Banking Event Modeling in Scenario-Oriented Stress Testing

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Abstract

The recent 2008 financial tsunami has made the financial regulators to realize the importance of stress testing in banking systems. One of the major challenges in stress testing is to model and calibrate "exceptional but plausible" scenarios in which macroeconomic shocks may cause contagious bank failures that may lead to the breakdown of a banking system. Presently, existingstress testing methods mainly focus on modeling single or multiple risk factors through a "static snapshot" of the banking systems. However, real-world bank crisis scenarios are much more dynamicsuch that different event occurrence sequences may have different impacts on individual banks and banking systems.For purposes of predicting contagious bank failures in stress testing, we propose the use of event-driven process chainsinmodelingbank failure scenarios. We refer to this approach as Banking Event-drivenScenario-oriented Stress Testing (or simply the BESST approach). We compare the pros and cons of the BESST approach with two existing approaches in an example scenario. In addition, we conducted a financial simulation based on this example scenario to demonstrate the validityof the BESST approach.

1. Introduction

The recent 2008 global financial tsunamihas been considered as the worst financial crisis since the Great Depression. It was triggered by the decline of U.S. housing prices and resulted in a liquidity shortfall in the U.S. banking system, pushing the banking system to the brink of a system-wide collapse. One of the major causes of this crisis is that the financial stakeholders, including the major banks and regulators, failed to model and calibrate the "exceptional but plausible" scenarios in bank stress testing in whichthe macroeconomicshocks may cause contagious bank failures and lead to the breakdown of a banking system(Hu, Zhao et al. 2010).

Such scenarios contain events of large magnitude and impacts on banking systems that are often very rare such as the bankruptcy of Lehman Brothers. Such high-impactand rare events that are beyond the realm of normal expectations are referred as "Black Swan" events (Taleb 2011). The rarity of such "Black Swan"events made it very difficult to model the bank stress testing scenarios

since most existing methods rely on historical financial data such as the Value at Risk measure (Jorion 1997).

Moreover, existing stress testing methods focusing on evaluating the vulnerability of the banking system to single risk factors, or just combining the analysis of multiple risk factors into a single estimation of the probability distribution of a bank's aggregate losses. However, real-world financial crisis scenarios are much more complex in which different occurrence sequences of the same set of macroeconomic shocks (events) may have quite different impacts on both individual banks and banking systems. For instance, injecting capitals to selected banks before a set of financial shocks and interbank transaction settlements may largelyprevent the breakdown of a banking system. However, injectingcapital to the same banksafter the shocks and settlementsmay have little effect. This is because thatthe shocks may already cause contagious bank failures through the network of interbank exposuresand affected far more banks than the selected injection banks. Therefore, a process-oriented perspective is needed to model the full dynamics both within and between banks in stress testing scenarios.

Third, constructing a stress testing scenarios requires modeling different types of risk events or factors such as market risk events and credit risk events. These events are often dependent on or correlated with each other. Current stress testing practices in a bank often requires inputs from different bank departments to model a complexscenario. Oftentimes there will be contradictions among the inputs from different departments. Assuming in a stress testing scenario, a bank's credit risk manager designs an event that U.S.Federal Reserve Committee has cutthe interest rate by 0.5%. In the same scenario, the exchange rate risk manager may design a following event that the U.S. dollar rose against other major currencies. However, in reality, the decreasing U.S. interest rate will actually drive the funds away from U.S. dollar and cause it devaluates. To address this problem, we need to develop a modeling approach that can automatically analyze and detect such inconsistencies in stress scenarios.

To address these three major challenges in modeling bank stress testing scenarios, we developed a process-driven modeling approach based event-driven process chains, which has been used to model business process. This approach provides banking stakeholders (i.e., bankers and regulators) an effective tool in modeling "exceptional but plausible" scenarios in banking systems, as well as evaluating the effectiveness of possible risk mitigation strategies.Moreover, to the best of our knowledge, our research is the first to study how to effectively model bank stress testing scenarios from a technological perspective.

2. Macro Stress Testing Methodologies

Sorge and Virolainen(2006) have reviewed current macro stress testing methodologies in finance literature. They proposed a schematic classification(Table 1)of existing stress testing approaches, mainly including two types: 1) the piecewise approach, and 2) the integrated approach. The "piecewise approach" mainly focuses on modeling banks'vulnerabilities to single risk factors by forecasting several financial indicators such as capital asset ratio and exposure to exchange rate risks under different economic environment. The "integrated approach" takes a further step to integrate the analysis of banks'vulnerabilities to multiple risk factors into a single estimate of the

probability distribution of banks'losses under a stress scenario.

Table 1 – Existing Macro Stress-Testing Methodologies in Finance

	Piecewise Approach	Integrated Approach
Main Modeling Approach	• Models a scenario as a set of macro fundamental variables • Linear functional forms	• Combining analysis of multiple risk factors into a single distribution • Macro-econometric risk models
Pros	• Simple and intuitive models • Low computational costs	• Integrating market and credit risks • Models nonlinear effects of macro shocks on credit risk
Cons	• Lack of empirical proofs for the validity of the linear relationships • No feedback effects	• Non-additivity of VaR measures across institutions • No feedback effects

The piecewise approach mainly focuses on modeling the direct relationships between macro fundamental variables (independent variables) and certain financial risk indicators (dependent variables) (e.g., capital adequacy ratio and return on equity). The estimated coefficients are used to simulate the impacts of possible adverse economic scenarios on the banks' financial risk indicators. Thus, the piecewise approach actually models an individual stress scenario as a combination of a specific set of macro fundamental variables. For instance, Kalirai and Scheicher(2002)models the aggregate loan loss provisions in the Austrian bankingsystem as a function of set of macroeconomic variables which include general economic indicators such as GDP, CPI inflation, and income, consumption and investment in the household and corporate sectors. Hoggarthet al.(2004) focused on the relationship between banks'loan write-offs and the UK output gap, retail and house price inflation, and the nominal short-term interest rate. Moreover, Saurina and Delgado (2004) studied the relationship between loan lossprovisions and a set of macroeconomic indicators which includes unemployment rate, interest rates and indebtedness. This piecewise approach is very intuitive and its computational cost is usually low since these models are often in linear functional forms.

The integrated approachdiffers from the piecewise approach mainly from two perspectives: 1) it focuses on integrating the analysis of banks' market and credit risk factors rather than several single financial risk indicators; 2) it enables researchers to model the relationships between the macroeconomic factors, as opposed to just modeling the direct linear relationship between the financial risk indicators and the macroeconomic factors. In this way, the integrated approach allows the risk managers to model and analyze non-linear relationships betweenmacroeconomic shocks and possible bank losses.

However, both piecewise and integrated approaches are limited in terms of their fundamental assumptions. First, both approachesassumed that all risk events (e.g., changes in macro fundamental variables) will not change during the course of study. But in reality the banks often response to various economical events to reduce its market and credit risk exposures. Thus these two approaches lack the ability to model such "dynamic" behavior responses and the impacts of such responses to other banks in the banking system.

Second, it was assumed that different occurrence sequences of risk events have the same effects on banks' liquidity status. As mentioned earlier in the introduction section, this assumption may

underestimate the "domino" effects of interbank exposures on contagious bank failures (i.e.,the network of interbank obligations may enable the default of one bank to have contagion effects on other banks, thereby causing more banks to be insolvent).

3. A Process-oriented Approach for Stress Testing Scenario Modeling

To address the two above limitations of the existing stress testing methodologies, we developed process-oriented approach can effectively model both the event occurrence sequences and the interbank exposures in stress testing scenarios. More specifically, we adopted event-driven process chain (EPC) as the main modeling tool to model stress testing scenarios. EPC is a type of flowchart and widely used for modeling business processes (van der Aalst 1999). It mainly consists of three types of elements: events, functions, and logical connectors. A function is a process step which needs to be executed and are linked by events. An event describes the situation before or after a function is executed. The logical connectors such as XOR node can be used to connect events and functions, thereby specifying the control flow.Existing EPC modeling paradigms is good at modelingactivity sequencingwhich made it suitable to model the occurrence sequences of risk events in stress testing scenarios.

Thus we adopt the event-driven process chainsproposed into formally represent of risk event processes in stress testing scenarios. In this research, the event node is used to represent variouseconomic risk events (e.g., U.S. Fed cut interest rate). The function node is used to represent various information processing activities (e.g., calculating a bank's losses). In addition, there are mainly three kinds of logical connector nodes, AND, OR and XOR node.

3.1Modeling a Bank Stress Testing Scenario

In this section, we model a typical bank stress testing scenariofrom a single bank *i*'s perspectiveusing all three aforementioned approaches includingBESST, aiming to demonstrate the advantages of the BESST approach in modeling event sequences and "contagion" effects.

Fig.1. A typical stress testing scenario for banking systems

We first describe the events of this stress testing scenario as Figure 1 shows.(A) There is one or more adverse economic shocks happened such as the burst of housing bubbles. These shock(s) caused drastic changes in major fundamental economic indicators such as increasing national interest rate, foreclosures, anddecliningstock marketindices.

(B) From an individual bank *i*'s perspective, the negative impacts of these shocks may causeone or more *i*'s counterparty banks (i.e., banks that have payment obligations to *i*) to suffer great losses and thereby default their obligations to *i*.

(C) Meanwhile, the declining housing prices also cause great losses in *i*'s investment portfolio on mortgage backed securities. Together with credit risks, this type of market-related risk will reduce *i*'sability to pay its obligations to others (Event D).

If the loss is greater than *i*'s capital reserve, *i* will be not able to honor its obligations to other banks (Event F). Then*i*'s survival depends on if the central bank will inject capital to it. If the central bank thinks *i*'s default will significantly contribute to contagious bank failures in the banking system, it may inject capital to *i* to prevent a system-wide meltdown (Event E).

3.2Comparingthe BESSTApproach with Piecewise and Integrated Approaches

3.2.1. Piecewise approach

To model the above scenario, the piecewise approach will analyze the market (Event A->B) and credit risk (Event A->C)separately. As reviewed in Sorge and Virolainen(2006), This approach can be represented as $E(\widetilde{Y}_{i,t+1} / \widetilde{X}_{t+1} \geq \overline{X}) = f\{X^t\}$, where for bank *i*'s expected loan loss (investment portfolio loss) Y at time t+1 is estimated as a linear function of past realizations of a vector X of macroeconomicvariables(e.g., interest rates).

3.2.2. Integrated approach

On the other hand, the integrated approach will focus on analyzing both types of risks (Event A->B,C) by incorporating the selected macro fundamental variables into value at risk (VaR) measures as follows: $VaR_{i,t}(\widetilde{Y}_{i,t+1} / \widetilde{X}_{t+1} \geq \overline{X}) = f\{E_{i,t}(X_t); P_t(X_t); PD_t(X_t)LGD_t(X_t); \Sigma_t(X_t)\}$.

The VaR measure for the portfolio of the banking system is represented by a vector E of both credit exposures andmarket positions at time t,and is calculated as a vector of security prices P, bank default probabilities PD, lossgiven default LGD and a matrix of default volatilities and correlations Σ . All these parameters are functions of the vector of macroeconomic variables X.

3.2.3. Event-driven Process Chains

Both piecewise and integrated approaches only focuses on modeling "static" and isolated events but failed to capture the dynamic processes in the scenario described in Section 3.1. For instance, after the initial economic shocks, if bank *i* fails to pay its debt obligation(s) to its counterparty banks, such failures may cause contagious bank failures through domino effects. But both modeling approaches fail to capture such transaction level risk events and the event occurrence sequences, which largely determine if contagious bank failures will happen.

The BESST approachprovides a process perspective on modeling such dynamic event

processesas shown in Figure 2.Unlike the other two approaches, the EPC models three different event processes depending on i's losses in the stress scenario. The event chain (A->(B,C)->E)indicates that bank i's failure may cause contagious bank failures. Following Eisenberg and Noe(2001),i's payment ability can be calculated as a payment clearing vector:

$$p_{i,t}^{*} = \begin{cases} d_{i,t} & if & \sum_{j=1}^{N} l_{ji,t} + e_{i,t} - Y_{i,t} \geq d_{i,t} \\ \sum_{j=1}^{N} l_{ji,t} p + e_{i,t} - Y_{i,t} & if & d_{i,t} > \sum_{j=1}^{N} l_{ji,t} + e_{i,t} - Y_{i,t} \geq 0 \\ 0 & if & \sum_{j=1}^{N} l_{ji,t} + e_{i,t} - Y_{i,t} < 0 \end{cases}$$

where $\sum_{j=1}^{N} l_{ji,t}$ represents all the payment obligations i receives from its counterparty banksat time t. $d_{it}$is the total amount of i's obligations to others, while$e_{it}$is i's capital reserve. $Y_{it}$is$i$'s estimated loss due to the economic shocks. Then Equation (3) can be used to assess the stability of the banking systems through calculating each bank's payment clearing vector at time t.

In addition, we conducted a financial simulation based on this example scenario to demonstrate the usefulness of the BESST approach.This simulation study mainly consists of three steps. First, we extract bank financial information from U.S. FDIC banking regulatory reports and the Federal Reserve Wire Network (Fedwire). Second, weuse the BESST approach to model theabove example scenario as Figure 1 shows. Third, we then use the extracted real-world bank data as the scenario settings and simulate the modeled financial shock events, aiming to estimate the vulnerability of the banking system to financial shocks.
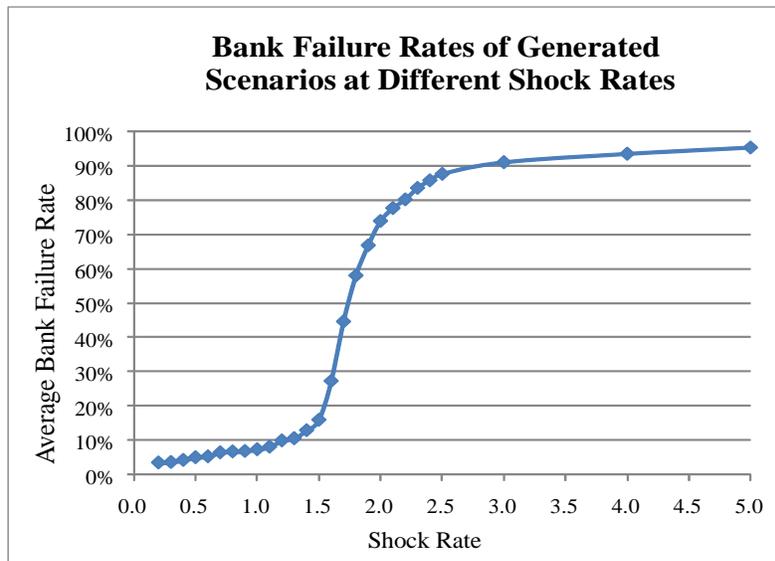

Figure.2. Bank Failure Rates in the ModeledScenarioswith Different Shock Rates

The simulation results in Figure 2 shows the bank failure rates (i.e., the percentage of the defaulted banks in the banking system) after the occurrences events (A->(B,C)->F). The shock rate β represents the magnitude to the simulated adverse economic shocks. When $\beta$is relatively low (0.1 to 1.4), the average bank failure rateγ are relatively low, ranging from 2.9% to 12.8%. Starting at $\beta = 1.5$, γ began to increase dramatically. When β reaches 2.0, more than 70% of the

banks failed, indicating a system-wide collapse of the banking system.

These results show that in the modeled scenarios, the banking system may sustain relatively mild shocks ($0 < \beta \leq 1.4$). However, when the shock rate exceeds a threshold value ($\beta \geq 1.5$), the bank failure rate starts to increase drastically, causing the collapse of the banking system. When $\beta \geq 2.0$, the effects of the shocks become marginal since most banks already failed.

4. Conclusions

We claimthat our Banking Event-driven Scenario-oriented Stress Testing (BESST) approachoffers three advantages inmodeling stress testing scenarios. First, it introduces a process perspective thatallows risk managers to model risk event processes, rather than just modeling a "static" snapshot of the banking system inthe two conventional approaches (so called piecewise and integrated approaches).The BESSTapproach alsoenablesrisk managers to model sequential interactions among risk events such as contagious bank failures. Moreover, event-driven process chains can be mapped to Petri nets thathave formal semantics and provide a wide range of analytical techniques(van der Aalst 1999). This feature allows risk managers to check the correctness and consistencies of given stress testing scenarios.

In summary, this paper presents a novel event modeling approach forscenario-oriented stress testing in banks that have both practical importance and academic value in the area of bank risk management, demonstrated through a simple yet realistic case.Our next step is to further validate the modeling framework and apply it in a banking environment. Specifically, we will use the BESST approach with the extracted real-world bank data to model more complex stress scenarios which include events such as capital injections.The simulation technique beneath the BESST approachcan be used to evaluate the effectiveness of bank risk mitigation strategies.

Acknowledgement

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