems using a firmwide risk scenario generator. The subsequent risk aggregation is a separate process.

In practice, many of the firmwide risk scenarios are specified as high-level, macroeconomic scenarios. To transform high-level macroeconomic stress scenarios to silo system risk factors, banks use various models. As discussed in Skoglund and Chen (2015), the models used to transfer stress from macroeconomic risk factors to actual portfolio risk factors can be based on distribution models or factor models. The models themselves are sometimes referred to as satellite models.

The Firmwide Risk Model Approach

Using existing silo risk systems for firmwide scenario analysis can be quite complicated in practice. The primary challenge is maintaining consistency in scenarios applied across systems and performing the subsequent aggregation of risk results across systems. In addition, the separation of risks into siloed risk systems can make it hard to consistently estimate key measures such as stressed earnings. For example, a bank’s asset and liability management system can certainly generate cash flows, but typically, it does not incorporate the credit models to convert credit scenarios into scenario credit loss and the resulting loss of cash flows at delinquency and default. Hence, when generating stressed credit losses in the credit risk system separately from the earnings cash flows in the asset and liability management system, it’s easy to create inconsistencies. These inconsistencies can also make it impossible to generate consistent loan-level scenarios on cash flows, accruals and credit loss.

But there are benefits as well. This approach provides a single, independent financial risk analysis for firmwide stress. In addition, there is no need to rely on silo systems for valuation and/or manage the subsequent aggregation from different systems. Another clear advantage of a firmwide risk model approach is that balance projections and management interventions can be more easily handled, as this work is done using a single, comprehensive model approach. This is especially key if management interventions at the next horizon depend on the projected risk results at the previous horizon, as this can create a complex feedback loop to silo risk systems that can be hard to manage consistently.

Implementation by Books of Business

At its core, the firmwide risk model approach tries to integrate the earnings and loss predictions into a single model. In practice, it may be difficult to have a complete firmwide risk model for all books of business. For this reason, this model is often implemented per book of business. Similar to the silo approach, this necessitates a subsequent results aggregation process in order to gain a firmwide view of risk. However, the aggregation is now distinct per book rather than by risk type for the same book of business. A gross decomposition is the aggregation of the trading book market risk and banking book earnings and loss. In practice, the banking book may be further decomposed into the different books of business such as mortgage, credit card, etc., so that each have their own models for integrated earnings and loss prediction.
Approximative Firmwide Risk Model

In practice, each risk is unique in terms of risk factor sources and risk calculations. Because of the complexity of real portfolios and the need to analyze firmwide risk in the context of high-level macroeconomic scenarios, it can be a natural choice for banks to implement the firmwide risk model as an approximation to some of the granular risk models in the silo risk systems. In other words, they use an approximate firmwide risk model. The approximation can be done two ways:

- By reducing in the number of risk factors.
- Through portfolio approximation.

One way of reducing the set of risk factors is to use factor models, especially for expressing portfolio risk in core factors such as equity indices, exchange rates, interest rates and macroeconomic factors such as property prices and unemployment rates. A classic example of a factor model is the CAPM (Capital Asset Pricing Model), where the universe of the equity returns risk can be reduced to a single market factor risk and equity betas. The CAPM model induces scenario values for the specific equities given the scenario values for the market factor.

The portfolio approximation in firmwide risk models can use multiple techniques to approximate the detailed portfolios for the specific risks. The best portfolio approximation to use is determined by the portfolio complexity and the error acceptance in the approximation. For example, a natural approximation for a relatively simple market risk portfolio is to use the linear delta approach. The linear delta approach (risk position approach) is also used in CCAR and EBA market risk stress tests. For the banking book earnings and loss projection, the approximation can be based on pooling or a smaller replicating portfolio for a quick approximate stress analysis (although in practice, loan-level models are more frequently being used). Sometimes, more elaborate approximation techniques must be used for complex portfolios that can have a large impact on stressed profit and loss (for example, Treasury interest rate risk hedges with optionality such as American and Bermudan swaptions).

Regulatory Benchmark Firmwide Risk Models

Regulators can also develop their own firmwide risk models for bank stress testing. For example, many central banks in Europe have developed high-level, macroeconomic bank risk models for stress testing. (As an example, see the Bank of England RAMSI model (2012), the European Central Bank stress test model (2013) and the Czech National Bank stress testing model (2013). These models rely mostly on balance sheet information from banks and macroeconomic risk models.)

Of course, banks themselves have more detailed information about their risk exposures, and hence a bank’s own firmwide risk model can incorporate more detailed portfolio information. As a result, it can also be used to challenge regulatory views.

Regulators may also develop their own, more granular benchmark models for specific risks. For example, the 2012 Federal Reserve CCAR supervisory credit stress tests used a specific quarterly delinquency transition matrix specification for residential mortgages. Since then, the Federal Reserve has been building supervisory models for CCAR using the collected bank data.

Multiple Model Approaches

In practice, banks can use multiple model approaches in stress testing that include both silo and firmwide risk model approaches. A centralized, firmwide stress testing team may be responsible for maintaining macroeconomic scenarios, satellite models and the firmwide risk model for firmwide stress testing. At the same time, the silo risk systems may be used to generate benchmark validations of stressed profits and losses under the same macroeconomic scenarios.

Firmwide Risk Capital Measures

Firmwide stress testing can provide significant value to bank management. For example, management, including regulators, can examine the capital planning and management decisions under different scenarios and ensure a satisfactory capital position for the bank under the scenarios. From a basic balance sheet point of view, a bank’s capital is defined as the total assets minus the total liabilities of the bank. At a specific point in time, the value of capital can increase or decrease due to the change of the balance sheet. The key to the firmwide stress testing exercise is to apply the stress scenario to the projection of both the asset and liability side of the balance sheet. An incremental projection, period by period, starting from the current state at the time of the analysis, means that the available capital can also be measured as the net earnings minus the losses adjusted by tax and capital actions. Capital actions include dividend plans and other accounting adjustments.

Figure 1 presents a conceptual view of the steps involved in risk-based capital stress testing. The first step applies stress scenarios to obtain a stressed income statement, which is adjusted for taxes and other adjustments such as asset sale gains, such that the bank can obtain a final projected income
Second, instead of taking a worst-case risk measure approach to capital (and liquidity sufficiency), banks can focus on sufficiency in a given, predefined worst-case stress scenario. Historically, regulatory risk capital for market and credit risks has followed the first approach, defining capital as a worst-case scenario from many scenarios using a risk measure. The liquidity regulation with Basel III instead focuses on the second approach, testing the sufficiency of the liquidity buffer using a given predefined worst-case stress scenario.

In both approaches, to test capital and liquidity sufficiency, banks must perform the following steps:

1. The firmwide scenario(s) are generated.
2. Satellite models are used to transfer the macroeconomic stress scenario(s) to actual portfolio risk factors if needed.
3. Scenario loss(es), earnings impact(s) and liquidity impact(s) are computed.
4. The available capital base and liquidity buffer are used to check sufficiency versus the risk measure (risk measure approach) or versus the loss and liquidity outflow in the scenario (stress scenario approach).
5. Depending on the outcome, management actions may be considered, for example, capital preserving or liquidity preserving actions.

Note that if scenario(s) are multihorizon, banks may consider taking reasonable actions – such as capital and liquidity preserving actions – at the end of a scenario horizon before the next horizon of the scenario. In a multihorizon scenario, the capital base or the liquidity buffer can be depleted over time.

**Figure 1: Firmwide Risk-Based Capital Stress Testing**

In the first step, a bank calculates the stressed net revenue before loss provision and loss adjusted by recovery. The net revenue before loss provision, also known as pre-provision net revenue (PPNR) in CCAR, is composed of interest income, non-interest income (including fees and trading profit and loss), interest expense and non-interest expense. Credit and operational losses will offset the net revenue for the same period. The second step calculates the available capital from the final projected income and the current available capital. This available capital is before management actions. Post-management action available capital is obtained in step three. Adjustments to the available capital in step two include decisions on dividend payouts and capital preserving actions such as equity raises and balance sheet reductions.

**Risk Measures and Stress Scenarios**

When using a firmwide scenario approach to generate firmwide risk and capital measures, banks can use two different approaches. First, they can generate a set of correlated, firmwide risk factor scenarios that span the different risks. They can then calculate the profit and loss resulting from the scenarios and create a distribution to which they can apply the usual risk measures, such as VaR.

In this risk measure approach, banks choose as their required firmwide capital a worst-case scenario or weighted average set of scenarios by the risk confidence level used in the risk measure. If the current capital base is not sufficient to cover, for instance, the calculated firmwide risk capital need, the bank can take capital preserving actions and plan for capital adjustments.

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A bank also has earnings from non-interest income and non-interest expense. Recall that in CCAR, the PPNR is the sum of three parts: net interest income, non-interest income and non-interest expense. All three parts need to be stressed. As a result, banks must develop models predicting non-interest income and non-interest expenses (such as bank fee income and administration, and salary expenses) under the macroeconomic stress.

Due to the lack of granular historical data and previous model practice, banks sometimes take a simplified “line item” approach for some of these non-interest income and non-interest expense earnings. The line-item approach uses risk factors and scenarios to analyze risk impacts, but it operates on an aggregated level – for example, on portfolio or income statement line items. Often, regression models are fitted to the past line item behavior, and the macroeconomic regressors are subsequently used to stress the line item behavior. (See Duane et al. [2014] on models and practices to predict non-interest income and non-interest expense.)

Having obtained the stressed earnings, banks can generate a scenario-based prediction of total losses using the profit-and-loss models for market risk, issuer credit risk and counterparty default risk.

With scenario stressed earnings and losses available, banks can create an aggregate stressed income statement per scenario, as shown in step one of Figure 1. They can also adjust their projected income statements with, for example, other projected incomes such as asset sale gains and earnings tax adjustments. This yields the bank’s final projected net income in step 2, as shown in Figure 1. Dividing the final projected income into earnings \( E_d \) and losses \( L_d \) contributions, banks can create the capital reserve \( CR_d \) for scenario \( d \) using the following calculation:

\[
CR_d = C + E_d - L_d \quad (1.1)
\]

where \( C \) is the current available capital base. The capital reserve corresponds to the remaining available capital in step 2 in Figure 1 and is before consideration of management actions.

In practice, the scenarios generated in step one, as described above, are high level. This is because a firmwide stress is being considered, so it’s practical to start with a set of high-level macroeconomic scenarios and then drill down to assess the impact on portfolio-specific risk factors. The fundamental idea is for the bank to get a forward-looking understanding of the aggregated risk profile based on the scenarios. The firmwide risk capital approach is different from a risk capital approach per risk type, as it focuses on a comprehensive, economically meaningful stress scenario. To capture reality, the macroeconomic scenario is generally a multihorizon scenario specifying a path that macroeconomic variables can follow.

The third step of the process yields a per-scenario projected income statement. This statement can include, for example, income statement line items earnings and loss contribution from:

* Earnings from the interest income projection from the assets and liabilities.
* Losses from market risk.
* Losses from issuer credit risk in banking book and trading book.
* Losses from counterparty default and CVA.
* Other losses (for example, from operational risk).

The earnings from the interest income projection is a traditional net interest income projection. It can include a joint modeling of issuer credit risk and cash flows or use a post-adjustment of the net interest income with credit system projected losses. The interest income comes from loans, leases, deposits and mortgages, for example. The interest expense comes from deposits, issued bank debt and other liabilities.

A Risk Reserve Approach: A Practical Illustration

The specific term-structure characteristics and the severity of the scenario are important factors to consider when deciding the exact outflows and the appropriate management response.

The earnings from the interest income projection is a traditional net interest income projection.
The Regulatory Stress Scenario Approach

While net profit and loss depend on the macroeconomic scenario, so does the required capital. Furthermore, the required capital is dependent on the balance and loss projection. For example, the credit risk weighted assets change when the total balance and credit quality of the banks’ assets change due to either growth or loss. On the flip side, if required capital increases too quickly to be sustained by the available capital business, banks may need to adjust their growth and capital actions, such as dividend payouts and equity buy-back plans.

This section focuses mainly on the bank-specific approach to regulatory firmwide stress testing. In addition, we briefly discuss the second round of analysis performed by central banks to analyze the financial system stability using either their own macroeconomic stress testing models or by rolling up the stress test results provided by a bank.

Bank-Specific Approach: A Total Balance Sheet View

Instead of focusing on stress scenarios to actually define the capital buffer for CCAR and EBA, firmwide stress testing focuses instead on banks maintaining minimum capital ratios under stress. The capital ratio is defined as actual capital divided by required capital. The compliance-to-regulatory stress scenarios are viewed as complementary to the already defined capital requirements. In this case, capital requirements are computed using risk models and a risk measure approach founded in a risk reserve approach. If the chosen risk measure, at the specific confidence level and time, implies a loss (that is, that the risk reserve is exhausted), it indicates a need to increase the capital buffer to ensure survival at that confidence level and time horizon.

The above approach to firmwide risk capital is based on a risk reserve approach, and thus it does not deplete the capital buffer under a particular stress scenario or use a risk measure on many scenarios. This approach is founded in classical risk theory in insurance and is the traditional regulatory approach to defining market and credit risk capital as well as defining the liquidity buffer. It is also the traditional approach for banks’ ICAAP models.

As we shall see, the CCAR and EBA firmwide stress approach is different. Rather than defining the capital buffer, it put limits on the minimum regulatory capital ratios.

\[
NE_d = [E_d - L_d]
\]

preserving actions by the bank. That is, the bank will not save positive contributions from the net earnings \(NE_d\)

in one period to build up the current available capital base \(C\) in the next period. This means that \(C\) is constant over time in this case (since there is no addition to the current available capital) and that we can calculate a required capital reserve over time, \(t = 1, ..., T\), in the multihorizon scenario \(d\) as

\[
CR_d(T) = C + \sum_{t=1}^{T} \min[NE_d(t), 0].
\]

If a bank uses a stress scenario approach to analyze the sufficiency of the initial capital buffer \(C\), they clearly cannot allow \(\{CR_d(t)\}_{t=1}^{T}\) negative at any \(t = 1, ..., T\) in the stress scenario. In the risk measure approach, we similarly sum all the negative contributions to \(\{CR_d(t)\}_{t=1}^{T}\) over time for each scenario \(d = 1, ..., D\) and apply a risk measure to the tail of summed negative contributions. If the chosen risk measure, at the specific confidence level and time, implies a loss (that is, that the risk reserve is exhausted), it indicates a need to increase the capital buffer \(C\) to ensure survival at that confidence level and time horizon.

Figure 2 presents a conceptual view of the elements involved in the regulatory stress scenario approach. Compared to Figure 1, notice that stress scenarios are also applied to the required capital calculation and that the focus is the capital ratio rather than available capital, per se. As part of the regulatory stress testing process, a bank may also face restrictions on what management actions can be assumed in step 3 to improve the capital ratio from step 2.

Both CCAR and EBA consider stress during multihorizon, macroeconomic stress scenarios. For example, the CCAR macroeconomic scenarios specify the evolution on a quarterly
basis over the next nine quarters. In EBA, the macroeconomic scenarios are based on the evolution over three years. The scenarios include both macroeconomic scenarios and specific market risk scenarios with detailed risk factors, funding shock scenarios and prescribed defaults of the largest exposure counterparty.

Creating the Balance Sheet Ratio

In both CCAR and EBA, the current balance sheet is the basis for the first horizon-projected income statement. The projected income statement becomes the basis for the projected balance sheet statement at the end of the first horizon. The scenario-realized capital ratios help determine if the bank must take management action to increase capital in order to maintain the minimum capital ratio under stress.

For example, a bank can create the balance sheet ratio \( R_d \) for a scenario \( d \) such that

\[
R_d = \frac{C + E_d - L_d}{\sim C_d}
\]

where, as in the equation (1.1), \( C \) is the current available capital base, \( E_d \) is the projected earnings in the scenario, \( L_d \) is the projected losses in the scenario, and \( \sim C_d \) is now a measure of required capital under stress.

As an alternative, banks can use retained earnings (\( RE_d \)) defined as the earnings minus losses, and any additional loss provisions needed.\(^1\) This results in a scenario capital ratio \( R_d \) that can be compared to a minimum required capital threshold.

\[
R_d = \frac{C + RE_d}{\sim C_d}
\]  

(1.2)

Because of the \( t = 1, \ldots, T \) multihorizon scenario, the capital ratio has a scenario term structure \( (R_d(t))_{t=1}^T \), which can be compared to time-based limits or a fixed limit over time.

\(^1\) For example, in Basel credit charges, the deterioration of the credit quality of the portfolio induces an increase in the provisions and Basel expected loss. The requirement is that 50 percent of the difference between the two must be subtracted from the available capital. This is in addition to the scenario loss \( (L_d) \).
In the regulatory stress scenario approach, the definition of required capital ($\sim C_d$) is the minimum regulatory capital, and $C$ is the capital base. Specifically, $C_d$ is the sum of all of the capital charges for the risks. However, we still need a specific definition of required capital for the different risks to calculate $\sim C_d$. This is generally based on the bank's approval for the specific risk models used in regulatory capital calculations. For example:

- **Market risk regulatory capital impact** can be based on the internal models approach with VaR and stressed VaR. In principle, a model-based charge can be based on a conditional distribution VaR, or use a simple replacement of VaR with stressed VaR as per the EBA. The conditional distribution VaR is the VaR obtained when we condition the portfolio risk factor distribution on the pre-specified stressed macroeconomic factors.
- **Issuer credit risk in banking book regulatory capital impact** can use the Basel advanced internal models approach for the banking book. The regulatory macroeconomic stress scenarios ultimately affect the risk inputs to the risk-weighted assets such as probability of default and loss given default.
- **Issuer credit risk in the bank's trading book can use a stressed (parameters) or conditional distribution (on the macroeconomic factors) VaR for the incremental risk charge, assuming the bank is currently using the model for the trading book credit risk.**
- **Counterparty credit risk default charges are issuer default risk charges in the banking book.** As a result, they are based on the risk-weighted assets using the estimated expected positive exposures, as discussed in Skoglund and Chen (2015). CVA charges can use a standardized, formula-based approach or a VaR model capturing the variation in CDS premia or bond spreads for the counterparty.

Skoglund and Chen (2015) provide explicit examples of stress testing market risk and credit risk, including the stressed capital impact. While the regulatory definition of $\sim C_d$ is the sum of the minimum regulatory capital, in principle, internal stress testing could be based on other measures such as economic capital in the denominator of the equation. This can involve using economic capital models for the specific risk types, as well as overriding the simple risk sum approach using a correlated aggregation model of the different risks to obtain $\sim C_d$.

**Management Intervention and Balance Growth Assumptions**

Given a stress scenario realized balance sheet and capital ratio at a certain time (with "t" as the time value in $R_d(t)$), banks can consider taking potential management interventions (such as capital preservation and dividend planning) and balance sheet growth assumptions for the next horizon, $t + 1$. For example, in the Bank of England RAMSI model (2012), the bank decision rule is to expand the balance sheet at $t + 1$ only if both retained earnings, $RE_d(t)$, are positive and the capital ratio, $R_d(t)$, exceeds the minimum stress level. When the capital ratio is below the minimum stress level, the retained earnings are used to build up the capital base. In case of negative retained earnings, the balance sheet is in runoff.

In practice, there are several variations between regulations in the actual calculation details. For example, when the EBA stress testing exercise is performed by a specific bank, no management intervention is allowed. In contrast, with CCAR, banks must incorporate both planned (baseline) and stress scenario-specific capital actions. Another difference is the treatment of the growth of the balance sheet, which is static in EBA stress testing. In practice, the revenue projection should incorporate the change of the asset and liability balance, which in turn affects the income and expenses. The balance sheet change should also reflect the scenario instead of being static. For example, the increase of deposit volume and the high-quality assets is typically lower in adverse scenarios than a normal scenario. Likewise, the interest income and expense due to the additional business can vary according to the scenario.

Figure 3 illustrates the firmwide stress testing process for scenario horizons $t = 1, 2, 3$. The process in Figure 3 includes both liquidity ratios and capital ratios. However, currently, both CCAR and EBA focus on the capital ratios under stress. Figure 3 also includes potential management interventions that can be taken, if allowed. If management intervention is not allowed, it's assumed that management projections such as balance forecasting are made at the beginning of the process and remain for the duration of the stress test. Alternatively, balances can simply be assumed to be constant. Of course, in principle, a management intervention of capital raising action can be an ex-post adjustment, as all of the scenario analysis horizons have run. However, this does not apply to the balance adjustments, as these adjustments will affect the next horizon's balance sheet that will be stressed for earnings, losses and capital requirements.
Since regulatory scenarios are very high-level and only include major macroeconomic risk drivers affecting the entire economic system, banks are expected to extend their regulatory scenarios to better reflect the risks that materially affect their own business operations. For example, while regulatory scenarios usually include national real estate price indices, a bank that has residential or commercial mortgage exposures in certain regions must either derive the regional indices down to the granular level that corresponds to the exposure concentration from the regulatory national index scenario values; or further augment the scenario by creating new scenarios with these regional indices.

Regulators also expect banks to build the enterprise stress testing into their own risk management-based decision making, and thus demand banks to develop macroeconomic scenarios that are relevant to their operations. Bank-developed scenarios can be an extension of the standard regulatory scenarios by adding more macroeconomic variables, overriding certain regulatory specifications, or creating a completely new scenario. The scenarios developed by banks should capture the key risk exposures and concentrations in their portfolios.

Due to the complexity of bank portfolios, it’s not easy for banks to determine the risk exposures that can traumatize their business. The task of finding severe impact scenarios requires considering reverse stress testing approaches. Skoglund and Chen (2015) discuss reverse stress testing methodologies as

Skoglund and Chen (2015) provide an extensive example of modeling earnings and loss cash flows with behavioral and business growth assumptions. The example uses the concept of target ending balances for future balances together with prepayment and default assumptions. It also illustrates the importance of addressing liquidity and funding needs with balance growth. The target-ending balance case is an example of a portfolio-level, top-down approach to balance growth. However, in practice, behavioral models such as prepayment and default can be granular while business plan models such as the target-ending balance approach can be a (per horizon) post-process adjustment. That is, detailed-level cash flows are aggregated to a higher level view where going-concern business growth is applied on aggregated balances (cash flows) for a product class.

**Bank-Specific Approaches to Stress Testing: Scenarios and Models**

While we have already discussed the typical firmwide stress testing scenario model approaches, the firmwide stress testing regulation calls for special attention on how banks manage the stress testing models and scenarios. This includes own scenario creation, the use of simplified models in some cases, the role of management overlay in analytical stress testing models, and the need to recognize and manage the inherent model risk in the stress testing models.

![Figure 3: The firmwide stress testing process](image-url)
well as associated dimension reduction methods for portfolios with many risk factors. The concept of reverse stress testing is universal. In general, it focuses on the outcomes that can hurt the bank significantly and then, through an appropriate method of reverse impact analysis, finds the stress scenarios that could generate such an outcome.

Long before the rise of the enterprise stress testing, economic capital has existed as a common practice for bank capital management. Stress testing has been seen as a supplement to the economic capital analysis often founded in model-based risk charges. This relationship can clearly be seen in the traditional ICAAP “risk reserve” process described above.

Of course, the goal of stress tests is to provide a forward-looking view of banks’ capital. This view complements the economic capital models that are often drawn from historical data. Skoglund and Chen (2015) also cover a few other perspectives of the interplay between stress testing and models. Specifically:

- A sound economic capital analysis can help identify the stress scenarios that can significantly affect a bank’s capital adequacy. (This is the practice of reverse stress testing discussed above.)
- The economic capital analysis can be enhanced with the inclusion of forward-looking stress scenarios under the heading of integration of stress and model analysis.

The Use of Simplified Time Series Forecasting Models for Line Items

Due to the lack of granular historical data and appropriate models, banks are sometimes taking historical line-item time series forecasting approaches for some components of the financial statements. A typical example is non-interest income and non-interest expense, which we have mentioned previously. There are many reasons why this approach is still acceptable to the regulators. Apart from the inherent data issues, in many cases the massive mergers and acquisitions that took place after the financial crisis have limited the ability of banks to present acceptable models for certain parts of the balance sheet. Banks may have introduced new business or changed the composition of the business.

In the United States, all the regulated banks are required to submit periodic financial and other information to their regulators. One of these reports is the quarterly consolidated report of condition and income, also known as the call report. Every national bank, state member bank and insured bank is required by the Federal Financial Institutions Examination Council (FFIEC) to file a call report every quarter. The granularity of the call report also provides a good match for the regulatory stress testing requirement. Many banks facing the challenge of the granular data and models develop quarterly projection models to be able to respond to the regulatory scenarios by employing historical values of the risk factors in the scenarios as covariates to the historical line-item numbers.

Management Overlay

Although quantitative models provide objective stress testing results, management overlay (or action) is still investible at times. In most cases, such overlays should be subject to management policies or actions, as management intervention and capital actions such as dividend plans are policy driven.

The Role of Model Risk Management

The enterprise stress testing exercise has put tremendous emphasis on the models used for the entire balance sheet. As a result, model risk management, including model governance, model validation and documentation, is being given more attention. The model risk management issues reviewed in Skoglund and Chen (2015) are all relevant to the firmwide stress testing. What’s important to emphasize is that these models can properly capture the tail behavior of the modeled subject. This includes the fact that market and consumer behavior can change significantly under stress situations. Such changes in behavior in stress typically affect correlations in ways that can be far different from the correlations used during normal times.

Systemic View: Financial System Analysis and Financial Contagion

The regulatory stress testing process described above focuses on the specific bank behavior under stress - the bank’s performance of capital ratios under stress. At any point in time during the multihorizon stress scenario, capital ratios are examined and compared to limits. Management actions, if allowed during the path of the multihorizon stress, take the form of remedial actions when limits are breached with an aim to improve the situation for the next horizon.

When central banks perform this stress testing exercise per bank using their macroeconomic stress testing models (or by rolling up banks’ stress test results), they also need to add another step in the analysis to capture systemic risks. Specifically, banks must account for the potential large losses or failure that can lead to negative contagion effects on other banks in the system. If a systemically important bank fails to pass the test, it can have consequences on other banks through
direct bilateral linkages - or more indirectly through financial system confidence effects. We refer to the European Central Bank macroeconomic stress testing framework for the systemic risks (2013) for an example of how central banks’ stress testing models that analyze the financial system as a whole include sophisticated financial network and contagion analysis models.

While regulators are increasingly using financial contagion models to analyze potential systemic risks in the banking system, it’s logical to expect that over time, banks themselves will be required to analyze potential contagion effects in their own portfolios. In addition, they will need to forecast how microeconomic events, not just general macroeconomic situations, can create initial losses and subsequent contagion effects within a specific bank. A classic liquidity risk example is a loss of trust in the bank due an event such as an operational loss, and how this loss of trust can evolve to the different providers of funds to the bank, resulting in a liquidity crunch.

The Future of Firmwide Stress Testing

Firmwide stress testing is certainly here to stay. Regulatory mandated, firmwide stress testing programs have also seen rapid expansion. The success of CCAR stress tests in the United States has inspired the development of the more recent stress tests by the EBA and other jurisdictions.

As discussed, the EBA and CCAR stress tests focus on macroeconomic scenarios that can affect a bank’s income statement (the profit and loss impact), as well as the subsequent balance sheet (the capital impact). When the regulatory stress scenario is hypothetical, models and/or expert judgment can be used to transfer stress. The use of models is critical to the materialization of the high-level macroeconomic scenario. Clearly, models are central to both firmwide stress testing and the traditional risk-based model charges.

The current focus of regulators on firmwide stress testing could be viewed as a trend toward replacing risk-based model charges with stress scenarios - and ultimately as a sign of distrust in models. The success of firmwide stress testing has also led to recommendations that risk-based model charges be replaced with stress testing charges. For example, on May 8, 2014, Federal Reserve Board Governor Daniel K. Tarullo spoke at the Federal Reserve Bank of Chicago Bank Structure Conference, arguing that the credit risk internal ratings-based approach is too complex, aids little in understanding the risks in the banks’ balance sheets, and is backward looking. His view is that the supervisory stress tests developed by the Federal Reserve in the United States provide a much better risk-sensitive basis for setting minimum capital requirements to define risk-based capital charges using supervisory stress scenarios.

In practice, focusing only on a regulatory stress scenario approach to capital charges may put too much burden on supervisors and banks to come up with the “right” scenarios that will help them anticipate future crisis events. To overcome the deficiencies of risk-based model charges, banks can complement model-based views with forward-looking stress events through the integration of stress and model analysis.

Even if regulators ultimately decide to abandon risk-based model charges for stress charges, the risk-based models will likely still play a vital role in the construction of banks’ own scenarios via reverse stress testing. The requirement that banks develop their own scenarios (focusing on what can hurt the bank significantly) is a necessary component of the stress testing process - especially if regulatory stress testing is to replace or downplay the importance of risk-based model charges. The fact that each bank’s unique risks need to be accounted for when developing their own scenarios puts greater pressure on regulators to understand the relevance of each bank’s scenarios.

Assessing and Managing Model Risk

In practice, the regulatory stress testing exercise has also developed into a test of the risk models used by banks. At the same time, it has increased regulatory scrutiny of the entire model life cycle – from model development to validation, implementation and governance. Both CCAR and EBA regulators have put a huge emphasis on model risk. In CCAR, the regulators view the stress testing process as a system of models and hence put emphasis on the need to measure model risk individually as well as across the network of models. Model sensitivity analysis is one of the tools to analyze the model impacts and to understand the models. Lack of adequate data, model insight and modeling expertise have proven to be major challenges for many banks to carry out effective firmwide stress testing.

Many banks have had firmwide risk models in place for years as part of their ICAAP process. However, these models focus mainly on the risk capacity and the firmwide risk exposure of the bank, rather than on putting limits on capital ratios under stress. More importantly, their ICAAP processes tend to be manual and involve simplified model approaches for assessing earnings and loss impacts; they are not part of a formal, risk-based planning process that includes both risk and finance. As a consequence, the new, mandated firmwide stress testing has
necessitated significant development of new firmwide risk models and firmwide risk processes. The resulting improvements in the firmwide stress testing have enabled banks to establish stronger, risk-based capital planning processes.

Conclusion

Firmwide stress testing is a complex yet important bank exercise. It requires a sound, single, end-to-end process that connects the macroeconomic scenarios, satellite models, the bank’s portfolio and valuations data and risk systems, and reporting systems. Regulators expect the process to be repeatable and sustainable.

Successfully completing the stress testing process involves both the bank’s risk experts (who are responsible for scenario and satellite model management and projecting the earnings, losses and capital under stress) and the bank’s finance experts. They must construct the projected income and balance sheet statements from the risk information, at a certain scenario horizon $t$, and financial information such as tax rates and current available capital. The capital ratios and losses are then compared to regulatory or internally set limits. Based on the performance of the bank in the scenario at a certain horizon $t$, management must identify the most suitable management actions.

Hopefully, banks will be inspired by the mandated CCAR and EBA firmwide stress testing and expand firmwide scenario analysis into a business practice for analyzing portfolio profitability under stress and using firmwide stress testing as a core component in forward looking, risk-based financial planning. As firmwide stress testing is more widely used for both regulation and business practice management, pressure will mount for a more formalized firmwide stress testing process with proper controls, overall management, transparency and auditability. For banks still operating their business units (and consequently their risk systems) in silos, adapting to support a more formalized, firmwide process will be a challenge. Banks respond by instituting central stress testing teams with an overall responsibility for the firmwide stress testing and capital planning processes.

References:


