UDC: 336; 336.71
JEL Classification: G21, G28, G29
Keywords: financial systems – financial soundness – stress testing

Stress Testing of Banking Systems

Martin ČIHÁK*

In response to increased financial instability in many countries in the 1990s, policy makers became interested in better understanding vulnerabilities in financial systems, and particularly in banks. One of the key techniques for quantifying vulnerabilities is stress testing.

This article reviews the literature on stress testing of banking systems. The first section introduces the concept of stress testing. The second section overviews stress tests performed by international financial institutions, central banks, and other researchers. The third section describes the implementation of stress tests. The fourth section discusses specific issues relating to individual shock factors. The fifth section provides a conclusion.

1. The Concept of Macroprudential Stress Testing

In the context of financial sector analysis, the term stress testing refers to a range of techniques used to help assess the vulnerability of financial institutions or the financial system to exceptional but plausible events.[1] Stress tests were originally developed for use at the portfolio level, to understand how the value of a portfolio changes if there are large changes to its risk factors (such as asset prices). They have become widely used as a risk management tool by financial institutions.[2] In recent years, the techniques have started to be applied in a broader context, with the aim of measuring the sensitivity of a group of financial institutions or even an entire financial system to common shocks.

This article focuses on macroprudential (system-focused) stress tests, which are based on applying a common set of shocks and scenarios to a set of financial institutions, in order to analyze both the aggregate impact and the distribution of the impact across the institutions. Compared to stress tests for individual institutions, the macroprudential stress tests have

* International Monetary Fund, Washington, D.C. (mcihak@imf.org)
Support by the Czech National Bank's (CNB's) Program of Economic Research (grant no. B6/2003-2004) is gratefully acknowledged. I would like to thank the following for useful suggestions on earlier drafts: Laurent Bouscharain, Michal Hlaváček, Jarmila Musilová, two anonymous referees of this journal and participants of two seminars at the CNB. All remaining errors and omissions are mine. The views presented in this article are those of the author and do not ne-cessarily represent those of the International Monetary Fund or the CNB.

[1] An internet search in April 2005 showed about 616,000 occurrences of the term, more than, for instance, "banking supervision" (about 164,000). This partly reflects the fact that stress tests are used in areas as diverse as cardiology, engineering, and software programming.

[2] The New Basel Capital Accord or "Basel II" – see (Basel Committee, 2004) – stipulates that banks that adopt the internal ratings-based approach for calculating capital requirements must undertake stress testing.

a broader coverage (the system as a whole or large part of it), are used for a different purpose (aggregate-level surveillance rather than risk management in individual institutions), focus more on contagion among institutions, and often use more streamlined techniques (because of the complexity of the calculations).

More specifically, this article covers stress tests for banking systems, which is where the literature has generally focused so far. This reflects the fact that in most countries, banks are a large (and often dominant) part of the financial system.[3] Stress testing for other parts of the financial system is relatively less well-developed, reflecting factors such as worse availability of data. Also, insurance companies are often considered to represent a lower level of systemic risk given that their liabilities often have a longer duration than banks; however, distress in the insurance sector can have important systemic implications, including through ownership relations with the banking sector and its impact on confidence in the financial sector as a whole. Recent macroprudential stress tests are therefore more likely to include non-bank financial institutions, such as insurance companies and pensions – e.g. (De Nederlandsche Bank, 2004).

The literature on macroprudential stress testing is in a nascent state. Most of this literature is written by staff of international financial institutions and central bank staffers. This reflects the fact that it is a newer concept as well as the fact that it requires comprehensive data for a number of financial institutions, which is typically available (for confidentiality reasons) only to a limited group of supervisory experts. For an introduction to macroprudential stress tests, see (Blaschke et al., 2001), (Jones et al., 2004), and (Sorge, 2004).[4] For a general discussion of macroprudential analysis and quantitative methods of analyzing financial systems, see for example (Sundararajan et al., 2002), (Worrell, 2004), or (Goodhart et al., 2003).

The key element of the definition of stress testing is the notion of an "exceptional but plausible" event. Some authors view stress testing as a subgroup of risk modeling focusing on "tail" events that is complementary to "standard" methods such as value at risk (VaR) and should be included in a comprehensive risk model – e.g. (Berkowitz, 1999). Others see stress testing as a separate approach that goes beyond the distributions of past shocks used in VaR and that is more an "art" than a science – e.g. (Kupiec, 2001). The present article takes a middle road: while recognizing difficulties involved in designing an "exact" stress testing scenario, especially for multiple risk factors, it maintains that the selection of stress test scenarios should be – to the extent possible – based on a measure of plausibility.

Stress tests can be classified, by methodology, into three main types: (i) *sensitivity analysis*, which looks at impacts of changes in relevant eco-

[3] We use here the definition of the financial system as comprising both financial intermediaries and financial markets. This definition seems to be prevalent in the literature – e.g. (Allen – Gale, 2000) –, even though some authors define the financial system differently, e.g. to include only the financial intermediaries.

[4] The literature on stress testing for individual institutions is much more evolved. For an introduction to stress tests for individual institutions, see (Laubsch, 2000) and (Dowd, 2002) in English or (Jílek, 2000) and (Sekerka, 1998) in Czech. For a survey of stress testing in major international banks, see (Committee on the Global Financial System, 2001).

nomic variables (such as interest rates and exchange rates); (ii) *scenario analysis*, which assesses the impacts of exceptional but plausible scenarios; and (iii) *contagion analysis*, which seeks to take account of the transmission of shocks from individual exposures to the system as a whole.

Stress testing is only one of a number of tools used to assess and monitor strengths and vulnerabilities of banking or financial systems. To arrive at a comprehensive financial stability assessment, one needs to combine stress tests with other quantitative information on the financial system as well as qualitative information on the institutional and regulatory framework.[5] In particular, measuring financial system soundness requires good quantitative inputs: information on the structure of the system, general macroeconomic indicators, and the "financial soundness indicators" (FSIs). The FSIs are indicators of the current financial health and soundness of the financial institutions in a country, and of their corporate and household counterparts. They include both aggregated individual institution data and indicators that are representative of the markets in which the financial institutions operate. Substantial efforts by the IMF and by country experts were undertaken to develop international definitions of FSIs and to identify the core FSIs useful in most countries (Sundararajan et al., 2002), (IMF, 2004). Reflecting the large role of the banking sector in most financial systems, the core FSIs include mostly banking sector FSIs, grouped according to six key areas of potential vulnerability in the CAMELS framework (capital adequacy, asset quality, management, earnings, liquidity, and sensitivity to market risk).[6] Most FSIs are compiled by aggregating micro-prudential indicators for individual institutions to produce a measure for key peer groups or the entire banking system. Non-bank FSIs (such as those for the corporate and household sectors) are used to assess credit risks arising for banks from their credit and other exposures to non-bank sectors.

There are a number of important differences between stress testing and FSIs. In particular, stress testing illustrates more clearly the potential cost of shocks. To serve this purpose, each stress testing exercise must be tailored to the features of a particular system. This higher flexibility means that is difficult to derive a "standard" stress testing methodology comparable to that for compiling FSIs (IMF, 2004). Stress testing attempts to find exposures that are latent, i.e. not obvious from the analysis of FSIs. Stress tests try to identify exposures that are less obvious, perhaps hidden across a wide variety of instruments, credits, and derivatives positions.

2. Stress Tests by International Financial Institutions and Central Banks

The International Monetary Fund (IMF) and the World Bank (WB) have initiated the *Financial Sector Assessment Program* (FSAP), which strives to assess strengths and vulnerabilities in their member countries' financial

[5] See (Sundararajan et al., 2002), (IMF, 2003), and (IMF – World Bank, 2003).

[6] The existing lists of FSIs – e.g. (IMF, 2004) – do not include indicators on management, which reflects the fact that it is quite difficult to measure management quality on an aggregated basis.

systems. Assessments under this program have so far covered some 120 jurisdictions and provided various recommendations for improvement in the financial system framework (many of the assessments are available on the IMF and WB websites). From the beginning of the FSAP, stress testing was a key element of the assessment of financial sector stability.

Stress testing in the FSAP has evolved. Most FSAP missions to date have included single-factor sensitivity analysis based on historical extreme values, although an increasing number have also applied scenario analyses, using multiple techniques to determine the size of shocks. While almost all stress tests relied on data provided by the authorities, the involvement of the authorities in the recent FSAP missions has gone beyond providing data, as they have also been actively involved in designing and implementing stress tests in the recent FSAP missions. Moreover, recent FSAP missions to industrialized countries have aimed to improve the effectiveness of stress tests through the use of macroeconomic models, the analysis of contagion resulting from interbank exposures, and the involvement of major financial institutions in the stress testing exercise (IMF – WB, 2003).

The experience of the FSAP to date suggests that the types of stress tests need to be tailored to country-specific circumstances, the complexity of the financial system, and data availability. In industrialized countries, the analysis can be strengthened by using macroeconomic models (to help calibrate the scenarios and arrive at a consistent set of assumptions for the tests), the analysis of interbank contagion, and the involvement of major financial institutions in the stress testing exercise. The experience also suggests that stress tests can have a number of benefits. In particular, they can help define the amount and nature of the data required for ongoing monitoring of financial stability, thereby playing an important role of "capacity building." They can also provide an independent verification of potential sources of vulnerability and broaden the understanding of linkages in the financial system (IMF – WB, 2003).

A number of central banks have recently started to conduct macroprudential stress tests and publish their results as part of their analyses of financial system stability, typically called financial stability reports (FSRs). The number of central banks publishing FSRs grew substantially (from two in mid-1990s to about 40 at end-2004),[7] and a larger share of FSRs now include summaries of stress tests increased (the share increased from zero in mid-1990s to more than one half at end-2004). This indicates that not only financial stability issues are gaining more prominence in central banks' work program, but also that stress testing has increasingly become an important analytical tool in financial stability work. *Table 1* is based on a review of recent FSRs from 40 central banks, focusing on the features of their stress tests. This review is based on the information available in the FSRs published by the central banks.

Table 1 compares the stress tests in FSRs in various countries. The fact that the analysis does not include stress tests or the fact that the stress tests do not explicitly include certain risks does not mean that the risks are

---

[7] In some cases, the name of the report was slightly different, e.g. *Financial Stability Review*. The Czech National Bank published its first Financial Stability Report in late 2004. The report presented results of stress tests for the banking system (Czech National Bank, 2004).

TABLE 1 Stress Tests in Selected European Financial Stability Reports

Country	Coverage	Main conclusion	Credit shock	Interest rate shock	Exchange rate shock	Other shock	Scenario	Indirect FX risk	Conta gion
Austria[a]	All banks	ST supported positive assessment of banks' risk-bearing capacity	Incr. in loan loss provisions to loans by 30 %	Upward shifts in EUR, USD, CHF curves; downward shift in YEN curve	Appreciation/depreciation of EUR by 10 %; worst case estimation	Equity price risk	Yes	Yes	Yes
Czech Republic	All banks	System basically stable. Recent shift from credit risk to interest rate risk	Increase in NPLs by 30 % or in the NPL/TL ratio by 3 pct points	Increase by 1 pct point/2 pct points; combination of weighted gap and duration methods	Domestic currency depreciates by 15 or by 20 %		Yes, two scenarios	Yes	Yes
Denmark	6 Nordic groups and 46 (out of 99) Danish institutions	The banking institutions increased their resilience considerably	An increase in losses on loans to non-public sector by 1 or 2.25 pct points	An increase in interest rates by 1 or by 3 pct points; decrease in the average lending rate by 1 pct point		Decrease in stock prices by 30 %; decrease in net fee and commission income by 40 %	Yes, several combinations of the shocks listed here	No	No
Germany	A sample of banks; insurance companies	No risk to financial stability at present	Credit risk estimated by an econometric model	Twists of the yield curve at the short end, parallel shifts across all maturities, and fluctuations in the medium-term range	EUR appreciates or depreciates by 15 %	30 % decline in stock prices in all markets	Yes, "oil price scenario", int. rate scenario; credit risk scenario using an econometric model	No	No
Hungary[b]	All active banks	Results indicate an improvement in the sectors' resilience	4 shocks to NPLs (e.g., doubling, increase by 2 st. dev.)	Domestic rates: +500 bp, -300 bp Foreign: +/-200 bp	+/- 40 %	No	No	No	No
Latvia	All banks	Vulnerability to overall credit risk decreased in 2004; household lending the biggest risk	Increase in NPL ratio by 3 pct points. A number of sectoral shocks, assuming that a percentage of loans to some sectors become NPLs	No explicit stress test included, the report notes that most loans are floating rate	USD depreciating by 10 % against EUR		No	No	No

Country	Coverage	Main conclusion	Credit shock	Interest rate shock	Exchange rate shock	Other shock	Scenario	Indirect FX risk	Contagion
Poland	All banks	The system exhibits high stability	Three shocks: (i) satisfactory and special mention loans migrate to doubtful; (ii) substandard and doubtful migrate to loss and (iii) bankruptcy of three largest borrowers	Not a stress test, but an analysis of gains/losses on interest-sensitive instruments, and the maturity of debt securities	Not a stress test, but an analysis of VaR and open positions	Equity price risk and property market risks analyzed (but without a stress test)		No	No
Nether-lands[a]	Major fin. institutions (84 % banks, 54 % insur.c., 50 % pens.f.)	Banks are sufficiently shock-resistant	+/-50 bps change in credit spreads (larger for insurance and pensions)	+/-100 bps parallel move; 50 bps flattening/steepen-ing of yield curves (larger for ins&pen)	+/-10% change in the exchange rate of EUR vs. other currencies	+/-15% change in all relevant stock indices; 25% increase in market volatilities	Yes, "domestic crisis of confidence", "dollar crisis"	No	Yes
Norway	All banks / seven largest conglome-rates	Short-term stability outlook satisfactory; However, increased vulnerability of household sector	Decline in economic growth, increased unemployment	Interest rates unchanged, but interest burden of real sector increas-ed appreciably		A fall in property prices reduces mortgage values, causing a rise in loss given default	Yes, all tied to credit risk	No	No
Sweden	Four major banks	The major banks improved their potential for coping with shocks	Failure of the largest counterparty, assumed recovery ratio of 25 %	Increase in interest rates by 1 pct points, and a 30 % fall in the stock market			No	No	Yes
Belgium	No explicit stress tests presented, but detailed analysis of credit and interest rate risks.								
ECB	No stress tests presented, even though a number of references included stress tests run by banks themselves.								
Slovakia	No stress tests presented, but has a chart showing the positive impact of a 2 percentage point reduction in interest rates.								
Slovenia	No stress tests presented, but the report includes an article that estimates a model for the probability of an individual commercial entity being in a specific credit risk category, and the report suggests that this could be a basis for a future stress testing model.								
UK	No stress tests presented in the recent FSR, but an earlier issue contained a summary of stress tests carried out in collaboration with the FSAP mission.								
Portugal	No stress tests presented, even though an analysis of banks' exposures and capital adequacy contained.								

Notes: [a] The latest FSR contained the stress tests carried out by (or in collaboration with) an FSAP mission.
[b] Based on end-2003 FSR. The subsequent two FSRs present only the "stress CAR", which shows a bank's financial position in a situation where all NPLs are written off.

Source: Central banks' recent financial stability reports, namely: Austrian National Bank (2004), Banco de Portugal (2004), Bank of England (2003), Bank of Slovenia (2004), Danmarks Nationalbank (2003), Deutsche Bundesbank (2004), De Nederlandsche Bank (2004), European Central Bank (2004), National Bank of Hungary (2003), National Bank of Poland (2004), National Bank of Slovakia (2004), Norges Bank (2004), and Sveriges Riksbank (2004).

not discussed and analyzed in the FSR. For example, even when an FSR does not contain an explicit stress test for exchange rate risk, the report would typically include a discussion of the open positions in foreign currency. Similarly, when a central bank does not publish an FSR or does not include stress tests in its FSR, it may still carry out stress tests for internal purposes, without publishing the results.

There is substantial cross-country variation in the sizes and range of shocks covered, and in the methodologies applied. The approaches vary from more mechanical approaches to those focusing more on sources of credit risk. Nonetheless, the stress tests in FSRs show several common features:

– The stress tests tend to have a wide coverage of the banking sector, covering either all banks or virtually all in terms of market share. Other parts of the financial sector are covered only exceptionally.

– Virtually all presented stress tests are based on bank-by-bank data. This can be understood as a recognition that stress tests done on aggregate data risk are missing some potentially important risks arising from concentration of risks in weaker institutions.

– Credit risk is covered in almost all stress tests. Interest rate risk is covered in most stress tests. Exchange rate risk is covered in some, but in many cases it is analyzed only in terms of open positions, without an explicit stress test.

– Most stress tests are simple sensitivity analysis calculations. Some include scenario analysis, based on historical or hypothetical scenarios. Only a few stress tests are based on an econometric model. When models are used, they tend to be relatively rudimentary compared to those used in other central bank work, such as inflation forecasting. Inclusion of indirect exchange rate effects and contagion is rare. When the latter is done, it is a basic exercise based on net interbank market exposures.

– Virtually all the surveyed FSRs have been positive in the overall assessment of the financial sector, suggesting that it is stable. Stress tests, in those FSRs that present them, tend to confirm this conclusion by finding that the system is robust, capable to withstand substantial shocks.

– The interest in stress tests was often spurred by an FSAP mission. In some cases, recent stability report(s) included a summary of the FSAP stress tests (Austria, Netherlands). In other cases (Denmark, Norway), the FSR started including "FSAP-style" stress tests in the run-up to the FSAP participation.

3. Implementing Stress Tests

Macroprudential stress testing can be seen as a *multi-step process* of examining the key vulnerabilities in the system. This process involves identifying the major risks and exposures in the system and formulating questions about those risks and exposures, defining the coverage and identifying the necessary data, calibrating the shocks or scenarios applied to the data, selecting and implementing the methodology, and interpreting the results.

3.1 Identifying Major Risks

To be relevant, stress tests must probe the consequences of potential shocks that are related to risks faced by the economy. The process of designing macroprudential stress tests therefore typically starts with a discussion of the potential macroeconomic risks. The discussion then suggests that certain types of shocks (e.g. a substantial increase in interest rates) are more likely in the economy than other types of shocks.

The fact that there are macroeconomic risks that could result in shocks to the financial system does not necessarily mean that the impact of the shocks would be large. The impact can be small if the exposures in the system are small. It is the purpose of the stress tests to assess how the risks combine with the exposures. The design of stress tests is often an iterative process, since some originally identified risks may lead to relatively small impacts, while some risks originally assessed as small may lead to large impacts if there are substantial exposures.

3.2 Defining Coverage and Identifying Data

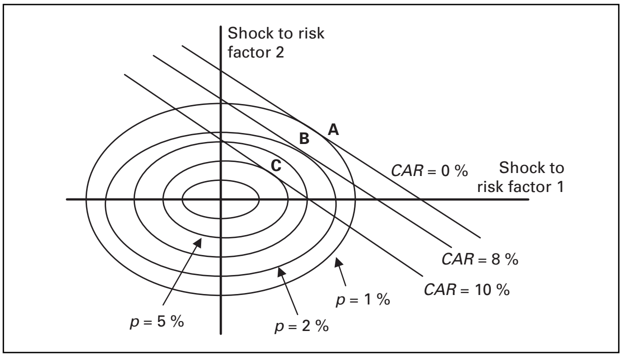
Another key step in designing stress tests is defining their coverage. The general rule is to include all systemically relevant institutions and exposures. The practical issues are what types of financial institutions to include (typically banks, since they dominate most financial systems, but sometimes also other institutions, such as insurance companies) and how to include foreign-owned financial institutions (a typical solution is to include subsidiaries but exclude branches of foreign-owned financial institutions). In terms of exposures, the most frequently covered are exposures to credit risk and market risks, and sometimes also liquidity risk and interbank contagion risk. The choice of coverage then determines the data needed for the calculation. In some cases, the lack of data (e.g., on institution-to--institution exposures) can limit some of the stress testing calculations.

3.3 Calibrating Shocks and Scenarios

There are two ways of asking questions about exposures in the financial system. The first way is to ask, for a given level of plausibility, what scenario has the worst impact on the system ("the worst case approach"). The second way is to ask, for a given impact on the system, what is the most plausible combination of shocks that would need to occur to have that impact ("threshold approach"). These two approaches are just two different ways of presenting the same vulnerabilities in the system.

Figure 1 shows the process of scenario selection under the worst case approach and the threshold approach, for a simplified case when there are only two risk factors (one can, for example, think of changes in the interest rate and the exchange rates). Each ellipse depicts the set of combinations of the two risk factors with the same probability of occurrence. The shape of the ellipse reflects the correlation between the two factors, and its size

FIGURE 1 Worst Case Approach vs. Threshold Approach



Source: Author

the level of plausibility (the larger the ellipse, the smaller the plausibility). The diagonal lines depict combinations of the risk factors leading to the same overall impact, measured here by a change in the system's capital adequacy ratio (CAR). The impact increases with the size of the shocks to the risk factors, so the CAR decreases in the northeast direction. The diagonal lines do not have to be straight; they are only depicted here as such for simplicity. Figure 1 illustrates that the worst case approach and the threshold approach are two essentially equivalent ways of analyzing the same problem.[8]

The worst case approach starts with selecting a level of plausibility (e.g., 1 %), and searching for the combination of shocks with this level of plausibility that have the worst impact on the portfolio. This means searching for the point on the largest ellipse that lies as far northeast as possible. In Figure 1, this is point A.

The threshold approach starts with selecting the threshold, i.e. the diagonal line; it then searches for the most plausible (i.e., smallest) shocks reaching this threshold. This is straightforward if there is only one risk factor; if there are two risk factors, one needs to take into account the correlation between the risk factors. For the specific correlation pattern in Figure 1, selecting a threshold of zero capital adequacy would lead again to the combination of shocks corresponding to point A.

Establishing the plausibility level of a scenario can be difficult in practice, given that the scenario should be a low probability, "tail" event. For risk factors with good time series of historical data (in particular, for market risks), the natural starting point is to base the scenarios on the past volatility and covariance patterns. Calibrating the shocks is particularly straightforward for single-factor stress tests: an exchange rate shock can be based on 3 standard deviations of past exchange rate changes (corresponding roughly to a 1% confidence level). With multiple risk factors, one needs also to look at the covariance statistics of the variables, or use stochastic simulations based on macroeconomic models. Such calculations are subject to a number of caveats mentioned earlier. In particular, models can

[8] To some readers, these two approaches may resemble the dual tasks of microeconomics.

break down for large shocks. Nonetheless, the models, if used cautiously, can help to find a first-cut approximation of stress test scenarios.

Another practical approach to scenario selection is to base the stress tests on an extreme historical scenario. This approach makes it possible to specify relatively complex stress tests with a number of risk factors. For Asian countries, for example, such a scenario might be the 1997 crisis; for the Czech Republic, it might be the 1997 exchange rate turbulence and the ensuing recession.[9] The advantage of this approach is that it is quite illustrative, simple to implement, and it is plausible (because such a crisis already happened). Its disadvantage is that it may be difficult to assess the exact plausibility level of such a crisis, and it can be doubted whether future crises will simply repeat the past.

In practice, future crises can go beyond historical experience. While some authors argue that stress tests should be based only on historical variance and covariance patterns (Berkowitz, 1999), most seem to agree that there can be plausible scenarios that have not yet happened. New crises may include, for example, new concentrations of risk emerging through cross-market linkages not present in the past. Specifying a hypothetical scenario means simulating shocks that are suspected to be more likely to occur than historical observation suggests (or that have never occurred); or reflect a structural break that could occur in the future. The scenario selection in hypothetical scenarios is the same as presented in Figure 1, i.e. it is based on (at least implicit) probability distribution, but the probability distribution is different from the distribution of past observations.

The easiest case in this context is if the hypothetical scenarios indicate that the exposures are small. In this case, the "threshold" approach is a useful presentation tool: for example, if one asks what shocks are needed to make a substantial impact on the financial system and finds that the shocks would have to be several times larger than the largest shocks observed so far, the stress testing scenario provides an important conclusion, namely that the financial system is not very exposed to the risks considered in the scenario. In this case, the extremely low plausibility of the stress testing scenario is actually an advantage, because it helps to make the case that the system is very robust.

A practical possibility for presenting hypothetical scenarios is to combine a historical scenario (e.g. a large crisis that happened in the past) with sensitivity analysis (i.e. alternative assumptions about individual shocks). This approach is still open to the criticism that the level of plausibility of these scenarios is unclear, but it at least provides an anchor (in the form of the historical scenario) and an assessment of the robustness of the scenario's results with respect to changes in the model assumptions.

3.4 Selecting and Implementing Methodology

Once a set of adjustment scenarios have been produced in a consistent macro framework, the next step is to translate the various outputs into the balance sheets and income statements of financial institutions. There

[9] The design of stress tests for the Czech Republic is discussed in more detail in (Čihák, 2004).

are two main approaches to translating macro scenarios into balance sheets: the "bottom-up" approach, where the impact is estimated using data on individual portfolios, and the "top-down" approach, where the impact is estimated using aggregated data. The bottom-up approach should generally lead to more precise results, but it may be hampered by insufficient data and by calculation complexities. The disadvantage of the top-down approach is that applying the tests only to aggregated data could disguise concentration of exposures at the level of individual institutions that could lead to failures of these institutions and then contagion to the rest of the system. Most macroprudential stress tests therefore try to combine the advantages and minimize the disadvantages of the bottom-up and top-down approaches.

The methodologies for individual shocks are discussed in more detail in Section 4. As a general point, when attempting to identify measurement techniques, it is important to understand where exposures may generate losses in the financial system. This requires estimating where these exposures are recorded as positions either on or off the balance sheets of the institutions. In particular in more developed financial systems, finding the exposures may require understanding the details of the risk transfers that have occurred through derivatives and securitization activities.

Isolating the exposures that generate stress loss estimates often requires that institutions "slice and dice" their on- and off-balance sheet positions into sector specific decompositions that they may not typically monitor. Exposure estimates that relate to shocks to a specific economic sector may be obtained by aggregating the exposures from a customized decomposition of a financial institution's alternative activities. For example, a decline in the output of an important industry may be reflected in the stress test by direct loan and bond related losses on credits extended to this industry, by an equity market price shock to investments in firms in this industry, by a rise in consumer credit and mortgage related losses to the extent that wages and employment are adversely affected by the shock, and by losses on the banking and insurance industries' off-balance sheet positions, as counterparties default on their obligations in response to the shock.

3.5 Interpreting Results

Stress tests should be interpreted as rough indicators of exposures rather than as forecasts of financial institutions' failures. By their nature, stress tests focus on extreme events, not on the most probable events. Also, stress test estimates, no matter how technical the model used, are at best only first order approximations of the true potential loss exposure.

When interpreting stress tests, their limitations and assumptions need to be taken into account. An important limitation of stress tests is that they typically assume no reaction by the institutions or supervisors. They view financial institutions as static portfolios rather than actively behaving units. A complete examination of vulnerabilities, however, must take into account also the fact that financial institutions adapt dynamically to shocks in the environment. Depending on the incentives that financial institutions face, these adaptations may exacerbate or mitigate the impact of the initial shock. To understand the structure of incentives that main agents in a financial system may face, it is necessary to look at the institutional environment, such as the corporate governance arrangements in financial institutions; the legal, accounting, tax, and regulatory conditions; and how claim holders on financial institutions may react in the bond and equity markets to actions that financial institutions take – see (Chai – Johnston, 2000).

Another limitation of stress tests is that they typically consider only a part of a financial institution's income generating operations. Financial institutions may have positions in assets that are unaffected under the specific stress scenarios analyzed. In particular, given their focus on financial asset and derivative value changes, stress testing calculations tend to ignore the importance of fee income and other financial institution income sources that are not formally "capitalized" on a financial institution's balance sheet or recognized in off-balance sheet position reports. The income from these operations might offset the losses that would arise in the stress scenario envisioned.

Finally, stress tests are typically based on marking-to-market, while regulatory capital requirements often rely on book values. Therefore, financial institutions may suffer substantial mark-to-market losses on their banking book assets without recording any adverse effect on their regulatory capital position. They can often remain open and avoid default as long as regulators allow them to continue operating, even if they are insolvent on a mark--to-market basis. Therefore, while mark-to-market loss estimates are informative as to an institution's financial risk exposures, they may be less informative about the ability of a financial institution to sustain losses and remain a going concern.

4. Specific Methodological Issues

This section will turn to methodological issues relating to the individual risk factors (in particular, exchange rate risk, interest rate risk, and credit risk) and to the modeling of interbank contagion. With the exception of interbank contagion risk, an introductory exposition is provided in (Blaschke et al., 2001).

4.1 Exchange Rate Risk: "Stress Testing 101"

Exchange rate risk is the risk that exchange rate changes affect the local currency value of financial institutions' assets, liabilities, and off-balance sheet items. Exchange rate risk consists of a *direct* risk, arising from positions in foreign currency (and those in local currency that are indexed to exchange rates), and an *indirect* risk, resulting from the impact of foreign exchange positions taken by borrowers on their creditworthiness and ability to repay, and thereby on financial institutions.

The *direct exchange rate risk* can be assessed using the net open position in foreign exchange, one of the "core FSIs," defined in (IMF, 2004). The direct exchange rate risk is arguably the simplest part of stress tests. To illustrate this stress test, let F denote the net open position in foreign exchange, C the capital, A_{RW} the risk-weighted assets (all in domestic currency units), and e the exchange rate in units of foreign currency per unit of domestic currency. A depreciation (decline) in the exchange rate leads to a proportional decline in the domestic currency value of the net open position, i.e. $\Delta e/e = \Delta F/F$ (for $F \neq 0$). Let us assume, for simplicity, that this translates directly into a decline in capital, i.e. $\Delta C/\Delta F = 1$.[10] The impact of the exchange rate shock on the ratio of capital to risk-weighted assets would then be:

$$\frac{\Delta[C(e)/A_{RW}(e)]}{\Delta e} \cong \frac{\frac{F}{e}A_{RW} - C\,\frac{\Delta A_{RW}}{\Delta C}\,\frac{F}{e}}{{A_{RW}}^2} \cong \frac{1}{e}\,\frac{F}{C}\,\frac{C}{A_{RW}}\left(1 - \frac{\Delta A_{RW}}{\Delta C}\,\frac{C}{A_{RW}}\right) \qquad (1)$$

which uses the fact that $\Delta C/\Delta e = \Delta F/\Delta e = F/e$. The symbol "≅" means that the equation is only approximate for larger than infinitesimal changes. Equation (1) can be rewritten as

$$\Delta[C(e)/A_{RW}(e)] \cong \frac{\Delta e}{e}\,\frac{F}{C}\,\frac{C}{A_{RW}}\left(1 - \frac{\Delta A_{RW}}{\Delta C}\,\frac{C}{A_{RW}}\right) \qquad (2)$$

The term $\Delta A_{RW}/\Delta C$ can have values from 0 to 1, reflecting the degree of co-movement of capital and the risk weighted assets.[11] In the special case of $\Delta A_{RW}/\Delta C = 0$, i.e. if the risk-weighted assets do not change, the change in the capital adequacy ratio equals simply the exchange rate shock times the exposure, measured as a product of the net open position to capital (F/C) and capital adequacy (C/A_{RW}), both of which are "core FSIs" as defined by IMF (2004). This is sometimes used as a short-hand calculation of the direct exchange rate stress test. It should be noted that (2) holds only as a linear approximation, which works well if foreign exchange portfolios are essentially linear. However, if financial institutions have large positions in foreign exchange options, the relationship between the exchange rate change and the impact on capital can become highly non-linear. In such cases, stress tests based on detailed decomposition of financial institutions' open positions are a superior analytical tool.[12]

The *indirect exchange rate risk* is often more significant than the direct one, because the direct exposure is relatively easy to measure and therefore to manage and regulate, while it is typically much more difficult to monitor the foreign exchange vulnerabilities of financial institutions' counterparties. Especially in countries with fixed or heavily managed exchange rates, firms and households can be lulled by the perceived absence of exchange rate risk and enter into large open positions in foreign exchange. In some of these countries, regulators have started to ask financial institu-

[10] An alternative, and arguably more realistic, approach would be to deduct the impact first from profits (if any), and then from capital. See (Čihák, 2004) for a discussion of the treatment of profits in stress tests.

[11] Empirically, $\Delta A_{RW}/\Delta C$ could be estimated by a regression.

[12] As a general point, stress tests should include all relevant off-balance sheet items.

tions to report on their largest borrowers' foreign exchange exposures. The information gathered in this way is useful, but it does not cover, for example, foreign exchange exposures in the household sector, credit to which has been growing rapidly in some countries. Čihák (2004) includes an example of the calculation of the indirect exchange rate risk.

Exchange rate risk was analyzed in almost all FSAP missions. Half of them calculated the impact on the net open foreign exchange position for individual institutions or for groups of financial institutions, which in turn was calibrated in terms of impact on capital. Regressions and Monte Carlo simulations to determine the effect of exchange rate changes on credit quality (NPLs) were applied in about 40 percent of the FSAP missions (IMF – WB, 2003).

4.2 Interest Rate Risk

Interest rate risk is the exposure of a financial institution's financial condition to adverse movements in interest rates. Interest rate changes affect interest income and interest expenses as well as the balance sheet through changes in market prices of financial instruments. Sources of interest rate risk are discussed in (Basel Committee, 2001).

The impact of changes in the interest rate on net interest income is typically measured using the "repricing gap" model. The model allocates interest-bearing assets and liabilities into buckets according to their time to repricing, and the gap between assets and liabilities in each bucket is used to estimate the net interest income exposure to interest rate changes – see (Blaschke, 2001) for practical examples. The position in interest-based financial derivatives can be incorporated into this analysis by recalculating the expected future receipts and payments as interest rates change.

There are two commonly used approaches to measuring the effect of interest rate changes on market prices of financial instruments: the duration model and the "gap" model. Duration, defined as the weighted average term to maturity of assets/liabilities, is a direct measure of the interest rate elasticity of an asset or liability.[13] The higher the duration, the more sensitive the price of an asset or liability to changes in interest rates,

$$\frac{\Delta A(r_A)}{A(r_A)} \cong \frac{-D_A \Delta r_A}{(1+r_A)}, \quad \frac{\Delta L(r_L)}{L(r_L)} \cong \frac{-D_L \Delta r_L}{(1+r_L)} \tag{3}$$

where $A(r_A)$ and $L(r_L)$ are market values of assets and liabilities, and r_A and r_L are annual interest rates on assets and liabilities (Bierwag, 1987). This feature of duration can be used to summarize the impact of interest rate changes on financial institutions' capital. In particular, capital can be defined as $A(r_A) - L(r_L)$, and expressed as a ratio to risk weighted assets.[14] Differentiating capital with respect to the interest rate on assets, and sub-

[13] For the formula defining duration and practical examples of its calculation, see (IMF, 2004).

[14] The impacts can also be expressed in terms of banks' profitability, which may be useful when branches of foreign banks, which typically do not have own capital, play an important role. Bierwag (1987) derives the impact on profits in the case of a single bank.

stituting from (3), the sensitivity of the C/A_{RW} ratio to interest rate changes can be expressed as:

$$\frac{\Delta[C(r_A, r_L)/A_{RW}(r_A)]}{\Delta r_A} \cong -\frac{(L/A_{RW})}{1 + r_A}\left(D_A - D_L \frac{1 + r_A}{1 + r_L}\frac{\Delta r_L}{\Delta r_A}\right)\frac{1 - \dfrac{\Delta A_{RW}}{A_{RW}}\dfrac{C}{\Delta C}}{1 - \dfrac{\Delta A}{A}\dfrac{C}{\Delta C}} \cong -\frac{(L/A_{RW})}{1 + r_A} GAP_D \qquad (4)$$

where the approximation on the second line assumes that the risk-weighted assets move proportionately to total assets, i.e. $\Delta A_{RW}/A_{RW} = \Delta A/A$. GAP_D is the duration gap, defined as:

$$GAP_D = D_A - D_L \frac{1 + r_A}{1 + r_L}\frac{\Delta r_L}{\Delta r_A} \qquad (5)$$

The formulas (3) and (4) are linear approximations that hold exactly for small changes in interest rates. For large changes in interest rates (typically assumed in stress tests), it is necessary to take into account nonlinearity, as duration can change with large changes in interest rates. Given that the price-yield relationship is convex rather than linear, duration typically overpredicts the fall in prices for large interest rate increases and underpredicts the increases in prices for large interest rate declines. A new parameter (named *CX* for "convexity") can be specified and estimated which increases the precision of the estimates of the changes in the value of assets and liabilities:[15]

$$\frac{\Delta A(r_A)}{A(r_A)} \cong \frac{-D_A \Delta r_A}{(1 + r_A)} + \frac{CX_A}{2}(\Delta r_A)^2, \quad \frac{\Delta L(r_L)}{L(r_L)} \cong \frac{-D_L \Delta r_L}{(1 + r_L)} + \frac{CX_L}{2}(\Delta r_L)^2 \qquad (6)$$

An alternative approach to assessing the price revaluation effect of an interest rate shock is to use "gap" analysis. Under this approach, expected payments on assets and liabilities are sorted into time "buckets" according to the time to repricing for floating-rate instruments, and the time until payments are due on fixed-rate instruments. The net present value of assets and liabilities can be derived by discounting the net cash flows in each time bucket, and the effect of an interest rate shock estimated by rediscounting the net cash flows using the changed interest rates. IMF (2004) provides a template for conducting such a gap analysis.

Interest rate risk was analyzed in the majority of the FSAP missions. Reflecting data constraints, most FSAPs used maturity buckets and gap analysis. Some used more advanced techniques based on duration or VaR. About 25 percent of FSAP missions did not obtain data on maturity buckets or duration and used income statement data instead to calculate simple earnings at risk (IMF – WB, 2003).

[15] For more details, see, e.g., (Saunders, 2000).

4.3 Credit Risk

Credit risk is the loss associated with unexpected changes in credit quality. Despite innovations in banking, credit risk is typically the most significant source of risk. Credit risk arises mostly from loans, but also from positions in corporate bonds or from over-the-counter transactions that involve the risk of a counterparty default.

Measuring credit risk involves estimation of a number of different parameters: the likelihood of default on each instrument both on average and under extreme conditions; the extent of the losses in the event of default, which may involve estimating the value of collateral; and the likelihood that other counterparties will default at the same time.

There are two general approaches to macroprudential stress tests for credit risk. First are approaches based on loan performance data (i.e. on the classification of loans into the various categories of performing and non-performing loans). Second are approaches based on data on borrowers, which are typically balance sheet or income statement data about financial institutions' borrowers.

More than half of the FSAP missions used NPL-based approaches to modeling credit risk. About 60 percent of the missions used ad-hoc NPL migration. About 30 percent of the missions applied regression analyses to examine the impact of potential macroeconomic shocks on the behavior of NPLs (IMF – WB, 2003).

4.3.1 Approaches Based on Loan Performance Data

The advantage of loan performance data is that they are readily available to supervisors. Also, they are available for all sectors, including the household sector, for which it is difficult to obtain reliable balance sheet or income statement information. The key disadvantage of this approach is that NPLs are lagging indicators of asset quality.

The first subgroup of these approaches are those based on asset reclassification, i.e. those that model a transition of loans (and similar assets) one or more classification categories down. The effect of the asset reclassification on the capital adequacy ratio is calculated after deducting the additional provisions from capital and from assets. There are various types of asset reclassification, purely mechanical (e.g. a percentage of loans in each category is moved down by a category), or based on experience with past crises (e.g. the same loan reclassification as happened during a recent crisis). If sufficiently detailed information is available, the reclassification can be based on "peer reviews" whereby loans to the same borrower from different institutions are reclassified according to the lowest grade assigned by an institution. Another version of this approach are "supervisory peer reviews": for example, if recent on-site examinations in some financial institutions uncovered significant discrepancies between reported and "true" classification of loans, a stress test could assess what would happen if similar discrepancies were present in other institutions.

The second subgroup of approaches in this group are those based on an econometric model including NPLs and a number of macroeconomic factors, such as real interest rates, GDP growth, and terms of trade changes.[16] The model can be a single equation regression, a vector auto-regression, or a structural model, but the first two approaches are more common. The regressions can be run on the level of economic sectors (if there are sectoral data on NPLs) or even on the individual financial institution level (to capture the financial institutions' different sensitivities to macroeconomic developments). However, the institution-by-institution approach can be too resource intensive. It is therefore more common to estimate regressions for aggregated data and to apply the estimated parameters into institution-by--institution calculations based on the individual financial institutions' positions (to use the terminology introduced earlier, this is a combination of a top-down approach with the bottom-up approach). Typical problems with the regression approach include the lack of long and consistent time series data on NPLs. Even where the data are available for a long time period, they may exhibit structural breaks due to changing definitions of NPLs or policy changes.

4.3.2 Approaches Based on Data on Borrowers

The advantage of borrower data is that they can provide more substance to the credit risk stress test by allowing to explicitly model linkages between the health of the real sector and the banking sector. Another advantage is that borrower data can help to indicate problems in the loan portfolio earlier than the loan classification. A disadvantage is that borrower data (in particular for households and small enterprises) are often difficult to obtain and are typically available only with long lags.

Cross-country calculations suggest that leverage (i.e. the ratio of borrowers' debt and equity) is a good predictor for the ratio of gross NPLs to total loans (NPL ratio). A panel data estimate included in (IMF, 2003) suggests that a 10 percentage point increase in corporate leverage is associated with a 1.8 percentage point rise in the NPL ratio after one year; and a 1 percentage point rise in GDP growth results on average in a 2.6 percentage point decline in the NPL ratio.

There is a wide range of approaches to modeling credit risk using borrower data. A relatively elaborate approach is to estimate a model predicting individual company bankruptcy probabilities as a function of company age, size, industry characteristics, and corporate soundness indicators (leverage, earnings, liquidity, financial strength) of a borrower. To capture the indirect risk, the model should include interest and exchange rates among explanatory variables. Individual financial institutions are linked to the exercise through their exposures to the various groups of companies (e.g., using a decomposition of their lending by industries). This can then be used to predict financial institutions' potential losses (taking into account collateral). (Eklund et al., 2001) is an example of a model of this type, used by the Bank of Norway.

[16] See (Blaschke et al., 2001) for an illustration.

In comparison with the direct exchange rate risk, the modeling of the indirect effect is more complex and dependent on additional assumptions or regression analysis. The calculation of the indirect effect needs to include the impacts on stocks as well as on flows. It must reflect the impact of exchange rate changes on the net present value of the corporate sector, which means taking into account changes in the net present value of future earnings. For example, in export-oriented companies, a depreciation can be expected to increase their future earnings. In terms of the net present value, the effect would be essentially equivalent to the impact of a long position in foreign currency. However, it may be more practical to calculate the impact on flows, by estimating the elasticity of earnings to interest and principal expenses with respect to the exchange rate, and then to estimate the relationship between this FSI and the NPL ratio. Alternatively, one can look at an indicator measuring the corporate sector's flow exposure, e.g. the ratio of earnings in foreign exchange to interest and principal expenses in foreign exchange.

4.4 Other Risks

Of other risk factors, liquidity risk – the risk that assets are not readily available to meet a demand for cash – is the most important one. Modeling liquidity risk is often considered to be much more difficult than modeling interest rate or exchange rate risk. Many central banks therefore rely on the liquidity stress tests conducted by the financial institutions themselves. The results of these stress tests are reported off-site, which is followed up by integrity checks during on-site visits.

The most challenging step in designing a liquidity stress test is identifying which assets that are normally considered liquid may become illiquid in periods of financial stress. (IMF, 2004) provides operational guidelines for defining liquid assets and liquid liabilities which could be used as the starting point for conducting stress tests. A straightforward approach to stress testing the liquidity risk is to shock the value of liquid resources by a certain percentage or amount. The percentage or amount could be determined based on past bank runs or on a rule of thumb, and it should generally be different for different maturities. A rule of thumb used by some supervisors is that a financial institution should be able to survive at least five days of a moderate liquidity run without outside support. The reason behind this choice of threshold is that this would make it possible for the financial institution to survive till the weekend, when they are closed for business. This "cooling-off" period would enable the institution and its supervisors to better assess the situation and, where appropriate, take necessary actions.

Other shocks include adverse changes in equity prices, real estate prices, and commodity prices. Equity price risk is modeled in a similar way to direct exchange rate risk. The calculation is based on the net open position in equities, which is defined in a similar fashion to the net open position in foreign exchange (IMF, 2004). Exposure to real estate price risk consists of (i) the direct exposure (investment in real estate), (ii) credit exposures (e.g. lending to real estate developers), and (iii) risk resulting from the degree

TABLE 2 Matrix of Bank-to-Bank Exposures

	Bank 1	Bank 2	. . .	Bank *n*
Bank 1	-- --	Net exposure of bank 1 to bank 2	. . .	Net exposure of bank 1 to bank *n*
Bank 2	Net exposure of bank 2 to bank 1	-- --	. . .	Net exposure of bank 2 to bank *n*
:	:	:	-- --	:
Bank *n*	Net exposure of bank *n* to bank 1	Net exposure of bank *n* to bank 2	. . .	-- --

of real estate collateralization. The risk arising from real estate collateral should be seen in relation to the credit risk; it increases with the loan-to--value ratio (i.e. the ratio of the outstanding loan to the value of the collateral) and with the default probability. Finally, stress tests for commodity price risk have been carried out in some FSAP missions and by some central banks, notably in developing countries, where trade in commodities is important (IMF – WB, 2003).

4.5 Interbank Contagion Stress Test

Interbank stress testing complements the standard set of stress tests by measuring the risk that the failure of a bank or a group of banks triggers failures of other banks in the system. There are a number of interbank contagion channels. The most direct one is contagion through uncollateralized interbank lending, an important transmission channel during the Asian crisis. Other plausible channels of contagion include reputational effects, whereby a perceived stability problem in a bank could make it difficult or more expensive for other banks in the system to borrow liquidity in international markets. The reputational effect of a failure of a bank can also lead to liquidity runs on other banks that are perceived as weak. Conceptually, modeling reputational effects is similar to modeling contagion through lending exposures. Empirically, however, it is easier to measure the exposures in terms of interbank lending rather than those in terms of reputational risk. Čihák (2004b) offers a discussion of proxy variables to assess the reputational contagion.

There are two basic types of interbank contagion stress tests: (i) *pure interbank stress test*, where the shock is the failure of one bank, triggered for example by fraud, and where the impact on other banks in the system is through the interbank exposures; (ii) *integrated interbank stress test*, where the banking system is first subjected to macroeconomic shocks or scenarios and if these shocks or scenarios trigger a failure of a bank or a group of banks, the interbank stress test is run to assess the impact of additional failures through interbank exposures, as in the pure interbank stress test.

The key element of all interbank contagion calculations is a matrix of bilateral interbank exposures (*Table 2*). In this matrix, the cell in the i-th row and j-th column contains the net uncollateralized lending from bank i to bank j, covering all on- and off-balance sheet exposures.

Let us focus on the *"pure" interbank contagion stress test*, which aims to estimate the impact of the failure of a bank or group of banks on the system. The test assumes that there is a failure in a bank (say, Bank 1), for instance due to fraud. The first round of the contagion calculation would derive the direct impact of Bank 1's failure on each of the other banks, assuming Bank 1 would not repay its uncollateralized interbank exposures (or part of the exposures). If some banks fail as a result of Bank 1's failure,[17] the second round of the calculation would derive the impact on each of the remaining banks of these newly failed banks not repaying their uncollateralized interbank exposures. The process can be repeated for a third time if there are new failures after the second run, and so on. Concrete examples of such interbank contagion tests and their results can be found in (Furfine, 2003) for US banks, in (Wells, 2002) for UK banks, in (Blåvarg – Nimander, 2002) for Swedish banks, and in (Elsinger – Lehar – Summer, 2002) for Austria.

Two indicators of systemic risk can be calculated from the output of the pure interbank stress test: (i) a frequency of bank failure indicator, which is the ratio of the cumulative number of failures to the number of banks in the system, (ii) statistical measures of the impact on bank system capital (e.g., mean, distribution, and quartiles). Specifically, one can define a "systemic risk index", the average reduction in capital ratios of banks in the system triggered by a failure of a bank. Such a measure could be computed for all banks in the system and used to rank them by their systemic importance. For an interesting example of presenting the network structure of the interbank market, see (Boss et al., 2004) for the case of Austria.

5. Conclusions

Macroprudential stress testing is a rapidly developing area of financial sector analysis. The usefulness of macroprudential stress tests derives from the fact that they provide a quantitative measure of the vulnerability of the financial system to substantial changes in risk factors. This can be used in combination with other analytical tools to draw conclusions about the overall stability of a financial system.

The methodology of macroprudential stress testing is, as illustrated in this review, far from standardized. This lack of standardization partly reflects the fact that stress testing of financial systems is still a new and rapidly developing area. It also reflects the fact that stress tests need to be tailored to individual circumstances, depending on the prevailing macroeconomic risks in a country, the structure of its financial system, and data availability. For these reasons, stress tests can hardly be as comparable among countries as national accounts data (in macroeconomic analysis) or

[17] The simplest way to implement this is to assume that a bank fails if its capital becomes negative as a result of the shock. A more complex calculation could be based on a mapping from capital adequacy to the probability of failure, if such mapping could be estimated based on past data.

financial soundness indicators (in financial sector analysis). Nonetheless, stress tests can still substantially contribute to understanding financial system vulnerabilities. In particular, if they are performed regularly and the development of their results over time is analyzed, stress tests can help assess how the risk profile of the financial system is changing over time, and can indicate possible sources for concern.

Judging from the growing number of central banks and other agencies in various countries that have recently started carrying out macroprudential stress tests, this stream of literature is likely to grow for some time. A key issue for future work is to improve credit risk modeling, which requires much better data on borrowers as well as further advances in the methodology. Related topics include improvements in modeling of indirect exchange rate risk and indirect interest rate risks, and contagion among banks as well as between non-bank financial institutions and banks.

REFERENCES

ALLEN, F. – GALE, D. (2000) *Comparing Financial Systems*. Cambridge, London, MIT, 2000.

Austrian National Bank (2004): *Financial Stability Report*, no. 7, June 2004.

Banco de Portugal (2004): The Banking System in the First Half of 2004. *Banco de Portugal, Economic Bulletin*, September 2004.

Bank of England (2003): *Financial Stability Review*, December 2003.

Bank of Slovenia (2004): *Financial Stability Report* for 2003. June 2004.

Basel Committee on Banking Supervision (2001): *Principles for the Management and Supervision of Interest Rate Risk.* Basel, Bank for International Settlements, 2001.

Basel Committee on Banking Supervision (2004): *Basel II: International Convergence of Capital Measurement and Capital Standards: a Revised Framework*. http://www.bis.org/publ/bcbs107.htm

BERKOWITZ, J. (1999): A Coherent Framework for Stress-Testing. Washington, *Board of Governors of the Federal Reserve Board*, *Finance and Economics Discussion Series*, July 1999.

BESSIS, J. (2003): *Risk Management in Banking*. Second Edition. J. Wiley & Sons, 2003.

BIERWAG, G. (1987): *Duration Analysis*. Harper & Row, Cambridge (Mass.), 1987.

BLASCHKE, W. – JONES, M. – MAJNONI, G. – MARTINEZ PERIA, S. (2001): Stress Testing of Financial Systems: An Overview of Issues, Methodologies, and FSAP Experiences. Washington, *International Monetary Fund, Working Paper*, no. 01/88.

BLÅVARG, M. – NIEMANDER, P. (2002): Inter-bank Exposures and Systemic Risk. *Sveriges Bank*, *Economic Review*, no. 2/2002.

BOSS, M. (2002): A Macroeconomic Credit Risk Model for Stress Testing the Austrian Credit Portfolio. *Austrian National Bank*, *Financial Stability Report*, 2002, no. 4.

ČIHÁK, M. (2004a): Stress Testing: A Review of Key Concepts. *CNB, Internal Research Policy Note*, no. 2/2004.

ČIHÁK, M. (2004b): Designing Stress Tests for the Czech Banking System. *CNB, Internal Research Policy Note,* no. 3/2004.

CHAI, J. – JOHNSTON, R. (2000): An Incentive Approach to Identifying Financial System Vulnerabilities. Washington, *International Monetary Fund, Working Paper*, no. 00/211.

Committee on the Global Financial System (2001): A *Survey of Stress Tests and Current Practice at Major Financial Institutions*. Basel, Bank for International Settlements, 2001.

Czech National Bank (2004): *Financial Stability Report 2004*.

Danmarks Nationalbank (2003): *Financial Stability 2003*.

Deutsche Bundesbank (2004): *Report on the Stability of the German Financial System*, *Monthly Report*, October 2004.

De Nederlandsche Bank (2004): *Overview of Financial Stability in the Netherlands*, December 2004, no. 1.

DOWD, K. (2002): An *Introduction to Market Risk Measurement*. John Wiley & Sons, 2002.

EKLUND, T. – LARSEN, K. – BERHARDSEN, E. (2001): Model for Analysing Credit Risk in the Enterprise Sector. *Bank of Norway Economic Bulletin*, no. Q3/2001.

ELSINGER, H. – LEHAR, A. – SUMMER, M. (2002): A New Approach to Assessing the Risk of Interbank Loans. *Austrian National Bank*, *Financial Stability Report,* 2002, no. 3.

European Central Bank (2004): *Financial Stability Review*, December 2004.

FURFINE, C. (2003): Interbank Exposures: Quantifying the Risk of Contagion. *Journal of Money, Credit, and Banking*, vol. 35, 2003, no. 1.

GOODHART, C. A. E. – SUNIRAND, P. – TSOMOCOS, D. P. (2003): A Model to Analyse Financial Fragility. *Oxford Financial Research Centre Working Paper*, no. 2003fe13.

International Monetary Fund (2003): *Financial Soundness Indicators – Background Paper*. http://www.imf.org/external/np/sta/fsi/eng/2003/051403b.htm

International Monetary Fund (2004): *Compilation Guide on Financial Soundness Indicators*. http://www.imf.org/external/np/sta/fsi/eng/2004/guide/index.htm

International Monetary Fund – the World Bank (2003): *Analytical Tools of the FSAP*. http://www.imf.org/external/np/fsap/2003/022403a.pdf

JÍLEK, J. (2000): *Finanční rizika*. Praha, Grada, 2000.

JONES, M. – HILBERS, P. – SLACK, G. (2004): Stress Testing Financial Systems: What to Do When the Governor Calls. Washington, *International Monetary Fund, Working Paper*, no. 04/127.

KALIRAI, H. – SCHEICHER, M. (2002): Macroeconomic Stress Testing: Preliminary Evidence for Austria. *Austrian National Bank*, *Financial Stability Report*, no. 3.

KUPIEC, P. (2001): *Stress Testing and Financial Sector Stability Assessments: A Basic Recipe for an FSAP Stress Test*. Washington, International Monetary Fund – mimeo.

LAUBSCH, A. (2000): *Stress Testing*. Chap. 2: "Risk Management, A Practical Guide". New York, RiskMetrics Group, 2000.

National Bank of Hungary (2003): *Report on Financial Stability*, June 2003.

National Bank of Poland (2004): *Financial Stability Review*, First Half of 2004.

National Bank of Slovakia (2004): *Financial Stability Report for 2003*.

Norges Bank (2004): *Financial Stability, 2004:1*. June 2004.

SAUNDERS, A. (2000): *Financial Institutions Management: A Modern Perspective*. 3rd Ed. McGraw-Hill, Boston, 2000.

SEKERKA, B. (1998): Řízení bankovních rizik. Praha, Profess Consulting, 1998.

SORGE, M. (2004): Stress-testing Financial Systems: an Overview of Current Methodologies. *BIS Working Paper*, no. 165.

SUNDARARAJAN, V. – ENOCH, C. – SAN JOSÉ, A. – HILBERS, P. – KRUEGER, R. – MORETTI, M. – SLACK, G. (2002): Financial Soundness Indicators: Analytical Aspects and Country Practices. Washington, *International Monetary Fund, Occasional Paper*, no. 212.

Sveriges Riksbank (2004): *Financial Stability Report, 2004:2.*

WELLS, S. (2002): UK Interbank Exposures: Systemic Risk Implications. *Bank of England, Financial Stability Review*, December 2002.

WORRELL, D. (2004): Quantitative Assessment of the Financial Sector: An Integrated Approach. *IMF Working Paper*, 2004, no. 153.

SUMMARY

JEL Classification: G21, G28, G29
Keywords: financial soundness – financial systems – stress testing

Stress Testing of Banking Systems

Martin ČIHÁK – International Monetary Fund, Washington, D.C. (mcihak@imf.org)

In response to the increased financial instability of many countries in the 1990s, policy makers sought a better understanding of the vulnerabilities of financial systems and of measures that could help prevent financial crises. A key technique for quantifying financial-sector vulnerabilities is stress testing. This paper surveys the literature in the developing field of stress-testing financial systems and in particular banking systems.

Stress tests are useful because they provide a quantitative measure of the vulnerability of a financial system to risk factors. This can be useful in combination with other analyses to draw conclusions about the overall stability of a financial system. The value added of macroprudential stress tests derives from their forward-looking macroeconomic perspective, their focus on the financial system as a whole, and their uniform approach to the assessment of risk exposures across institutions. The value added of stress tests can be particularly high if tests are performed regularly and their results analyzed over time.