Dynamically Stress Testing Financial Systems

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Abstract

Turmoil in financial markets revealed a need to advance analytical and monitoring frameworks at central and national banks, specifically in the area of a systemic risk. System Dynamics offers an innovative approach to assess financial sector performance and inform policy reform for global regulators by employing tools to diagnose the strength of the finance and banking system. Banking entities can examine the intersections and interactions between the banking system value chains, analyze the various economic subsystems that affect overall banking system stability, and model the complex system relationships through causal feedback loops and system flows. As a result system dynamic models assist banks in planning for emergency liquidity assistance by determining when the risk occurs and quantifying losses.

Introduction

As a result of the need for advanced analytics and monitoring at central and national banks, we were asked by the central bank of a middle-eastern country to build a custom system dynamics model (Forrester, 1991) (Sterman, 2000) that may be used as an early warning system. The ultimate goal was to enhance and provide clarity for a study concerning stabilizing and strengthening the country's banking system.

The Stress Test Analytical Framework (STAF) is a customized model that enables a Central Bank and its major stakeholders to stress specific metrics within the financial system and to analyze and assess the possible impacts it may have on individual banks or the system as a whole. The model provides a platform for analyzing the impacts of stress factors on the financial system when applied to the baseline data collected from individual banks, the central bank, and other official sources or regulatory agencies. STAF provides quantitative answers to challenging questions such as: If non-performing loans increase 25% which banks still have enough capital to operate? Or how will the failure of a bank impact the rest of the system?

While most risk factors may be applied individually to each bank, due to specific policy changes or prevention, the model also has the ability to stress macro-economic factors that affect the entire financial system. (Haldane & May, 2011) Additionally, the model included demands on the interbank market and contagion factors to further assess how one bank's risks may impact others within the system.

Model Description

The STAF model has the ability to simulate and stress up to fifteen banks all acting as part of the banking/financial system. It attempts to recreate the daily activities and key interactions within the banking system based on the variables set by the user. For example, the bank will fund new loans, buy and sell securities, generate revenue, incur expenses, gain new deposits, and borrow from the interbank market as needed on a daily basis. The user can change settings by bank and over time try to replicate plausible shocks that the banking sector could face. By understanding the flows of funds in and out and the regulations that govern the system, the model predicts the effects of any one change on all the interconnected system components and relationships.

The STAF model is organized by starting with a simplified version of a bank's balance sheet. (Low, 1977) This data will primarily come directly from the regulatory reports that banks submit to the Central Bank on a periodic basis.

Starting Values and Balance Sheet Components

The bank's asset portfolio will drive many of the revenue generating components of the model. The model tracks six main asset types that will generate interest and mature over time. All assets have an assigned risk weight that will be used for capital adequacy calculations. Assets are divided into the following categories:

- Highly Liquid Assets (Cash and Due from Central Bank)
- Domestic Interbank Loans and Placements
- Foreign Interbank Loans and Placements
- Investments and Securities
- Loans
- Other Assets (including fixed).

Within assets the user is able to further distinguish between six loan types and five investment types for additional detail and control within the simulation. In addition to investment types there are three classifications within the investment portfolio: Hold-to-Maturity, Available-for-Sale, and Trading.

Loan types include:

1. Real Estate and Construction
2. Household Sector
3. Equity Loans (both commercial and consumer)
4. Investment Companies
5. Other Loan Types
6. Ijarah Loans (Capital Leasing).

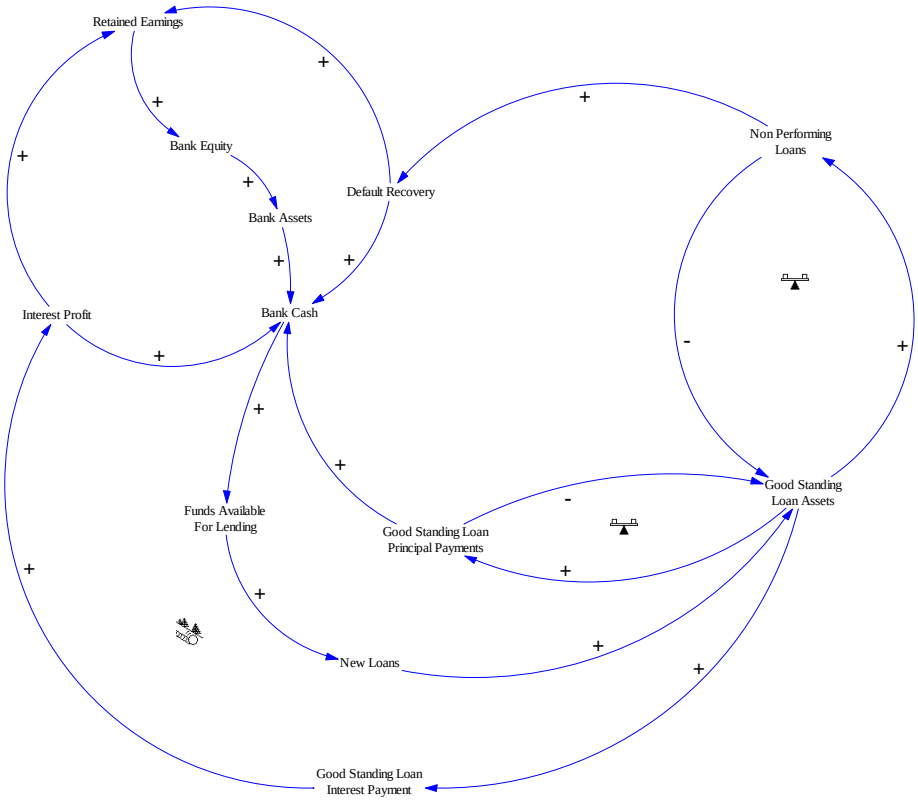

Figure 1: Loan Asset Causal Loop Diagram

Investment types include:

1. Government Securities
2. Non-Government Securities
3. Corporate Fixed Income Securities
4. Equity Investments
5. Real Estate Investments.

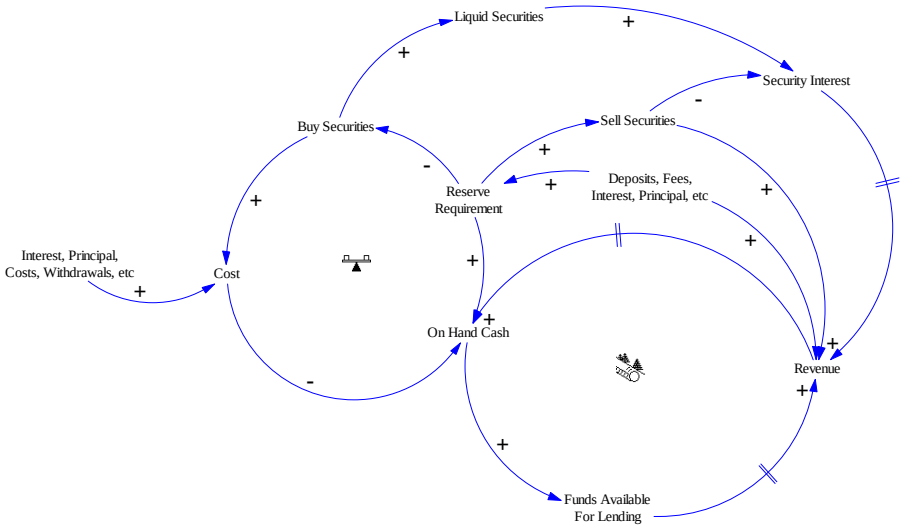

Figure 2: Securities and Investments Causal Loop Diagram

The bank's liabilities will drive many of the expenses that the banks face as a result of lending and investing. The model tracks liability types that incur interest expense and mature over time. Bank Liabilities consist of eight broad categories:

1. Central Bank Loans
2. Domestic Interbank Loans and Placements
3. Foreign Interbank Loans and Placements
4. Due to other Financial Institutions
5. Borrowing from the government
6. Demand Deposits
7. Time Deposits and Savings
8. Other Liabilities.

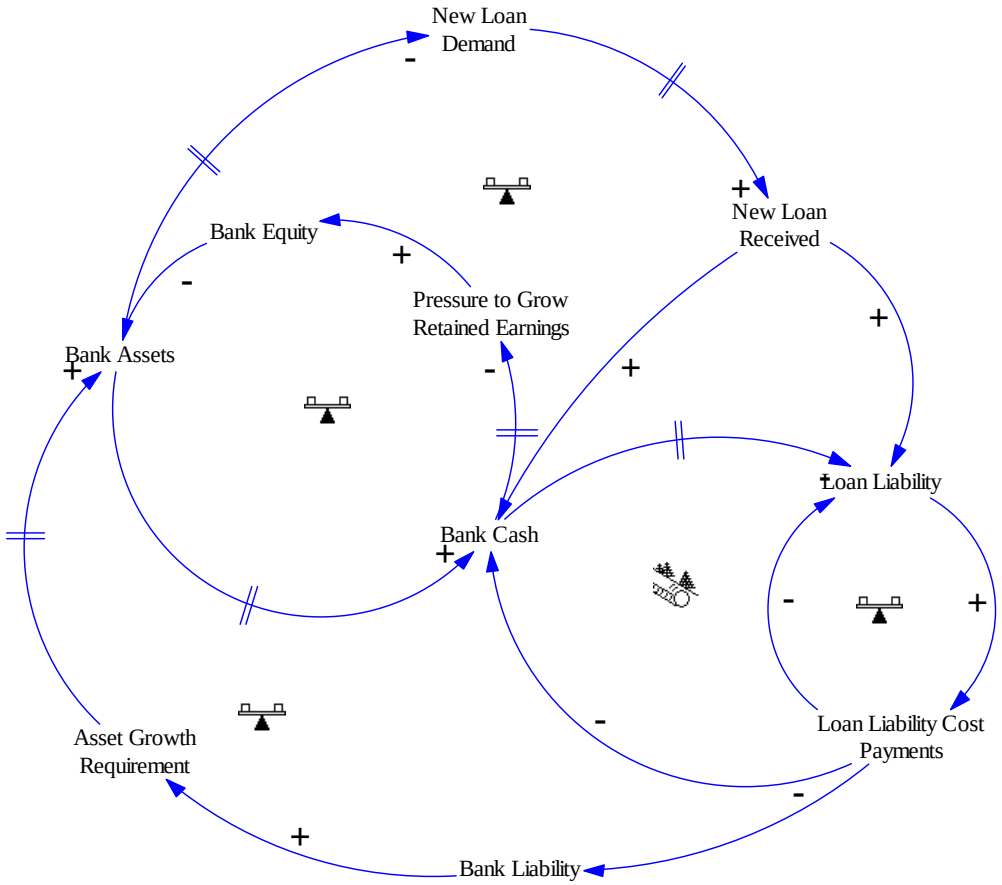

Figure 3: Loan Liability Causal Loop Diagram

Included with the model is an excel spreadsheet that will open and run in parallel to the model file when it is opened. Due to the extensive nature of control required by the client, the spreadsheet allows the user to individually define values for each asset and liability type at each quarterly interval over a three year period. This Excel spreadsheet stores the necessary model data and acts as an interface for the user to alter bank parameters associated with the stress test scenarios. The data input sheet is organized into 25 color coded tabs/sheets.

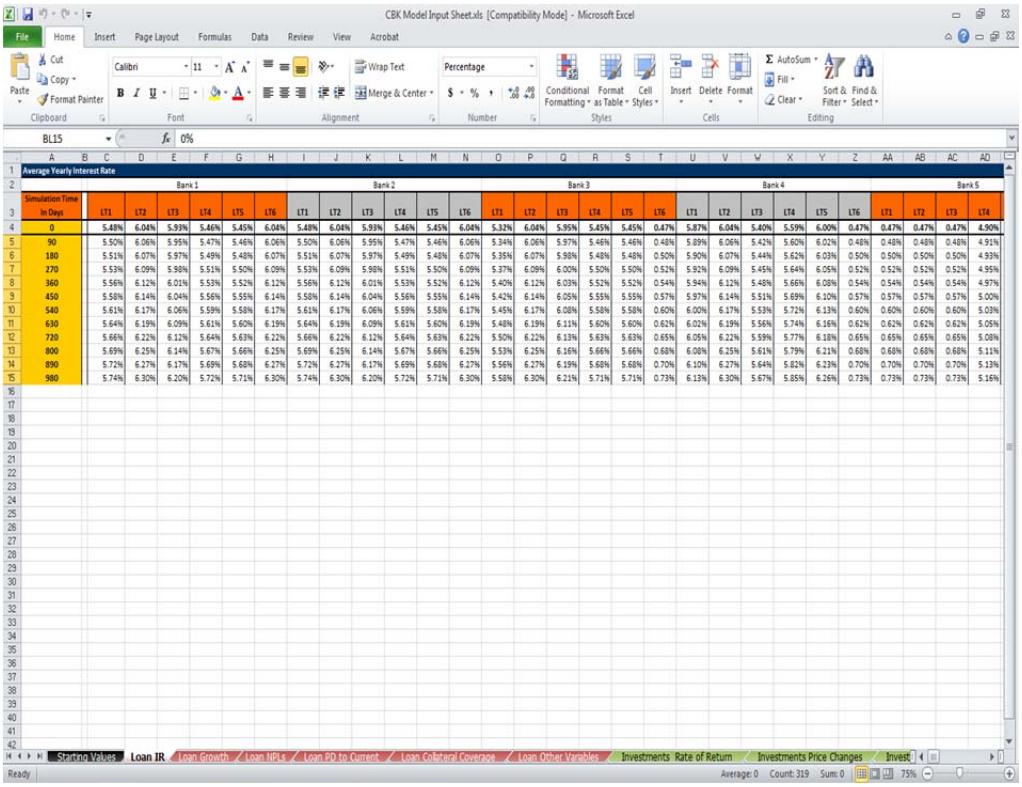

Figure 4: Model Input Sheet

The initial sheet contains all of the bank's starting values, including all of its assets, liabilities and equity, capital values, off balance sheet items, and any other pertinent categories. The next series of tabs encompass all of the loan user variables, including interest rates, loan growth, non-performing loans, past due to current rates, collateral coverage, and any other loan variables. Another set of tabs include the investment rate of return, price changes, credit loss, and all other investment variables. There also is a tab that contains the repayment window variables for all other asset types.

The interest rate, growth, withdrawals, bank runs, runoff percentage, run time span, and deposit flow controls and variables are included in the spreadsheet. Off Balance Sheet growth, collateral, and utilization are organized on following tabs. The next series of tabs governs derivative growth, expiration, pricing factors, credit events, percentages, recovery rates, and duration.

A special series of input tabs encompasses many of the risk weighted assets, provisions, regulatory, and interbank controls. Finally, the last two tabs manage the macroeconomic inputs and the regression equations defined by the client representatives. Regression analysis was used to develop formulas and methodologies for conducting macroeconomic stresses on the banking system. The variables developed allowed the user to either set the above variables independently using the spreadsheet described above or to override these entries based on the macroeconomic variable settings.

Figures 5 and 6 map out the macroeconomic variables and their relationship to other model variables within the model. The red numbered circles indicate a switch whereby the user may input the variables they chose or override those values based on the regression formulas that determine the macroeconomic relationships. For example, the bank may enter any "Real GDP Growth" values it wants using the spreadsheet control tabs or flip the switch and allow the "Real GDP Growth" to be determined by the input of the "Oil Price" into the regression formula.

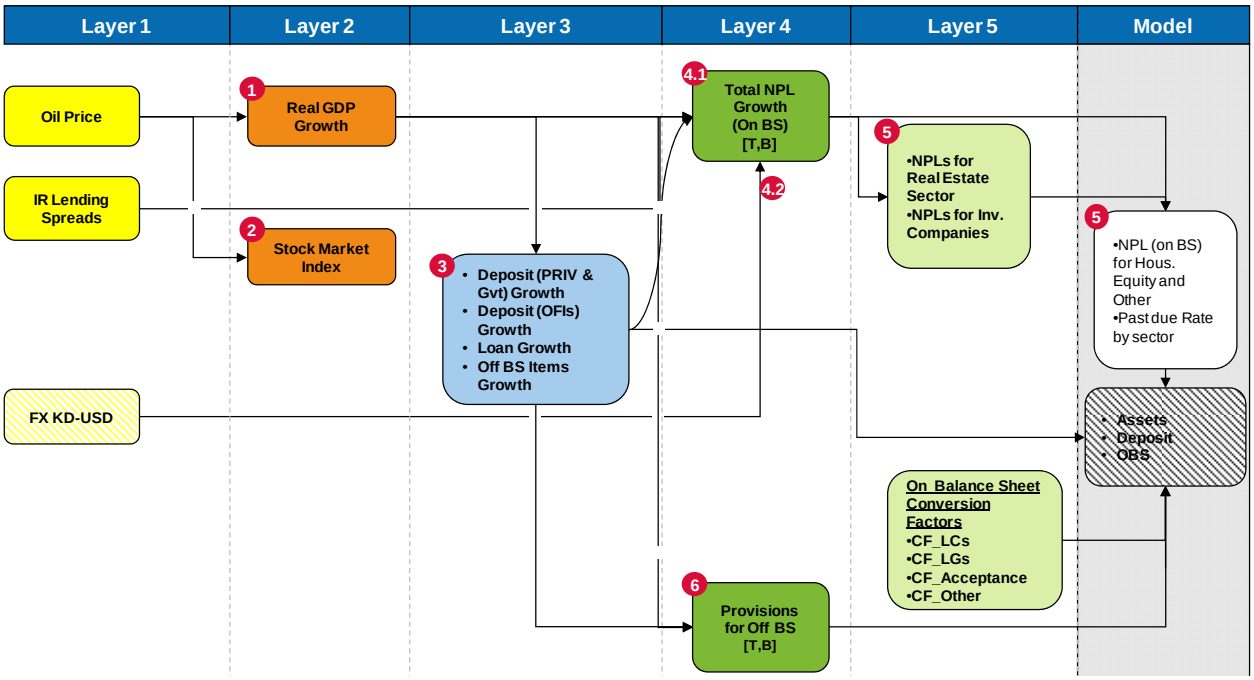

Figure 5: Macro Model Variables and Relationships

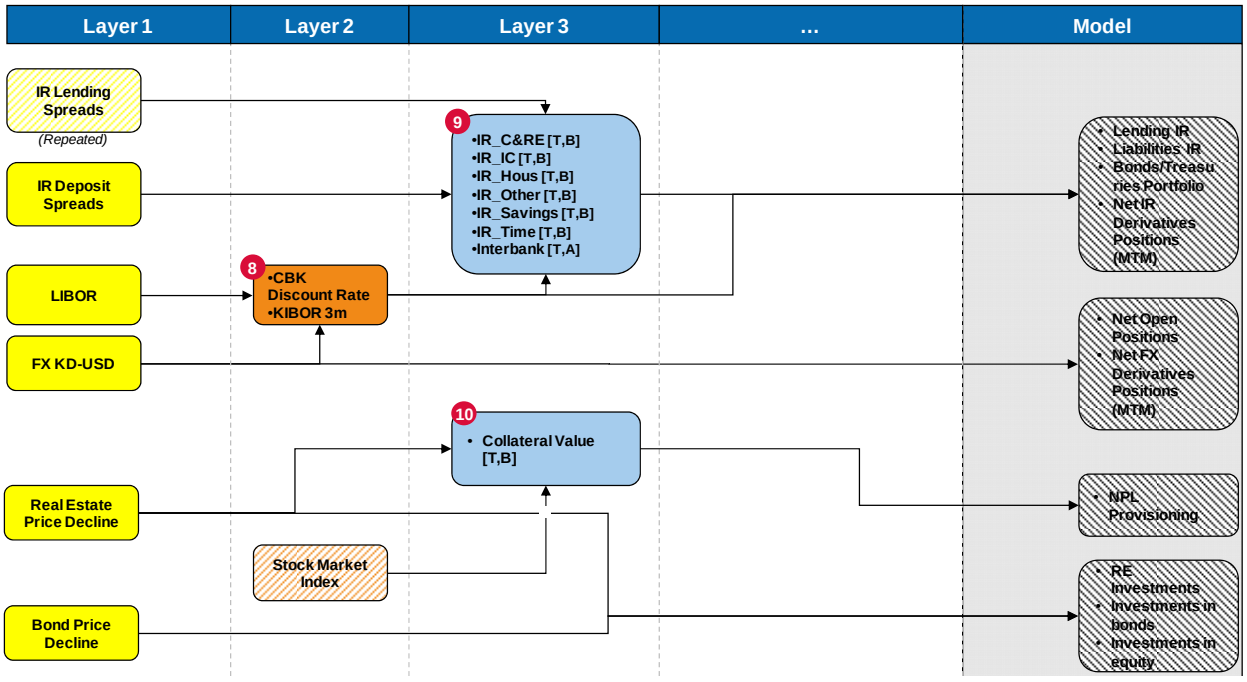

Figure 6: Macro Model Variables and Relationships (Continued)

The simulation can be run for any period of time, but is often used to represent a three year time span to permit analysis of policy and procedural changes over a meaningful time period. The simulation provides data output each day of the simulation period so you can understand subtle changes in systemic rules that would cause changes within a time increment, defined as days.

The STAF Model represents the current state of up to fifteen banks represented within the financial system. It allows you to simulate a policy change and assess how it impacts an individual bank or system performance. For example, you could create a scenario to simulate the effect of a shock to non-performing loan rates, investment price changes, utilization of off-balance sheet items, etc. By adjusting the variables at each stage of the system, you can see the consequences, if any, to all parts of the system that would be affected by the change.

The financial instruments as they impact the model are described at a high level below.

Table 1. Major Model Functions

	Description
Loans	This consists of good standing and nonperforming loans governed by past due, NPL, default, and nonperforming to performing rates as they age through the system.
Interbank Markets	This refers to domestic and foreign interbank lending governed by the demand of the banks within the system and the contagion effect.
Loan Loss Allowance	This consists of the provisions against non-payment or default of loans at various stages within the loan process.
Cash Process Flow	This relates to the cash the bank has on hand as it makes loans, buys and sells securities, funds the interbank market, handles derivatives and deposits, pays taxes, dividends, operating costs, and other factors that may affect the amount of cash on hand.
Securities and Investments	This refers to the AFS, trading, and held-to-maturity investments affected by price changes, credit events, and liquidity funding parameters.
Deposits	This consists of time and demand deposits, both governed by interest rates, withdrawals, and bank runs.
Off Balance Sheet Items	This consists of the items that are held until utilized, when they become good standing loans.
Derivatives	This consists of the hedging and trading derivatives as they are affected by 3 month foreign forward change rate, 3 month LIBOR, pricing factors, and credit events.
Liquidity	This consists of the prioritization of events the bank undergoes to maintain adequate levels of liquidity.
Loan Liability	This consists of the forms of debt banks may incur from the interbank market or the central bank.
Ratios and RWA	This consists of the calculation of Tier One and Tier Two Ratios and Risk weighted assets within the system.

Income Statement	This refers to the calculations including interest expense, revenue, and margin, operating income, gross profit, net income before and after tax, etc.
Equity	This refers to the effect of dividend, net income after tax, and ultimately the effect of retained earnings on a bank.
Macroeconomic Factors	This refers to a series of factors that may impact some or all of the above items directly or indirectly through regression equations or historical trends in the economy.

Analysis

The results of the analysis are not included in this report due to the sensitive nature of the information. This information was provided to the client only. A small selection of generic data and scenarios, however, were run to provide examples of the model output and capabilities.

The STAF Model allows the user to apply risk factors using a series of variables and demonstrate the impact to the banks in the system through both custom data and graphical formats. Below is an overview of the risk factors that the model will simulate:

- Credit Risk: Increases in Non-Performing Loans and Loan Defaults, Bond Defaults, Counterparty Risk (banking and trading), Collateral
- Interest Rate Risk: Net Interest Margin Compression / Profitability
- Market Risk: Market Risk for Bonds and Derivatives, Equity and Real Estate Prices, Foreign Exchange
- Liquidity Risk: Deposits, Interbank Funding, Government Sources
- Interbank/Contagion Risk: Bilateral exposures in the interbank market that would be distrusted as a result of a failure in the market
- Macroeconomic: Other external factors such as oil price or GDP.

While we determined these scenarios may be interpreted and modeled in a variety of ways, we modeled a market liquidity scenario as a loss in cash by shocking the bank with a significant decrease in incoming deposits. Our credit scenario represents increased difficulty to pay back loans by shocking the bank with an increase in non-performing loans. Figures 6-8 show the impact on specific bank metrics by comparing the baseline to the market liquidity and credit scenarios.

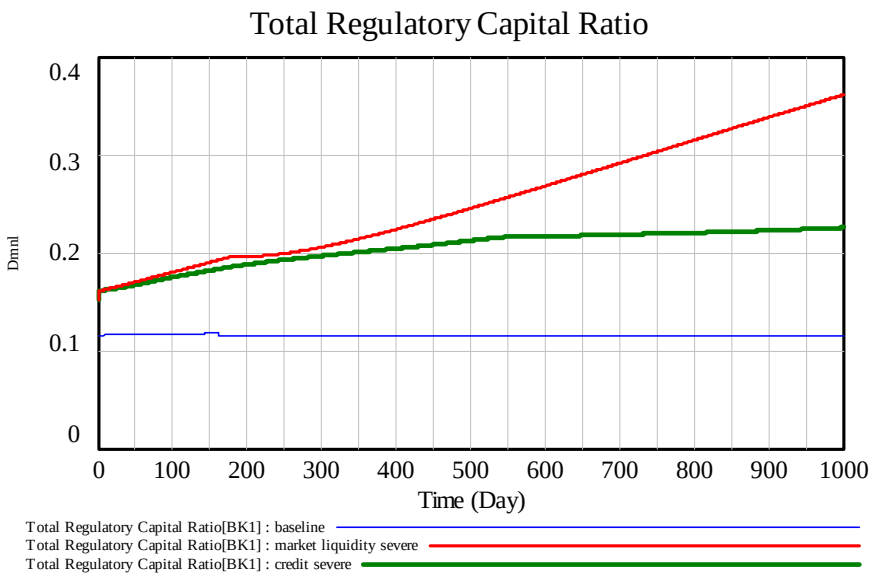

Figure 7: Total Regulatory Capital Ratio

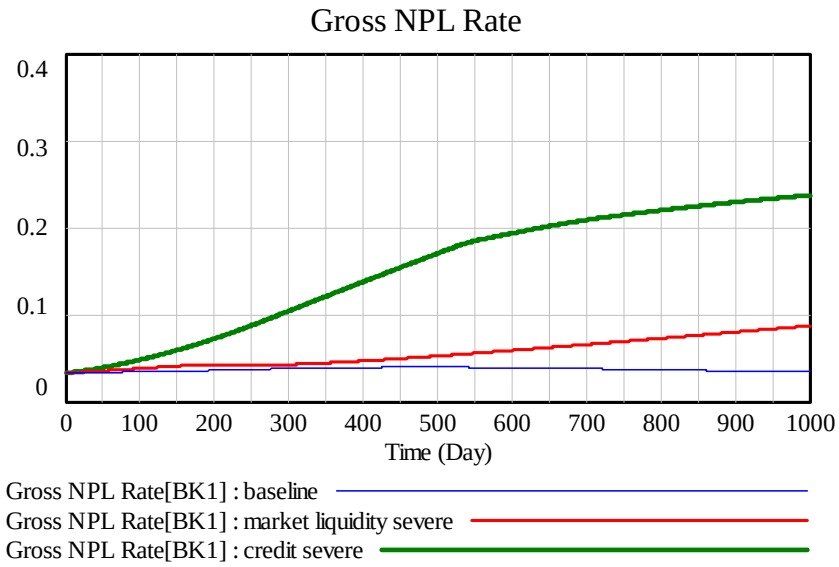

Figure 8: Gross Non-Performing Loan Rate

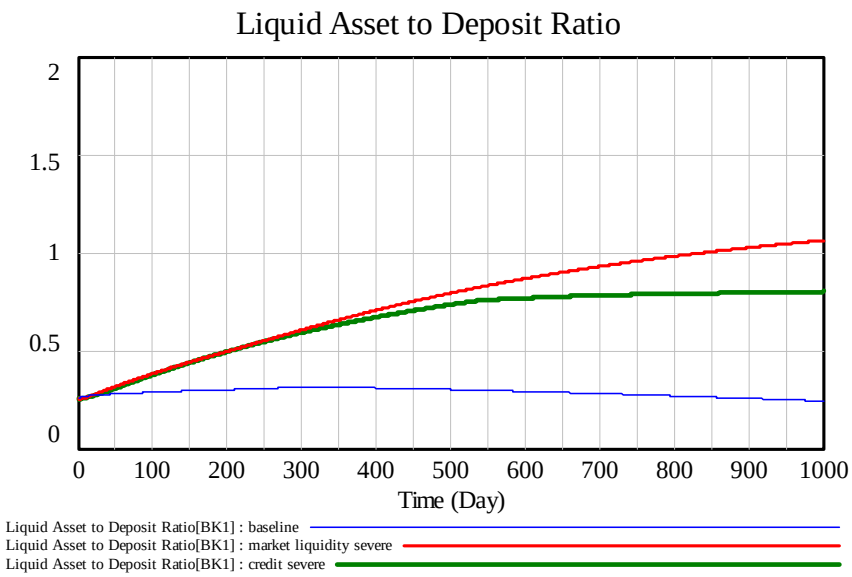

Figure 9: Liquid Asset to Deposit Ratio

To demonstrate the macroeconomic features of the model, we shocked GDP with a 5% reduction to the demand for oil by the top importing partners. The resulting shock to GDP and its established relationship to non-performing loans through regression formulas drove up the amount of non-performing loans and with it the Total Regulatory Capital Ratio as shown in Figure 9 and 10.

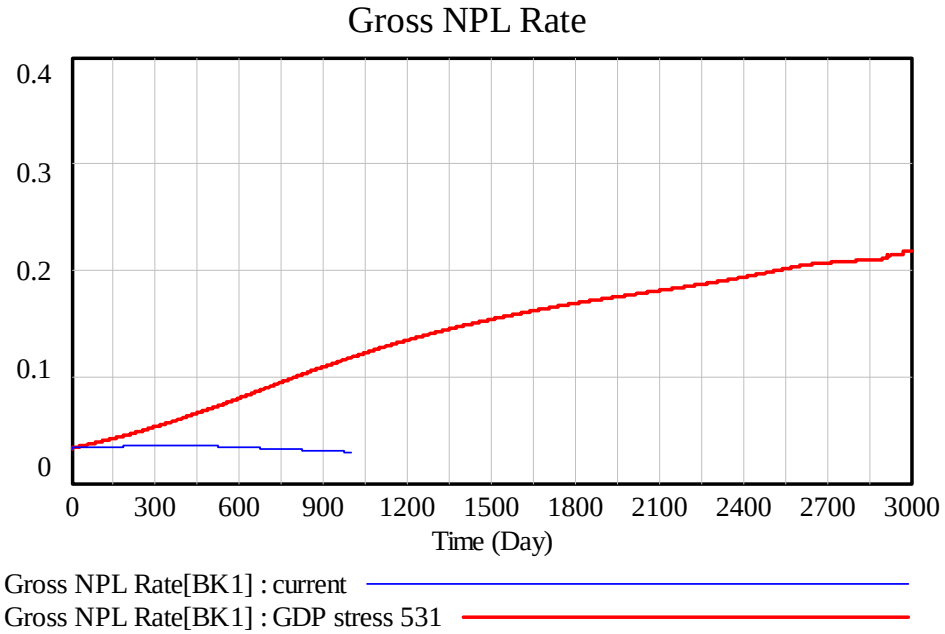

Figure 10: Gross Non-Performing Loan Rate attributed to macro-economic scenario

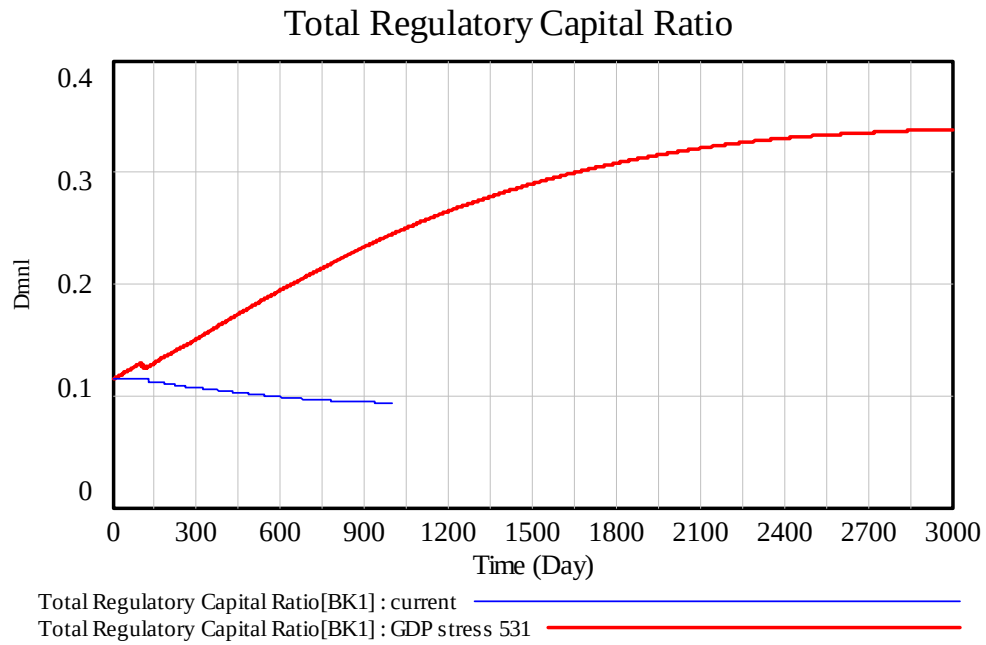

Figure 11: Total Regulatory Capital Ratio attributed to macro-economic scenario

To develop this scenario we experimented with applying the shock within the Oxford economic model (Oxford Economics Ltd, 2011) and using the resulting GDP data as inputs into the STAF system dynamics model. For the purposes of these examples we simply showed the results for a single bank. For analysis purposes any number of bank results may be shown for comparison if needed.

Conclusion

Central and National Banks, and World Bank Group entities that support them, can use similar models and methodologies either for a stand-alone project or as part of a longer-term implementation effort to help drive a financial sector reform strategy. The methodology can be tailored to serve as a platform for multiple purposes, from modeling and scenario analysis exercises, assisting in the development of long-term initiatives, improving the stability and resilience of the financial system and overall competitiveness of the economic system:

- Provides a framework and the tools required by risk practitioners and risk managers who need to integrate a forward-looking, multi-variant risk assessment into their operations and strategic decision making

- Produces advancements that allow for multiple stress testing issues to be handled, including multi-factor analyses, second-round effects, contagion impact and extreme, but plausible shocks

- Provides policy makers insight into regulatory regimes such as depositor protection, emergency liquidity assistance and prompt corrective action

- Provides justifiable and quantifiable insights into improvements to macro-prudential regulation and to improvements of procedures, policies and communications between various entities responsible for risk management

The STAF model was custom built for a Central Bank and reflects the background analysis done on that specific banking system with direct input from Central Bank staff. STAF is a management tool that can be used to create "what if" scenarios and examine the potential impacts of stress situations. The model has sophisticated methodology and captures thousands of variables in which to create and analyze stresses, however, the model is only as good as that input data that feeds it and the underlying assumptions that it was based on. STAF is not designed to predict every possible situation that could arise or model irrational economic behavior. However, the model provides the user a reliable management tool that can be utilized in the supervisory process. There are always improvements and enhancements that can be made over time as the Bank further refines it knowledge and uses of the model. Below is a summary of observations by the modeling team of areas in which future enhancements could be made.

- Stress testing data collection in a single /standard template. In order to obtain the information required to utilize all the functionalities within the model, data had to be collected from multiple sources and sometimes ad-hoc requests had to be made to a specific banking institution. Combining this information from multiple sources requires a manual process be used to get starting model values into the data input sheet.

- Increased Analysis and collection of data on macroeconomic factors and their impact on the banking system. Regression analysis was used to develop formulas and methodologies for conducting macroeconomic stresses on the banking system. In some cases, there was no ideal statistical sample size that could produce the best modeling results.

- Enhanced Analysis for certain model settings in which assumptions had to be made. Certain settings in the model required general assumptions to be made and more detailed data may be able to be collected from institutions in the future. Examples of these types of model variables include: Collateral Coverage Assumptions, Average Risk Weighted Assets by Category, Loss to Default or Loan Write off Rates, and Interbank Exposure for Contagion Risk.

- Additional adjustments to further differentiate between the operations of traditional and Islamic banks. There were adjustments made in the model to simulate the differences between Traditional and Islamic Banks within the system. Examples of these specific adjustments include profit distribution vs. Interest Expense (Islamic), the inclusion of capital leases (Islamic), and fixed revenue rates (Islamic) vs. floating interest rates (Traditional). Future enhancements could be included in the model to further refine and differentiate between these institutions.

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