Stress Testing Financial Systems: A Macro Perspective

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ABSTRACT

The recent financial crisis has perpetuated the need for a greater emphasis on stress testing the financial system. A greater level of preparedness is required on the part of institutions that form a part of this system. This makes the task of analyzing stress testing at the macro level an interesting exercise. This paper has three objectives. First, it provides an overview of macro stress testing. This section deals with issues of scope, design, specification and aggregation. Second, it focuses on two main methodologies used for stress testing analysis- the piecewise and integrated approach. While the former focuses on evaluating vulnerability to single risk factors, the latter combines the sensitivity to multiple risk factors into a single estimate of expected losses. Finally, it looks at the methodological challenges of inter-bank linkages, feedback effects and endogenous parameter instability etc.

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INTRODUCTION

In recent years the world has been through a series of dramatic changes. Financial systems have become more complex and diverse, and this has led to a corresponding increase in the risk management techniques in place by financial institutions and their regulators. The continuous evolution of risk management systems is also attributed to the economic crises that are witnessed time and again. Stress- testing as a risk management tool gained prominence after the East-Asian debacle and is now propagated as a widely accepted mechanism to identify potential vulnerabilities to the system. It was a major component of the Financial Sector Assessment Program (FSAPs) launched by the IMF and World Bank in the late 1990's.

However, till date its use and applicability by individual institutions is very restricted. Here is a case in point. Consider the following scenario adapted from an IMF Working paper by Jones, Hilbers and Slack (2004):

There is an increase in housing prices because of rapid employment growth, rising household disposable incomes, and low interest rates- all of which contribute to a spiral increase in mortgage lending. Bank balance sheets and income statements indicate a strong dependence on mortgage lending in both the stock of assets and in the flow of income. Suppose now that we see a rise in unemployment and a fall in disposable incomes, as is the case in the current financial crises. A stress test for bank balance sheets could help assess the possible impact for these institutions.

If rational stress management systems and proper implementation of their results had been in place, the losses due to the current crises would have been far less, as institutions would have stepped up their capital adequacy requirements. Therefore, there is an urgent need to lay greater emphasis on stress testing, especially at the macro level to assess possible losses and take suitable action before hand.

The purpose of stress testing is not to identify when will the next crisis happen, but to estimate the impact of extreme but plausible shocks on the financial system. Individual banks use stress tests to make risks more transparent for capital allocation decisions,

while central banks use them to ensure that monetary policies meet objectives of price stability, exchange stability, full employment, maximum output and high rate of growth.

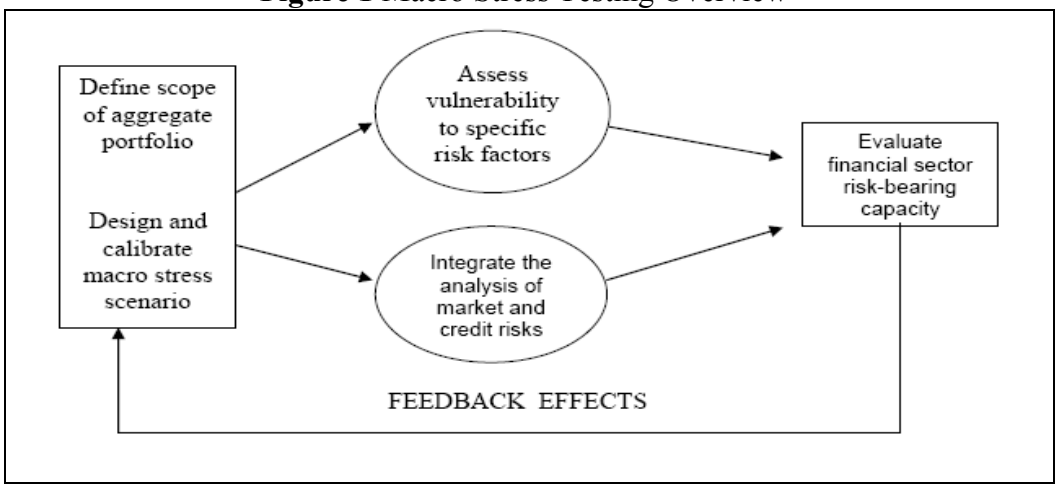
The paper is divided into three broad sections. Section I provides an overview of macro stress testing. This encompasses issues of scope, design and calibration of a macro stress scenario, assessment of vulnerability to specific risk factors, integration of market and credit risks and feedback effects. Section II deals with two broad approaches to macro stress testing: the 'piece-wise' and 'integrated' approach. The two approaches have been exemplified with the help of existing literature on the subject. Section III explains the methodological challenges faced by regulators and financial institutions, addressing which will help make their results more comprehensive and robust. Finally, Section IV concludes the paper.

1. OVERVIEW OF MACRO- STRESS TESTING

As illustrated in the BIS Working Paper by Marco Sorge (2004) macro stress tests can be performed in a number of stages including:

- Defining the scope of the analysis in terms of the relevant set of institutions and portfolios
- Designing and calibrating a macroeconomic stress scenario
- Quantifying the direct impact of the stimulated scenario on the balance sheet of the financial sector, either focusing on forecasting single financial soundness indicators (FSIs) under stress or integrating the analysis of market and credit risks into a single estimate of the probability distribution of aggregate losses that could materialize in the stimulated stress scenario
- Interpreting results to evaluate the overall risk bearing capacity of the financial system
- Accounting for potential feedback effects both within the financial system and from the financial sector on to the real economy

Figure 1 Macro Stress Testing Overview



Source: BIS Working Papers No 165, Marco Sorge (2004)

Sorge says that the possible consequences for financial stability of a macroeconomic stress scenario can be evaluated as follows:

$$\Omega\left(\tilde{Y}_{t+1} / \tilde{X}_{t+1} \geq \bar{X}\right) = f\{X^t, Z^t\}$$

where:

- $\tilde{Y}_{t+1}/\tilde{X}_{t+1} \geq \bar{X}$ indicates the uncertain future realization of an aggregate measure of distress for the financial system in the event of a simulated stress scenario (i.e. conditional on a tail realization).
- Ω is the risk metric used to compare financial system vulnerability across portfolios and scenarios.
- f(.) is the loss function that maps an initial set of macroeconomic shocks to the final impact measured on the aggregate portfolio of the financial sector. This function includes risk exposures, default probabilities correlations, feed back effects etc.
- X represents the history of past realizations of macroeconomic variables and Z represents the other relevant factors.

1.1 Scope

The most important question here is to identify the set of relevant financial institutions for stress testing analysis. From a stability point of view, the analysis can be restricted to the major banks if non-bank financial institutions (eg: insurance companies, pension funds) do not present a systemic threat to the operation of the financial system. As Jones, Hilbert and Slack (2004) note, ' The coverage of the stress testing exercise should be broad enough to represent a meaningful critical mass of the financial system, while keeping the number of institutions covered at a feasible level'. They propose the set up of a cut off point in terms of the total market share of institutions involved. If they are significant inter-linkages between the bank and non-bank financial entities then excluding the non-bank entities from the analysis would forbid us from identifying several potential vulnerabilities to the system.

Other key questions in this domain relate to which specific asset classes in a financial institution should be used? Should institutions of foreign ownership be taken into account? There may be countries in which foreign owned institutions transmit and absorb shocks depending on the parent company's health. For instance, the LTCM collapse affected prominent institutions in countries like Italy, Kuwait, Hong Kong, Taiwan and Singapore.

Another dilemma exists with respect to risk exposure. Should it be measured both in the trading and the banking books? Moreover, the portfolios of institutions are in continuous evolution over time according to changing hedging and investment strategies. This makes the task of quantifying risk exposure even more difficult. Identifying the relevant portfolio becomes a problem due to data constraints. The book on Financial Sector Assessment by IMF and World Bank (2005) lists four forms of data limitations:

- Basic data availability: This is true of countries where information on balance sheet exposures may not be available.
- Difficulty isolating specific exposures: This is mainly a problem of large institutions with complex structures.
- Lack of risk data: Countries where risk management systems are less sophisticated may have little data on duration or default measures etc.
- Confidentiality issues: These arise due to limitations on what supervisors are legally able to share with other parties.

Because of these constraints, much of the existing literature has focused on constructing hypothetical portfolios whose composition mimics distribution of assets and risk exposures in a system.

1.2 Design and Calibration of Stress Scenario

Firstly, the most important question to answer in this context is the choice of type of risks to analyse. The most widely used ones are:

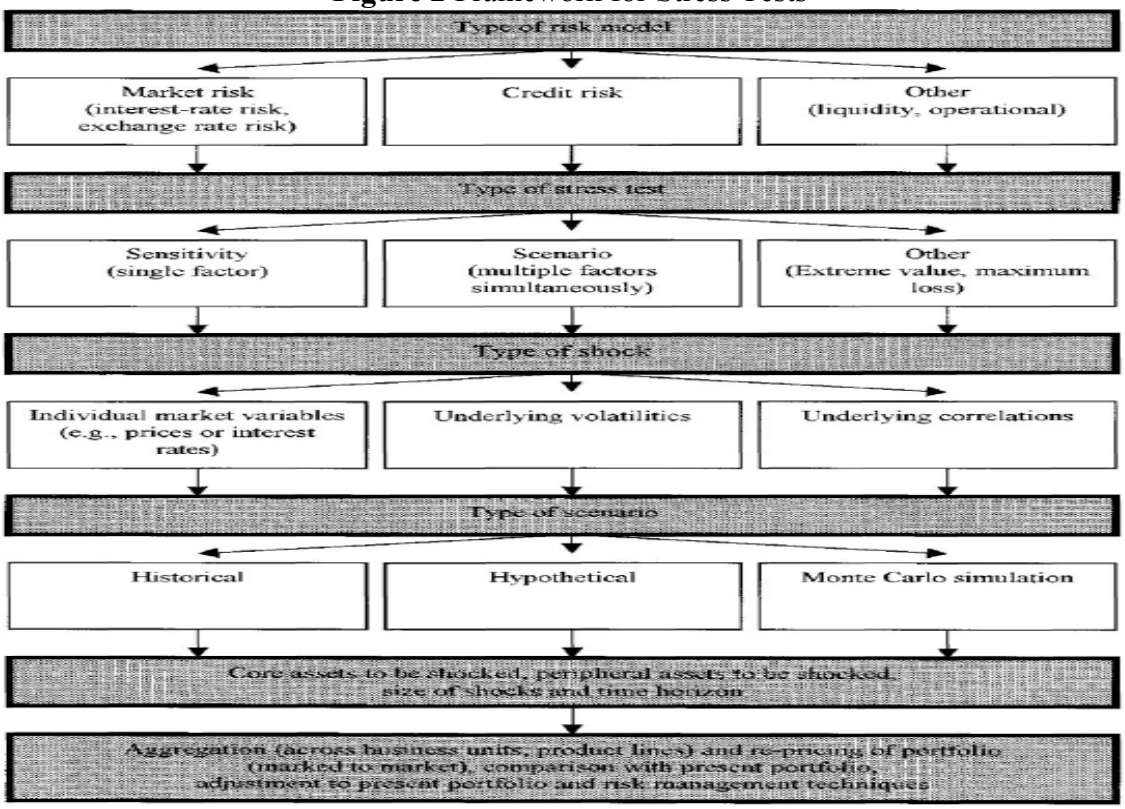
- Market Risk: It is defined as the risk of losses on a portfolio arising from movements in market prices[1]. The four standard market risk factors are-
    1. Interest Rate risk
    2. Exchange rate risk
    3. Equity Risk
    4. Commodity Risk

[1] As defined by the Basel Committee on Banking Supervision (1996)

- Credit Risk: It is the risk of loss associated with debtor's default of a loan or any other lines of credit like principal or interest or both.
- Other forms of Risk: There are some other important forms of risk like-
    1. Liquidity Risk is of two forms- asset and funding liquidity. Asset risk arises due to inability to carry out an asset transaction because of the huge amount involved. Funding liquidity arises because of paucity of funds to meet debt commitments.
    2. Operational Risk is the risk associated with a business entity's operations.

Secondly, a decision needs to be made about the type of stress test to use. Those tests that involve evaluating the impact of a change in a single risk factor are called simple sensitivity tests. In contrast, the scenario analysis evaluates the impact of multiple risk factors such as equity prices, foreign exchange rates and interest rates simultaneously.

Figure 2 Framework for Stress Tests



Source: Blaschke et al, IMF Working Paper (2001)

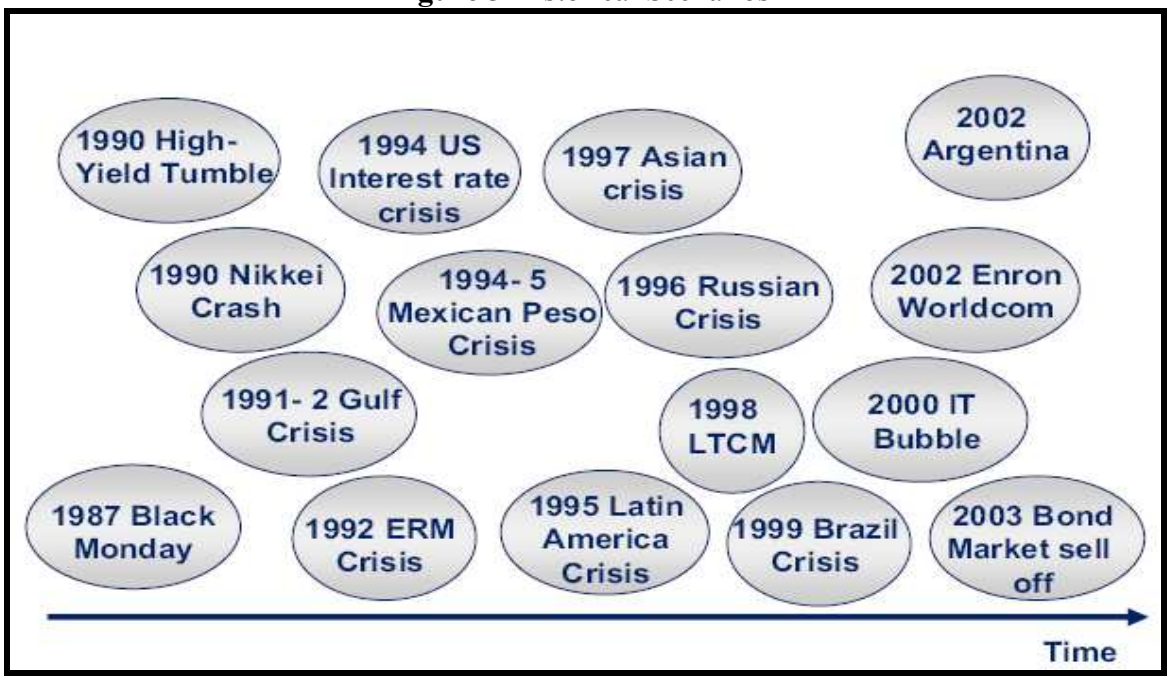
Mr. Faidon Kalfaoglou[2] from Bank of Greece discussed these tests at a stress management seminar in Egypt. He claimed that the scenario analysis technique is more demanding in terms of application, requires the use of sophisticated econometric models, and is hence limited to sophisticated institutions. Sensitivity analysis is not as realistic as the scenario analysis because in times of shock, almost surely, more than one risk factor is affected. Therefore, it is mostly useful for analysis over a short time horizon. But despite its shortcomings, Kalfaoglou says, the sensitivity tests reflect the subjective views of risk managers about the expected changes in risk factors and are used as a first indicator of the influence of the change in a certain variable on the bank.

Thirdly, the parameters to be shocked are decided. Stress tests can be designed to encompass both movements in individual factors such as prices, interest rates etc. or study the changes in the underlying relationships between different asset markets represented by their respective correlations or volatilities.

Fourthly, the type of scenario used to conduct the stress tests is critical to our analysis. The historical scenario approach is based on past realizations, using shocks that occurred in the past as a benchmark for future analysis. For instance, we could analyze the impact of an increase in the history based stressed probability of default on the macro fundamentals. We could also use a replication of a historical break down of correlation between parameters of interest or a failure of hedging techniques witnessed in the past as a subject of study. Lily and Hong (2004) model stress tests in Singapore based on historical scenarios of growing terrorism threats in the wake of September'11 attacks, growing concern of SARS as a pandemic, sluggish economic growth in Europe and Japan etc. A number of other historical scenarios are shown in the figure below.

[2] Extracted from summary of speeches at the seminar 'Stress testing best practices and risk management implications for Egyptian banks' (2007)

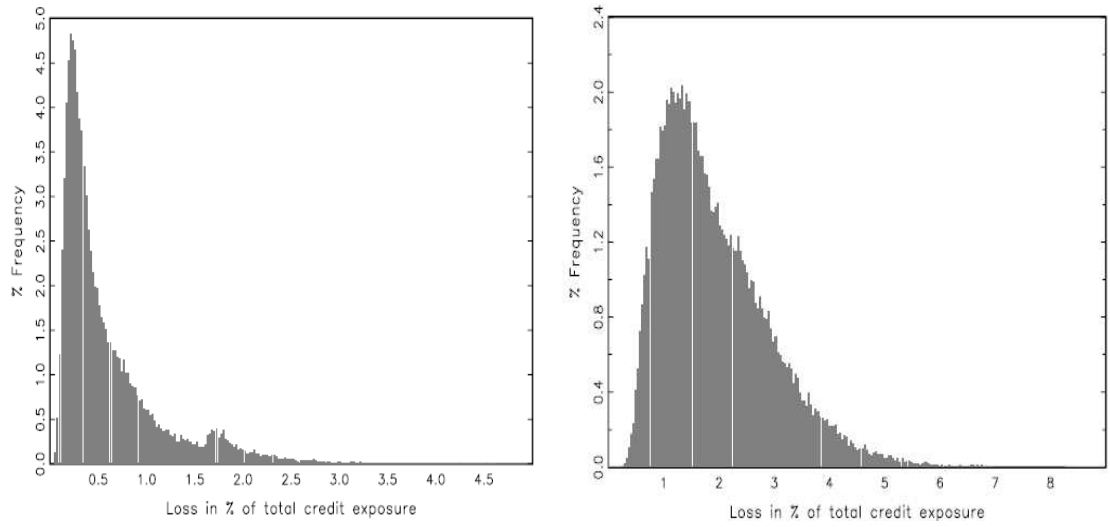
Figure 3 Historical Scenarios



Source: MAS Information Paper, 01-2003; BIS, Stress testing at major financial institutions: survey results and practice, 2005

On the other hand, hypothetical scenarios are used to measure stress under exceptional situations that have no historical precedent, but are plausible in the future. For instance, Virolainen (2004) in his study of Finland creates a hypothetical scenario of an interest rate shock. The short-term interest rate is suddenly assumed to increase by one percentage point for four consecutive quarters, and then remains at this higher level for a two-year period.

Figure 4 Loss Distribution due to Interest rate shock



One year horizon Three year horizon

Source: Macro Stress Testing with a Macroeconomic Credit Risk Model for Finland; Kimmi Virolainen (2004)

The figures given above illustrate the loss distribution due to an interest rate shock. They also illustrate an important aspect i.e. the choice of the time horizon – the losses for the three-year horizon are in greater percentage than the one-year horizon. It is very important to select the appropriate horizon for measuring losses; else our inferences may be biased.

Monte Carlo simulations use techniques to look jointly at the sensitivities and probability distributions of various input variables. They are carried out in two principle ways: (i) by the generation of random values of input variables based upon a hypothetical joint distribution of input variables and (ii) by bootstrapping using empirical data.

An important concern in calibration is that of taking second round effects into account. For example, an oil price shock will not only affect the GDP, but factors such as inflation, interest rates etc. Sorge (2004) proposes the use of structural macro-econometric models that should be employed fully to characterize the interacting shocks affecting key real economy indicators or asset prices that define the scenario of interest.

1.3 Assessing vulnerability to specific risk factors

Jones, Hilbers and Slack (2004) list down macro-level, structural and financial soundness indicators that can be used to identify vulnerabilities in the system. At the macro level, information from the following sectors can be utilized,

- Real Sector: Indicators such as the growth performance of the economy relative to potential growth rates for consumption, investment and incomes; unemployment rates; inflationary pressures on consumer, wholesale and asset prices can be used. For the household and corporate sectors, these would include measures of indebtedness, leverage, income growth and debt servicing stability.

- Government Sector: Indicators of relative magnitude of the government deficit, debt stock, and associated debt sustainability; the size of the present fiscal impulse; and how the government budget is financed.

- External Sector: Indicators of the magnitude of current account deficit, official reserves, and how the deficit is financed; the relative size, maturity structure and currency composition of external debt; the extent of exchange rate misalignment and whether there are any pressures on the exchange rate.

Following have been identified as the key structural indicators:

- Ownership and market shares: This data could include total assets or profits, broken down by bank, institutions or other sectors.

- Balance sheet structures: These can be used to analyze growth rates of credit by various types of institutions and to different sectors.

- Flow of funds accounts: They provide insights into the patterns of intermediation in the economy, and trends in fund raising by different sectors and instruments.

Movements in the level of the Financial Soundness Indicators (FSIs) provide important information on exposures and capital adequacy. IMF has developed a core set of FSIs, focusing on the banking sector as it plays a pivotal role in the financial system. These indicators have been laid down by the IMF as being essential for testing any country's financial system. There are no data problems with regard to these indicators. An encouraged set of FSIs includes additional indicators for the banking system as well as FSIs for some key non- financial sectors, which are a source of credit risk for banks and, hence, help detect vulnerabilities at an earlier stage. A list of the core and encouraged set of FSIs is given in the Appendix.

Use of the individual balance sheet measures characterizes the 'piece-wise approach', which we shall discuss in the following section. A comprehensive picture of system wide vulnerabilities can be obtained by studying dependencies among FSIs. This is what we shall come to know as the 'integrated approach'.

1.4 Integrating market and credit risks

Sorge (2004) gives a brief description of methods used to assess losses due to market and credit risks. Losses due to market risk are estimated using: (i) Local valuation methods that use first and second order approximations to capture sensitivity of the portfolio around its present market value and then estimate the loss distribution under different stress scenarios; or (ii) Full valuation methods that re-estimate the value of the portfolio in different scenarios using a new vector of prices inferred from historical analysis or drawn from known distributions by Monte Carlo simulations. On the other hand, two main models to evaluate credit risk have gained prominence in the literature: (i) Reduced-form models that assume an exogenous functional form for the link between default probabilities and a number of primary risk factors whose evolution over time follows data driven stochastic processes; and (ii) Structural models that track the impact of risk factors on the assets and liabilities of obligors and derive default probabilities based on the distance between the expected value of the assets at maturity and the default threshold determined by the level of liabilities.

There is widespread consensus amongst economists that macroeconomic shocks lead both to market losses and changes in the credit quality of the obligors. Therefore, there is a need to come up with models that take both these risks into account. Relatively few studies have attempted to integrate these risks and subsequent discussions of some of these will be presented in our analysis of the integrated approach in the next section.

1.5 Aggregation

There are two main approaches used for aggregation.

Bottom-up approach: Under this approach individual institutions perform their own stress tests, which are then aggregated for analysis. This is the approach propagated by IMF's Financial sector Assessment Programs (FSAPs). Two mappings are required. One mapping is from the macroeconomic scenarios to the set of common risk factors. These common risk factors may be limited in number to simplify the process of aggregation across a large number of institutions. An example of this process from Jones, Hilbers and Slack (2004) may be a noteworthy mention here:

- "Suppose the macro model only produces two interest rates: an overnight cash rate and a 10-year bond rate. An empirical model of the term-structure of interest rates could be used to produce an estimated set of interest rates for a larger set of maturities. In turn, this data could be used to derive credit spreads".

The second mapping happens from the common risk factors into all of the instruments in portfolios of individual institutions. Mostly, these institutions use their own internal models of expertise to develop an appropriate mapping. Jones et al (2004) highlight the use of models for credit scores, transition matrices, or default probabilities as key inputs in understanding the credit risk of a portfolio.

Since different entities employ different methodologies and modeling assumptions, substantial measurement error may be introduced. Besides, if the number of common

scenarios to which institutions agree is small we will fail to develop an accurate estimate of the risks associated with a portfolio.

Top down approach: Under this approach, portfolio data is gathered from the relevant institutions and the supervisor uses it to perform stress tests with a common scenario and methodology. This approach is mostly seen in countries where banks do not have sophisticated risk management techniques internally and it becomes necessary for the supervisor to conduct the analysis. Let us illustrate an example here from a paper by Allan Kearns (2006). The paper stress tests the balance sheet effect of an exchange rate risk in Ireland. It captures the impact of a change in exchange rates and the knock-on revaluation of assets and liabilities held in foreign currencies, and whether the size of the consolidated balance sheet increases or falls when measured in the local currency.

Table 1 Exchange Rate Risk

	Ratio of total assets (ex-post) to total assets (ex-ante)
30% appreciation in Euro vis-à-vis all foreign currencies	90
No change exchange rate	100
30% depreciation in euro vis-à-vis all foreign currencies	113
Special Case:	
30% appreciation in euro vis-à-vis dollar only	97

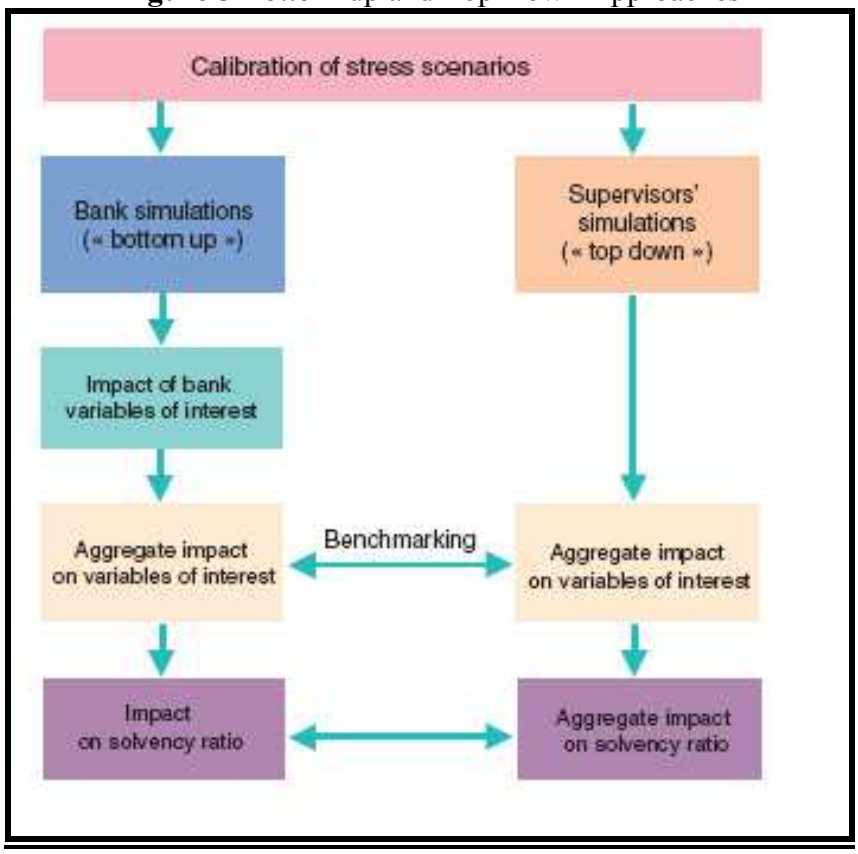
Source: 'Top down stress testing: Key Results' by Allan Kearns (2006)

As the given table shows, the size of the Irish banks is extremely sensitive to exchange rate risk as a significant share of assets is held in foreign currencies.

Bottom- up v/s Top-down: The top-down approach is more advantageous in the sense that it uses a common methodology and scenario, and is hence, more meaningful. However, it imposes a higher burden on the supervisors, as they need to develop a certain expertise to conduct the analysis. Blaschke et al (2001) say that supervisors need to have

in- depth knowledge of portfolio structures and the strategic direction of firms involved so that a comprehensive analysis can be undertaken.

Figure 5 Bottom-up and Top Down Approaches



Source: Oung et al (2004)

1.6 Feedback effects

Mizuho Kida (2008) in his paper on 'A macro stress-testing model with feedback effects' lists four types of feedback effects as considered important in stress testing literature.

(i) Inter-bank contagion- The level of inter-bank exposures leads to otherwise solvent banks being exposed to risks associated with losses or defaults of other banks via a domino effect. This however, rests on the assumption of a static matrix of inter-bank claims. In reality, banks re-optimize their exposures. It is important to distinguish between static and dynamic feedback effects.

(ii) Interaction between asset prices and bank's portfolio adjustment mechanisms- how change in asset prices damage bank's balance sheets, forcing sale of assets and depressing asset prices even further.

(iii) Transmission of shocks between the financial system and the real economy- how turbulences in the banking system affect aggregate supply and demand and the overall economic activity.

(iv) Correlation between credit and market risks- for example, how shocks to interest rates raise default risks, resulting in higher interest rates.

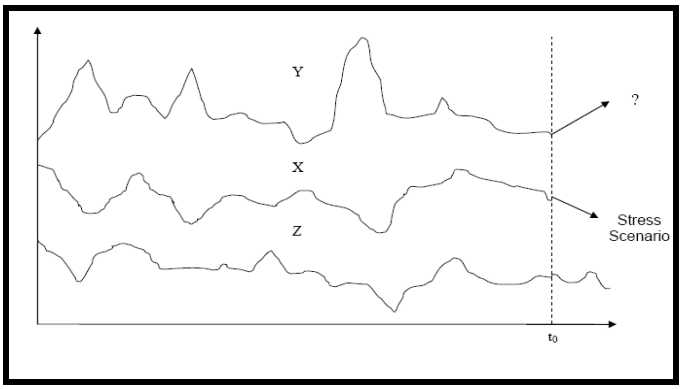
For our analysis here, we will focus on the first three effects in greater detail in the last section on methodological challenges.

2. MACRO- STRESS TESTING METHODOLOGIES

2.1 Piecewise approach:

As the name suggests, the piecewise approach focuses on estimating the impact of a macroeconomic shock on a single financial indicator (such as loan write-offs). A direct economic relationship is estimated using historical data between the macroeconomic variables (X) and the various risk measures (Y). The estimated coefficients are then used to study the vulnerabilities of the financial systems to an adverse scenario. Sorge (2004) expresses this relationship through the graph given below.

Figure 6 Predicting the impact of macroeconomic shocks on FSIs



Source: BIS Working Papers No 165, Marco Sorge (2004)

In the given figure Y can be taken to be any of the financial soundness indicators we mentioned in the previous section.

There are two broad categories of econometric models found in the literature to conduct analysis under this approach:

(i) Models that use reduced form relationships using either panel or time series data techniques

(ii) Economy wide or inter-industry structural macroeconometric models

Sorge discusses the advantages that one model has over the other. Structural models, he says, achieve a more complete characterization of the adverse macro scenario including the repercussions of the original exogenous shock on all other macroeconomic variables. They help assess the conflicts and tradeoffs arising between the pursuit of monetary and financial stability and evaluate interdependencies and production flows among industries. However, both models find widespread use because of their easy implementation. The piecewise approach has a limitation in that rigid linear relationships are estimated between bank risk and macro fundamentals, and its lack of ability to characterize the entire loss distribution.

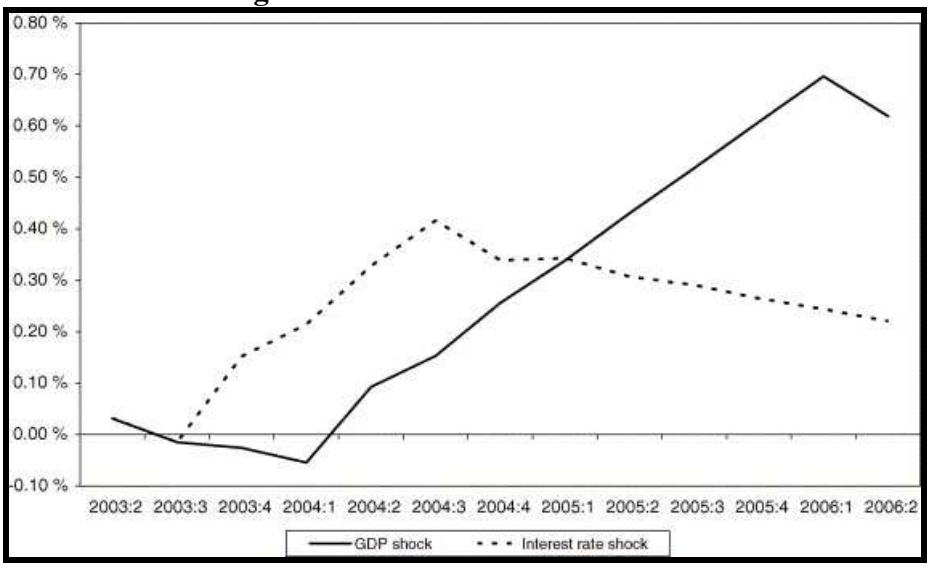
2.1.1 Time series technique Illustration: Sorge and Virolainen (2006) use historical data from Finland since the early 1990's, when it experienced the most severe recession. Several quarters of negative growth in 1992-1993 were accompanied by a significant increase in the ratio of banks' loan-loss provisions to total loans. The change in this ratio is regressed on the macroeconomic determinants, seasonally adjusted GDP growth and the short-term interest rate to obtain the coefficients shown in the table below. These coefficients are then used to study two macro stress test scenarios: (i) the quarterly real GDP declines by 2 percent for eight consecutive quarters after 2003 Q2 and (ii) the short term interest rate goes up by one percentage point for four consecutive quarters after 2003 Q2.

Table 2 Linking loan loss provisions to macroeconomic factors

Dependent variable: change in the ratio of loan loss provisions (LLP) to total loans		
Change in LLP ratio (−1)	−0.492 (−3.83)	−0.492 (−3.48)
GDP growth (−3)	−0.066 (−3.09)	−0.066 (−2.17)
Change in interest rate (−1)	0.178 (4.70)	0.178 (2.15)

Dependent variable: change in the ratio of loan loss provisions (LLP) to total loans		
Adjusted R^2	0.39	
SEE	0.002	

Figure 7 GDP and Interest Rate Shock



Source: Sorge and Virolainen (2006)

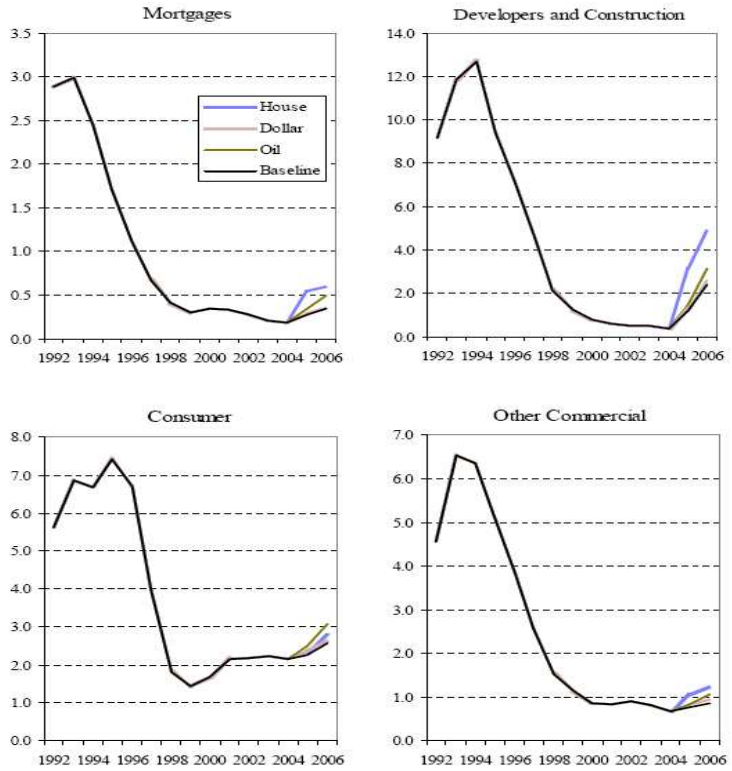
As seen from the above figure, the impact of the interest rate shock is more immediate whereas the GDP effect is more persistent. Once the impact of the shocks is absorbed, loan loss provisions revert to their long-term downward trend. Estimated losses were put at 0.7 % of total loans quarterly. This was far above the actual reported figure of 0.18%.

2.1.2 <u>Panel data technique Illustration</u>: The IMF, together with the Bank of Spain, conducted a series of tests to model NPL determinants as a function of macro variables in order to simulate the impact of changes in the macro scenario. The model used for analysis is represented by:

$$NPL_{i,t} = \alpha_i + \rho\, NPL_{i,t-1} + \Sigma\, \beta_{F,t-s}\, MACRO_{F,t-s}$$

where $NPL_{i,t}$ stands for the logit transformation of non-performing loans of credit institution i in year t; α_i stands for the fixed effect for credit institution i, and $MACRO_{F,\ t\text{-}s}$ stands for macroeconomic factor F, in period t-s. Several macroeconomic variables were considered, including GDP growth, unemployment, household indebtedness, real disposable income per household, short and long-term interest rates, and the real growth of house prices. The estimated coefficients showed substantial differences in the sensitivity of loan quality to changes in macroeconomic conditions across portfolio categories. For each credit institution, loan quality was then projected over a two-year horizon, subject to a number of different scenarios of dollar depreciation, oil price increase and drop in house prices. A deterioration in loan quality was seen under all scenarios, with substantial variation across loan categories, as shown in the figure below. Such type of analysis gives us a more comprehensive picture in the sense that we can make inferences both at a broad level and at an intrinsic level of variations between sub-categories.

Figure 8 Projected NPLs by scenarios and portfolio categories in percent of loans in category (1992-2006)



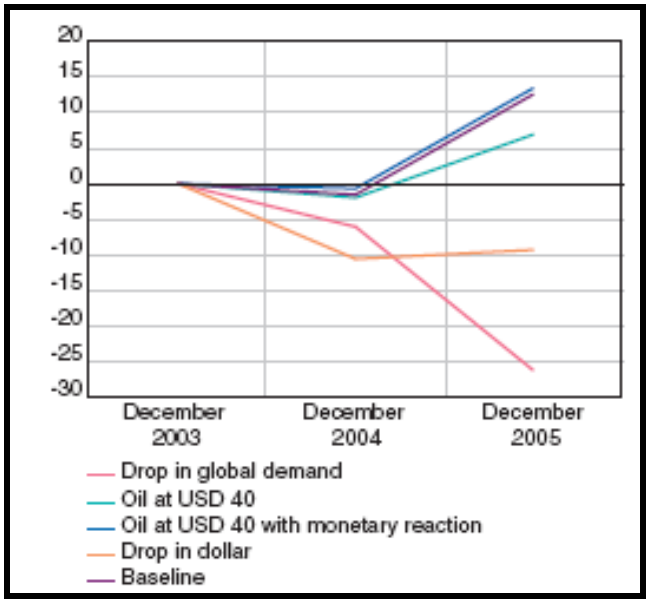
Source: Spain- Financial Sector Assessment Program, IMF Country Report (2006)

2.1.3 <u>Structural Model technique Illustration</u>: Oung et al (2004) use the following model to simulate the profitability of banks in France:

$$M_{i,t} = 0.64 + 0.68\, M_{i,t-1} + 0.35\, p_t^{*} - 0.59\, \sigma^{*}_{p,t} + 0.29\, p_t^{*} \Delta L_{i,t} - 0.20\, \Pi_{i,t} + \varepsilon_t$$

where:
$M_{i,t}$ = net interest margin of bank i at time t
p_t^* = difference in riskless (credit risk) interest rates : 5 years - 3 months
$\sigma^{*}_{p,t}$ = volatility of the slope : 5 years - 3 months
$\Delta L_{i,t}$ = nominal rate of growth in lending for bank *i* at time *t*
$\Pi_{i,t}$ = cost of risk expected by bank *i* at time *t*

Figure 9 Net profitability after a shock



Source: Oung et al (2004)

Stress scenarios were constructed with Banque De France's Mascotte macroeconomic model and then used to simulate the exogenous changes in the factors of the model. This was then used to estimate the impact of shocks on bank profitability as shown in the figure above.

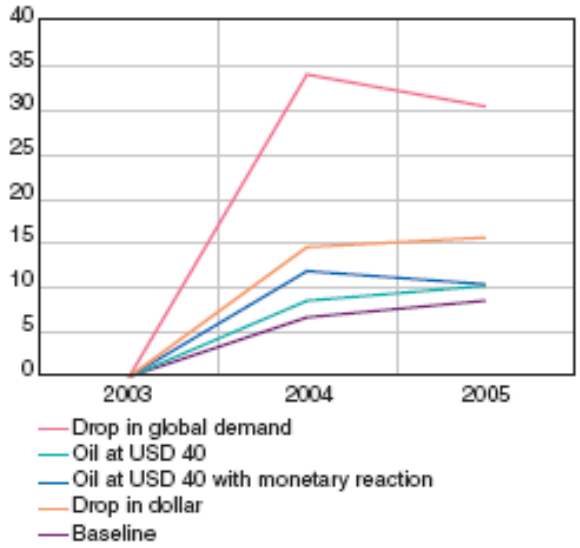
In a similar manner, the impact of an increase in risk-weighted assets was studied using a model that links the probability of migration, for each state in the transition matrix, to cyclical factors. The complete model varying from 1 to N-1 is:

$$z_{ijt} = log\ (\ P\ (rating_t <= j \mid rating_{t-1} = i\ ) - log\ (P\ (rating_t > j \mid rating_{t-1} = i\ )$$

$$z_{ijt} = \theta_{ij} z_{ijt-1} + \alpha_{ij} + \beta_{ij} X_t + \varepsilon_{ij,t}$$

where X is a vector of macroeconomic variables and ε_t is the error term. This model can be used to estimate a stressed transition matrix under different macro scenarios, which can then be applied to produce a final stressed portfolio and study the impact of a shock on regulatory capital as seen from the figure below.

Figure 10 Increase in risk weighted assets



Source: Oung et al (2004)

2.2 Integrated Approach

This approach combines the sensitivity of financial systems to multiple risk factors (both credit and market) into a single estimate of expected losses. Sorge (2004) conducts an interesting discussion of the approach. He notes that in a mark to market framework, portfolio managers continuously revalue their assets and liabilities under different macro scenarios. A conditional probability distribution of losses can be obtained under every simulated scenario. Value at risk is the most commonly used summary statistic of this distribution. Many recent studies have incorporated macro-fundamentals into value at risk measures as follows:

$$VaR_{i,t}(\tilde{Y}_{t+1}/\tilde{X}_{t+1} \geq \tilde{X}) = f\{E_{i,t}(X_t); P_t(X_t); PD_t(X_t); LGD_t(X_t); \sum_t(X_t)$$

$$X_t = h(X_{t-1},\ldots\ldots,X_{t-p}) + \varepsilon_t$$

where:

E: vector of both credit exposures and market positions

P: vector of prices at time 't'

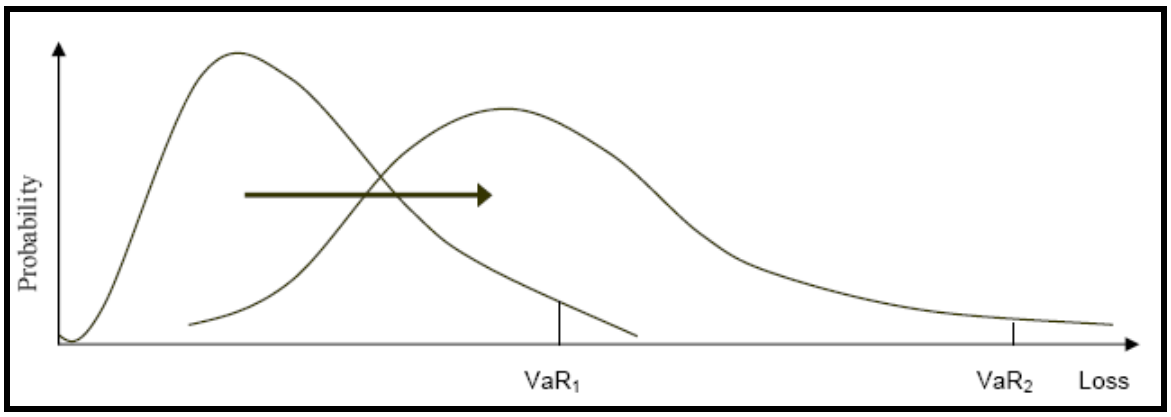
PD: default probabilities

LGD: loss given default

∑: matrix of default volatilities and correlations

A stressed scenario is simulated by selecting the vector of correlated innovations, ε. This affects the macroeconomic variables, X, which in turn feedbacks through changes in prices and credit quality and endogenous adjustments in default volatilities and correlations into the loss function. Sorge shows graphically how a change in the macroeconomic scenario produces a shift in the conditional loss distribution.

Figure 11 Shift in the probability distribution of losses conditional on an adverse macroeconomic scenario



Source: BIS Working Papers No 165, Marco Sorge (2004)

2.2.1 Illustration: Jandacka, Krenn and Breuer (2005) show the importance of integrated credit and market risk measurement as compared to summing up separate risk numbers for credit and market risk. They exemplify this claim with a recent example of the Russian crisis in 1998. Some banks held dollar/rubel forwards with Russian banks and matching rubel/ dollar forwards with US banks. These positions were hedged against

exchange rate movements. If one party defaulted, the other could obtain the currency at no loss if the exchange rate stayed the same. Since the rubel regime was managed, a situation of change in exchange rate was highly unlikely. From the perspective of pure credit or market risk, the risk of the portfolio was zero. However, during the 1998 crisis when Russian counterparties defaulted, the value of the rubel also fell drastically. The US banks suffered serious losses, as the deliverables purchased on the market did not give them much rubel in return. The authors conducted an integrated analysis through two methods. Crude integration was carried out by looking at risk numbers for market risk, assuming constant default probability. Full integration was achieved by varying the market and credit risk factors simultaneously according to their joint distribution. Both, the value at risk and expected shortfall figures were found to be higher than those for simple sum of pure market and credit risks.

Sorge (2004) discusses the literature associated with the integrated approach. Allowing the risk parameters specified in the VAR equation above to be state or time dependent helps address concerns of parameter instability. In most recent studies, however, all components of the loss function other than default probabilities have been treated as constant, rather than being modeled endogenously. The approach also allows for non-linear relationships between macroeconomic shocks and default measures. But, a problem with VAR measures is the non-additivity across portfolios. As a result, most studies focus on an aggregate portfolio that fails to take into account the domino effects among single financial institutions.

3. METHODOLOGICAL CHALLENGES

3.1 Time horizon effects

The issue about appropriate time horizons is discussed in some detail in a Consultative paper of the Basel Committee on Banking Supervision (2009). The paper emphasizes the need of including various time horizons in stress testing analysis depending on the risk characteristics of the exposures and whether the particular test is intended for tactical or strategic use. Substantially longer periods should be considered for the risk management horizon of the target portfolio and the liquidity of the underlying exposures. This is because liquidity conditions change rapidly under stressed scenarios. Besides, lengthening the time period also brings with it the work of correctly listing down assumptions for our analysis. Most banks run stress test scenarios covering either short term (eg: four-week or so) or long (eg: 12-month) term horizons, but very few consider both. It is important to test scenarios for all time horizons that are relevant to a bank's maturity profile and vulnerabilities.

3.2 Feedback Effects

(i) Inter-bank contagion: The Financial Sector assessment handbook by IMF (2005) lists down two types of stress tests important to take the contagion effect into account. The first is a pure inter-bank stress test, in which the shock is the failure of one bank, and the effect is transmitted through inter-bank exposures. The second is an integrated inter-bank stress test, in which the banking sector is first subjected to a macroeconomic shock. If this shock leads to the failure of one or more banks, then inter-bank stress tests are conducted to assess the effects of additional failures through inter-bank exposures.

A number of studies have been undertaken to examine the linkages. Upper and Worms (2002) use balance sheet information to formulate the matrix of bilateral credit relationships for the German banking system and check if the breakdown of a single bank gives rise to contagion effects. The paper concludes that the failure of a single bank could cause the breakdown of upto 15% of the banking system in terms of assets. Gropp and Vesala (2004), using

market data, find significant presence of cross-border contagion in the EU. Some papers reveal little impact of the contagion effect. Degryse and Nguyen (2006) study the systemic risk of the Belgian banking system. They find that a change from a complete symmetric link structure towards a more concentrated banking market has decreased the risk and impact of contagion. An increase in the proportion of cross-border inter-bank assets has reduced the risk and impact of local contagion. Craig Furfine (1999) of the Kellogg School of Management used bilateral federal funds exposures to simulate the impact of various failure scenarios, and the risk of contagion was found to be economically small between banks.

(ii) Interaction between asset prices and bank's portfolio adjustment mechanisms:
A basic problem in stress testing analysis is that the bank's portfolio and asset prices are assumed to be constant over the time period of the simulation scenario. However, in a down turn, capital adequacy requirements may force the sale of several assets. This in turn has the effect of increasing supply and hence depressing asset prices, which the simulated scenario usually fails to take into account. There is definitely a possibility that the banks will adjust their behavioral responses and reallocate their portfolios several times over the simulation horizon. Adrian and Shin (2008) show that asset prices affected by market liquidity conditions impact bank's balances through a financial accelerator. Incidentally, Alessandri et al (2008) take into account the feedback effects of asset prices on heterogeneous banks in a model used by the Bank of England to conduct stress tests. The feedback effects are found to have a significant impact and their inclusion makes the results robust.

(iii) Transmission of shocks between the financial system and the real economy:
Most stress tests don't take into account the feedback effect of the stimulated scenario on the real economy. Hosoya and Shimizu (2002) in their review of the impact of a major global economic downturn on the Japanese economy predict a decline in the country's nominal GDP by two percent over the

sample period. However, they note that if negative feedback effects through financial and loan markets were taken into account the initial stress scenario required to bring a similar level decline in GDP would be drastically lower. Kick and Koetter (2007) use an integrated micro-macro approach to take into account feed back effects between bank distress in Germany and the real economy. Keith Hall at the Reserve Bank of Australia (2006) suggests an iterative approach to solve the feedback effect problem. This can be done by providing banks with only the first year scenario, say a demand side shock to household and business credit. Banks will adjust credit growth to the new demand conditions and hence macro forecasts based on these estimates will help us develop a second year profile. Policy changes to the scenario could be introduced wherever necessary.

3.3 Endogenous parameter Instability

Sorge (2004) reviews the issue of endogenous parameters. He says that reduced form models help address the issue of second round effects to some extent. Time series and panel regressions use historical inputs to calibrate a relationship between macroeconomic and financial stability indicators and this encompasses past behavioral responses. But, if feedback effects are not allowed for, future trends may not indicate a relation to historical patterns. This implies that reduced form models dealing with time invariant relationships will be faced with problems of parameter instability and reverse causation. Some studies have tried to address this issue. Goodhart et al (2006) take account of endogenous feedback mechanisms in their analysis of heterogeneous banks and household investors. Liquidity affects the credit supply of banks to household and other bank entities, keeping default parameters endogenous in the system.

Sorge highlights the idea of structural breaks that may arise due to large macro economic shocks. Endogenous responses of economic agents may bring about new trends that are completely different to those witnessed in the past. Another important issue is that we must distinguish correctly between exogenous and endogenous parameter instability. He exemplifies this issue with an example. Exogenous instability arises in a situation where

the bank's exposure changes due to exogenous trends like increased use of credit derivatives or greater inter-dependence in financial markets. However, endogenous instability arises in the case when estimated coefficients and correlation patterns lose their properties due to the impact of simulated macroeconomic scenarios.

4. CONCLUSION

The paper has dealt in detail with its three core objectives. Firstly, an overview of the macro stress-testing framework was provided. This section helped us answer questions such as how to identify the set of relevant institutions given data constraints? , What are the parameters required to be shocked?, Should I use a hypothetical or a historical simulation?, What type of risks should I analyse?, Which financial soundness indicators are best suited for my analysis?, How do I integrate market and credit risks?, Do I use the bottom-up or top-down approach for aggregation?, What kind of feedback effects are most likely to affect my stress scenarios? Secondly, the two approaches of macro- stress testing, piece-wise and integrated approach were studied. While for the piece wise approach, we analyzed case studies using time series, panel and structural data techniques; the integrated approach case study highlighted two key forms of integration- the crude and full integration techniques. Finally, the section on methodological challenges looked at greater depth into the feedback effects due to inter- bank contagion- a classical case of which was the recent Lehman disaster, transmission of shocks between the financial system and the real economy and interaction between asset prices and bank's endogenous portfolio adjustment mechanisms. This section also laid stress on problems of endogenous parameter instability and that they need to be distinguished from exogenous parameter problems.

The issue of stress-testing has never been given as much importance in history as has been seen in what may be the worst economic depression the world has ever known. Timothy Geithner, the current United States Secretary of Treasury conducted stress-tests on the nation's biggest banks in May'2009 and has asked 10 of them to raise an estimated total of 75 billion dollars in extra capital by November. However, critics claim that these stress-tests don't potentially account for feedback effects of the stressed scenarios and lack a comprehensive analysis. Such issues and many more are central to the study of stress testing. Attempts should be made to run macro stress tests that provide a holistic picture of the situation and allow adequate capital buffers to be put in place. An attempt has been made to cover the key issues raised in macro stress testing through this paper.

5. APPENDIX

Sets of Financial Soundness Indicators

Core Set

Deposit-Takers	
Capital Adequacy	Regulatory capital to risk weighted assets
	Regulatory Tier 1 capital to risk weighted assets
	Non-performing loans net of provisions to capital
Asset quality	Non-performing loans to total gross loans
	Sectoral Distribution of loans to total loans
Earnings and Profitability	Return on assets
	Return on equity
	Interest margin to gross income
	Noninterest expenses to gross income
Liquidity	Liquid assets to total assets (liquid-asset ratio)
	Liquid assets to short term liabilities
Sensitivity to market risk	Net open position in foreign exchange to capital

Encouraged set

Deposit takers	**Capital to assets**
	Large exposures to capital
	Geographical distribution of loans to total loans
	Gross asset position in financial derivatives to capital
	Gross liability position in financial derivatives to capital

	Trading income to total income
	Personnel expenses to noninterest expenses
	Spread between reference lending and deposit rates
	Spread between highest and lowest interbank rate
	Customer deposits to total (noninterbank) loans
	Foreign currency denominated loans to total loans
	Foreign currency denominated liabilities to total liabilities
	Net open position in equities to capital
Other financial corporations	Assets to total financial system assets
	Assets to total GDP
Nonfinancial corporations sector	Total debt to equity
	Return on equity
	Earnings to interest and principal expenses
	Net foreign exchange exposure to equity
	Number of applications for protection from creditors
Households	Household debt to GDP
	Household debt service and principal payments to income
Market Liquidity	Average bid-ask spread in the securities market
	Average daily turnover ratio in the securities market
Real estate markets	Residential real estate prices
	Commercial real estate prices
	Residential real estate loans to total loans

Source: IMF (2003)

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