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New Approaches to Stress Testing the Czech Banking Sector

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Abstract
This paper provides an overview of the stress testing of the Czech banking sector conducted by the Czech National Bank. The paper begins by updating historical and hypothetical stress-testing scenarios. It also includes a sensitivity analysis of the interest-rate risk and new presentation forms of such. The results of interbank contagion tests (both simple and combined) based on Czech banks' exposures on the interbank market are offered. Finally, the paper integrates the stress testing with CNB macroeconomic forecasts (i.e., the quasi--phase-matching model). The authors' stress testing was also integrated with the macroeconomic credit-risk model, with the impact on individual bank portfolios, and with interbank contagion. One baseline and three alternative scenarios were tested they have shown that the Czech banking sector was relatively resilient to the shocks. However, the exercise also revealed certain limitations of the stress-testing approach, to which the authors offer recommendations for the further development of this apparatus.

1. Introduction

Financial stability may be viewed as a situation where the financial system shows a high degree of resilience to exogenous shocks. Macroprudential stress testing is a key tool of measuring financial stability because its aim is to quantify the impact of extreme, but plausible shocks to the financial system.[2] Reflecting the importance of stress testing in financial stability, about 75 % of the central banks publishing Financial Stability Reports or similar publications presented stress-testing results in these reports at the end of 2005 (Čihák, 2006).[3]

The subject of this article is to describe stress tests developed in the Czech National Bank. The basic methodology for stress tests for the Czech National Bank is

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[2] The focus of this paper is macroprudential stress tests, which try to assess the robustness of the financial system as a whole. Stress tests can also be carried out for portfolios of individual institutions, for risk management or supervisory purposes. These so-called microprudential stress tests are not the subject of this article. A short survey of stress-testing practices in Czech banks is provided in Čihák (2005). A survey for the major global financial institutions can be found in Committee on the Global Financial System (2005).

[3] For a general discussion of the goals and features of the financial stability analysis, see Schinasi (2005).

described in detail in (Čihák, 2004b), (Čihák, 2005) and (Čihák, Heřmánek, 2005). Stress-test methodology described in those articles was then applied (with some modifications and further developments to the methodology) in the CNB's Financial Stability Reports (CNB, 2005), (CNB, 2006). This paper includes updates for the results of the stress test together with some new forms of presentation of its results. The more advanced forms of stress testing (Section 5) integrate risk scenarios based on the CNB's official forecast (QPM macroeconomic model (see (CNB, 2003)), with the macroeconomic credit-risk model ((see (Jakubík, 2007)) and with previously described methods of interbank contagion (see Section 4 of this article).

As part of the quantitative assessment of financial stability, a series of stress tests were performed to examine the resilience of the banking sector to the impact of selected macroeconomic shocks. These tests focus on detecting risks in the credit, exchange-rate and interest-rate structures of portfolios and capturing the potential impacts of interbank contagion. Although the tests are constructed for the financial sector as a whole, they use the data on the individual banks' balance sheets. The impacts of shocks on portfolios of individual banks are then aggregated (the so-called "bottom-up approach"). The stress tests were based on the principles and procedures used by the International Monetary Fund and the World Bank in missions of the Financial Sector Assessment Program (FSAP). Similar tests are also conducted by numerous foreign central banks.[4]

The article is organized as follows: The first section contains results of updated basic tests according to the methodology presented in the CNB's 2004 *Financial Stability Report* (CNB, 2005). Although these tests are relatively simple from the methodological point of view, their advantage is that they have been conducted on a consistent basis since the end of 2000, which allows analyzing the development in the sensitivity of the banking sector to external shocks. The second section focuses on the impacts of the interest shock. It presents sensitivity analysis of the approach used in the first section in terms of different sizes of the shock as well as different types of changes to the yield curve. The third section newly presents the results of analysis of contagion among banks through their exposures in the interbank market. The fourth section presents the results of macro stress tests, based on a consistent macroeconomic model. The fifth section concludes the article and provides suggestions for further work in this area.

2. Basic Stress Tests with Historical Scenarios

These basic tests are based on the methodology of two scenarios (scenarios I and II) representing two different types of stress.[5] The values of the parameters in each scenario were set in the same way as in the CNB's *Financial Stability Reports* in order to allow for comparisons. These scenarios take into account the prevailing

[4] As in many other countries, the first impetus to carry out regular stress tests of the Czech banking sector came from the country's participation in the IMF-World Bank Financial Stability Assessment Program (FSAP). The FSAP for the Czech Republic was conducted in 2001. The CNB's stress testing methodology was further developed in (Čihák, 2004b), (Čihák, 2005) and (Čihák, Heřmánek, 2005). A survey of the use of tests around the world and the testing methodology are included in (IMF, World Bank, 2003, 2005a).

[5] The basic stress test methodology, including the results of the impact of the shocks in scenarios I and II, was published in the *Financial Stability Reports* (CNB, 2005, 2006), (Čihák, 2004b), and (Čihák, Heřmánek, 2005).

TABLE 1 Summary of Stress Test Results, Banking Sector
(data in % unless indicated otherwise)

	December 2000	December 2002	December 2004	June 2006
Pre-test CAR [a]	***14.9***	***14.1***	***12.6***	***11.5***
large banks	13.8	13.5	11.2	10.3
medium banks	16.7	16.9	16.8	15.8
small banks	21.6	19.5	18.9	14.1
Scenario I				
Total impact of the shocks (percentage points)	-3.2	-3.2	-2.3	-2.2
Interest rate shock	-0.9	-1.2	-1.6	-1.6
Exchange rate shock	1.2	0.7	1.0	1.1
Credit shock	-3.6	-2.7	-1.7	-1.6
of which indirect impact of exchange rate shock	-1.5	-1.2	-1.1	-1.1
Allocation of profits (percentage points) [b]	-0.1	0.8	1.7	1.6
Post-test CAR	***11.6***	***11.7***	***12.0***	***11.0***
large banks	10.9	11.6	11.2	10.3
medium banks	12.0	11.7	15.2	14.1
small banks	14.3	11.3	17.0	13.5
Capital injections (% of GDP) [c]	0.2	0.1	0.0	0.1
Share of banks with negative capital after shock [d]	2.2	0.1	0.0	1.0
Effect on dividens and bonuses [e]	-79.5	-92.7	-53.9	-65.9
Scenario II				
Total impact of the shocks (percentage points)	-3.1	-4.7	-5.0	-4.8
Interest rate shock	-1.8	-2.5	-3.3	-3.3
Exchange rate shock	1.7	0.9	1.4	1.5
Credit shock	-3.0	-3.2	-3.1	-3.0
of which indirect impact of exchange rate shock	-2.0	-1.6	-1.5	-1.4
Allocation of profits (percentage points) [b]	0.0	1.3	2.8	2.8
Post-test CAR	***11.7***	***10.6***	***10.4***	***9.6***
large banks	11.5	10.6	10.2	9.3
medium banks	10.6	10.8	13.5	12.3
small banks	14.0	10.3	15.5	12.9
Capital injections (% of GDP) [c]	0.3	0.3	0.5	0.5
Share of banks with negative capital after shock [d]	2.2	4.0	9.3	2.3
Effect on dividens and bonuses [e]	-93.2	-96.0	-95.3	-100.0

Notes: [a] CAR capital adequacy ratio, defined in accordance with relevant CNB regulations.

[b] Both scenarios assume that in the absence of shocks each bank would generate a profit (loss) equal to the average of the previous five years and that it would use any profit as a first line of defence against a reduction in its CAR.

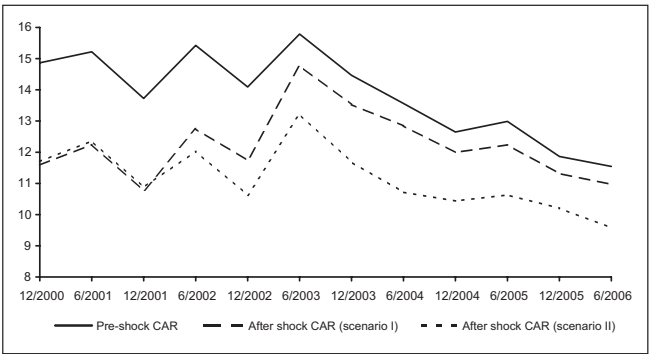
[c] The capital needed to ensure that each bank in the system has a post-test CAR of at least 8 %.

[d] Market share of banks with negative capital folloving the assumed shocks (in % of total assets).

[e] In % of dividends and bonuses of the previous calendar year.

international practice and the Czech conditions. In choosing the parameters, historical shocks (the Czech Republic's experience in 1997–1999) were taken into account. Scenario I is a combination of a hypothetical increase in interest rates of one percentage point, a 15% depreciation of the exchange rate and a 30% increase in the share of nonperforming loans (NPLs) by reclassification of loans. Scenario II combines an increase in interest rates of two percentage points, a depreciation of 20 % and an increase in the share of NPLs in total loans of three percentage points.[6] The impacts of these two scenarios were assessed by comparing the capital adequacy ratio (CAR) before the hypothetical shocks (the pre-test CAR) and after the impact of

CHART 1 Results of Stress-Testing Scenarios for the Banking Sector of the Czech Republic (CAR in %)



Source: CNB – single methodology for stress testing 2005

the model shocks on the banks' portfolios (the post-test CAR, see *Table 1*). The data from the end of the first half of 2006 were used. The results of the stress tests were compared with the results of the tests performed under the same methodology for the previous period starting from 2000. The stress tests followed the "bottom-up" methodology, i.e. they were implemented on financial data of individual banks and subsequently aggregated for the entire banking sector.[7]

The pre-test CAR[8] declined by 3.4 percentage points between 2000 and mid--2006. This decline was due to the fact that some banks used retained profits for the payment of dividends and also to an increase in risk-weighted assets. In the same period, the post-test CAR declined by only 0.6 percentage point (for Scenario I) and by 2.1 percentage points (for Scenario II). The fact that this decline in the post-test CARs was lower than the decline in the pre-test CAR suggests that the banks' exposure to basic types of risk also declined. Also, even after the decline, the post-shock CARs in both Scenario I and Scenario II remained above the 8% regulatory minimum (see *Chart 1*).

When interpreting stress-testing results, it is important to asses the distribution of the capital adequacy prior to and after shocks. Even if the post-test CAR for the banking sector as a whole might be favourable, it could be below 8 % (the regulatory minimum) for individual banks. Reaching this minimum would require a capital injection by the banks' owners. The dispersion [9] of the pre-test and post-test CARs declined (see *Chart 2*), which indicates an improvement in financial stability, since ceteris paribus lower dispersion means that a lower share of the banking sector could

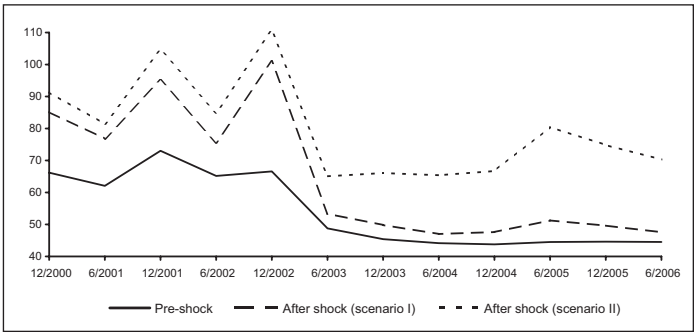
[6] The impact of the stress test in Scenario I is much smaller in 2006 than in 2000 (see Table 1 and Chart 1). This is mainly because of the construction of the credit risk shock under this scenario defined as a percentage of the total level of the NPLs. The NPLs share in total credit was 22.1% at the end of 2000, thus the 30% increase of NPLs under Scenario I would lead to an increase of this share of 6.6 p.p. In June 2006 the share of NPLs was only 3.6 %, thus the increase of NPLs would cause an increase of this ratio of 1.1 p.p.

[7] The basic stress tests concerned 24 banks that held the entire capital of the banking sector and 90.5 % of its total assets. The remaining portion of assets comprise the balance sheets of 12 branches of foreign banks that do not hold any capital in the Czech Republic.

[8] i.e., the actual CAR measured as the ratio of capital to risk-weighted assets of the banking sector

[9] This dispersion was calculated as weighted standard deviation among individual banks, where the weights were the shares of the individual banks on the risk weighted assets (RWA).

CHART 2 Dispersion of the CA among banks (in % of total CAR)



Source: CNB – single methodology for stress testing 2005

experience problems after an additional shock (i.e. a lower share of banks would have capital adequacy lower than 8 %). However, Scenario II leads to an increase in the dispersion compared to the pre-shock CAR, i.e. banks that are more exposed to the risks in Scenario II have lower capital buffers compared to their peers. In the optimal situation, the relative capital buffer should be linked to the exposure of each bank to the risks from stress-testing scenarios and thus the dispersion of the after-shock CAR among banks should be lower than this dispersion before imposing the shock.

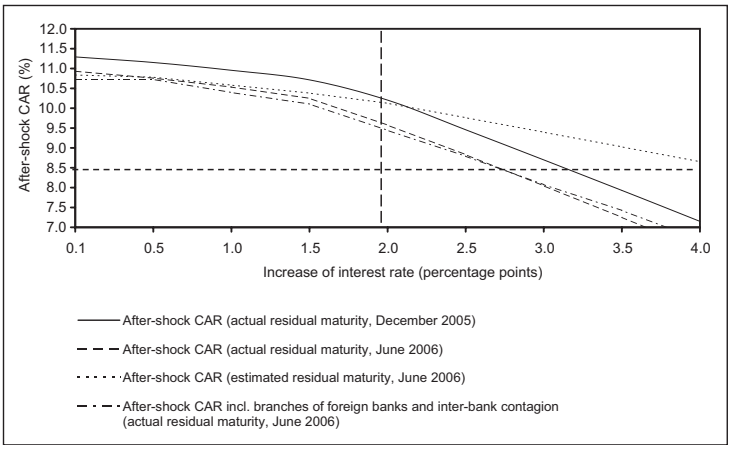
The weight of individual risk factors changed in the period under review. In the context of an overall decline in risks, the negative impact of the interest-rate risk increased in absolute terms, the exchange-rate risk impact decreased in absolute terms, and the impact of credit risk stagnated. Large banks experienced a decline in their post-test CAR, but the banks are better prepared to absorb adverse stress than previously under both scenarios. The small and medium-sized banks had an acceptable CAR even after the tests.

3. Resilience to an Interest-Rate Shock

Whereas the previous section presented the stress-testing results for the two scenarios combining a number of risk factors, in this section we focus on one risk factor, namely interest risk, and analyze it in more detail. The effect of the stress induced by a gradual increase in the interest-rate shock was examined within the results of Scenario II, with the other parameters of the scenario remaining constant (see *Chart 3*). The banking sector was capable of absorbing the impact of an immediate increase in interest rates of up to three percentage points, especially if, under these adverse circumstances, the banks were to hold the one-or-more-year bonds in their portfolios to maturity. For the estimated residual maturity[10] the robustness of the stress test would correspond to a parallel shift in the yield curve of up to four percentage points, without the CAR of the banking sector declining below 8 %.[11] Compared to the previous two years the bank portfolios are relatively more sensitive to unexpected increases of the interest rates.

[10] Banking experts of commercial banks specify in their reports the estimated maturity of bonds and other financial instruments they are able to sell (or that will be redeemed) based on their estimates even prior to their formal contractual maturity.

CHART 3 Robustness of the Stress Test under Scenario II for the Interest-Rate Shock



Note: Estimated residual maturity is based on estimate of banking experts of individual commercial banks.

Source: Calculation based on CNB data

In scenarios I and II, the interest-rate shock is modeled as a parallel shift in the entire yield curve. However, the yield curve may change its shape and slope in stressful periods. For instance, short-term rates may increase more than long-term rates, causing the yield curve to flatten, or expectations may arise of an increase in short-term interest rates in the near future concurrently with an assumption of stable long-term interest rates, resulting in a yield curve with a peak. To assess which interest rates the banks' portfolios are most sensitive to, we have analysed the impact of changes in the shape of the yield curve.

In addition to the parallel shift in the yield curve, we have selected two hypothetical scenarios of changes in the shape of the yield curve: a twist and a change in the peak. The scenarios were parameterized using extreme values of the historical variability of short-term, medium-term, and long-term yields for the countries of the Central European region (Czech Republic, Hungary, Poland, and Slovakia) in 2000–2005. For instance, an analysis of short-term three-month rates reveals that the maximum month-on-month change ranged between 40 (Czech Republic) and 350 (Hungary) basis points. For the test, we used the average value (140 basis points) for the four countries over the six years under observation. The other parameter values were derived in a similar way and are comparable to those used by other central banks.[12]

The assumed yield-curve twist would have a bigger effect than the assumed change in the peak of the yield curve, but both of the impacts would be lower than the impact of the assumed parallel shifts in the yield curve in both Scenario I and Scenario II (*Table 2*). Given that the assumed changes in yield-curve shape are based

[11] The analysis presented here is an example of the so-called "threshold approach," which tries to identify the maximum shock that a banking sector would be able to withstand (Čihák, 2004a).

[12] See the survey of stress tests in central banks' financial stability reports in (Čihák, 2005) and (Čihák, 2006). Similar scenarios can be found for example in (Deutsche Bundesbank, 2005).

TABLE 2 Impacts of Changes in the Shape of the Yield Curve

Tested portfolios Scenarios Shape of yield curve	Short-term up to 1 year	Medium-term 1–5 years	Long-term over 5 years	Interest rate shock 2005 % of CAR
	Change in basis points (±)			
Rotation	140	70	40	-1.28
Change in peak	0	60	0	-0.20
Parallel shift Scen. I	100	100	100	-1.72
Scen. II	200	200	200	-3.46

on extreme value from the Central European region, while the parallel interest-rate shock in Scenario I does not go beyond the monitored historical variability in the Central European region, the results suggest that the banks' portfolios are relatively more exposed to parallel shifts in the yield curve than to its twist or a change in its peak.

4. Interbank Contagion Tests

4.1 Interbank Contagion-Test Methodology

Bank-to-bank exposures in the interbank market can play an important role in spreading failures from one bank to another. Overall, credit exposures of resident banks in the interbank market fell by about half between 1997 and mid-2006 (see *Chart 4*). However, the overall numbers provide only a very rough indication of the interconnectedness in the interbank market. To analyze the linkages more precisely, one needs to look at the sizes of the individual bank-by-bank credit exposures.[13]

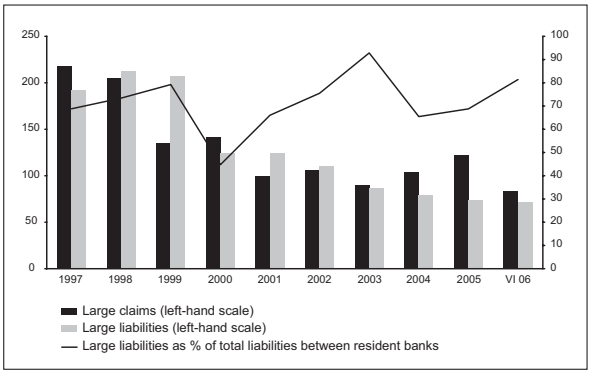
The contagion tests examine the situation of a bank (or a group of banks) defaulting on obligations to another bank or group of banks. This involves capturing the impacts of contagion in the interbank market in the event of a bank´s capital inadequacy. We test the extent to which banks are sensitive to interbank contagion risk and the banks' ability to cover by capital their own liabilities and outstanding claims vis-à-vis banks in default.[14]

The contagion tests use as inputs data from interbank exposure matrices based on the banking and trading portfolios and loans and deposits received. Two methods are used to determine the net exposure of creditor and debtor banks. Under method 1, the test uses the greater of the values of assets and liabilities of interbank exposures that constitute the worst-case scenario. This is the maximum outstanding amount over the entire duration of the contractual relations between the banks. Under method 2, the test uses uncollateralised loans and deposits received that represent the immediate outstanding amount from the exposures (their aggregate impact on banks is lower and so some of them are not reported separately in the summary of

[13] Exposures here mean the mutual claims monitored in a report on exposures and over-limit deposits and loans received. These are the claims of one bank against another in both the banking portfolio (interbank loans) and the trading portfolio (holdings of bank bonds). The statement does not include all interbank claims, only those which exceed a particular share of the bank's capital.

[14] We focus here on contagion through insolvency, following the examples in (Degryse, Nguyen, 2004), (Upper, Worms, 2002), and (Čihák, 2004 a,b). Another possible contagion channel is through liquidity. The methodology for modeling liquidity contagion would be very similar; however, its implementation would be more complicated due to the difficulties of estimating the relationships between liquidity outflows in different institutions (the matrix of "liquidity exposures").

CHART 4 Significant Exposures of Banks on the Interbank Market (CZK billions, %)



Source: CNB

results of the individual tests). In the contagion tests the interbank exposure is reassessed for each bank with respect to any other bank. Both tests use a 100% and 40% expected loss given default.

Compared to the preliminary interbank contagion results presented in (CNB, 2006), this article shows results of extended tests that also consider exposures of the foreign bank branches active in the Czech Republic.[15] These banks could offer banking services in the Czech Republic and are present on the Czech interbank market, so they could eventually be the source of shock to the banking system as a whole. An important complication with analyzing foreign bank branches is that they do not report capital levels because the parent company's capital would be used to cover the losses in the branch. However, the parent company also has risky exposures in other subsidiaries against which it needs to hold capital. To approximate the capital needed to hold against the exposures of the Czech branch, we use the branch's reported levels of risk-weighted assets, and assume that the foreign bank branches have the CAR equal to the rest of the banking sector.[16] This approach has the advantage that it does not change the overall pre-shock capital adequacy figures, and it provides a good picture of possible contagion arising from failures in the foreign banks. As to the impact of resident banks' failures on the foreign banks, our calculations provide only a broad (and prudent) approximation of the risks, because the parent company would normally have in place more capital than needed for the branch's exposures (unless it also faces failures in other countries where it operates).

The interbank test could be performed either as a simple test or as a combined test. Both tests are based on the same set of interbank exposures, but differ in whether or not they take into account the probability of default of individual banks.

[15] These interbank contagion tests covered only 11 from 12 existing foreign bank braches as one of the branches entered the Czech banking market in the first half of 2006.

[16] An alternative approach would be to use the CAR of the parent institution of the branch. However, as the foreign bank branches originate from different states and jurisdictions, the comparability of such figures would be questionable.

4.1.1 Simple Test

The simple test examines the potential impact of the failure of each individual bank on the banking sector as a whole. The test assumes that the bank becomes insolvent ("primary insolvency") and defaults on its obligations in the interbank market. This test does not examine the reasons of such a failure and its probability.

The test consists of calculating how the default may impact other banks that have uncovered exposures to the insolvent bank. If one (or more) of these banks becomes insolvent ("secondary insolvency"), we need to perform a second iteration of the test and calculate how this secondary insolvency impacts other banks in the system through their net uncovered exposures vis-à-vis the banks facing secondary insolvency. If the test reveals that secondary insolvency leads to other banks becoming insolvent ("tertiary insolvency"), we need to perform a third iteration of the calculation, and continue until this "domino effect" stops, i.e. until the insolvency induced in one bank or group of banks does not lead to other bank insolvencies.

The simple interbank contagion test consists of 35 separate sub-tests, one for each bank in the system. The difference between the pre-test and post-test CAR of the banking system may be viewed as a measure of the bank's systemic significance: the bigger the decline in the CAR of the system, the greater the systemic importance of the bank whose failure is assumed.

4.1.2 Combined Test

The combined test uses a similar calculation method as the simple test, but takes into account the different probabilities of default of the banks. This test examines changes in the external risk factors that affect all banks simultaneously. Unlike the simple test, then, this method does not use 35 separate sub-tests, but just one integrated test in which the probability of insolvency is higher in banks that are more sensitive to changes in the external risk factors. Unlike in the simple test, it is possible that primary insolvency will occur in several banks simultaneously. Another different feature of this test is that the subsequent calculations of contagion are performed in a system that is already weakened by the effects of the initial macroeconomic stress scenario (Table 4).

Bank default can be modeled in stress tests in various ways. The simpler method that was used in the above-mentioned simple interbank test is based on the assumption that banks with negative capital will default and, conversely, that banks with positive capital will not default. In practice, however, even banks with positive capital can fail. In order to make it more realistic, the combined test – unlike the simple test – also took into account the fact that the probability of default of banks with positive capital is not zero. It was assumed that this probability decreases with increasing capital of each of the individual banks (*Table 3*).[17] The iterative calculation of the "domino effect" is performed along similar lines as in the case of the simple test, i.e. as long as the new iterations result in some other bank in the test being included in a worse CAR group (i.e. a group with higher probability of default) or ceasing to receive capital.[18]

[17] The calculation of the expected loss $E = Exp*LGD*PD$, where *Exp* stands for the amount of the bank's exposure, *LGD* denotes the expected loss given default (100 % or 40 %) and *PD* stands for the probability of default of the bank. The probability of default parameters were calibrated based on experience from abroad.

TABLE 3 Explicit Combination of CAR and Probability of the Bank's Failure (Default) in Interbank Contagion Stress Testing

CAR	Probability of failure/default (PD)
< 0 %	100 %
0–5 %	25 %
5–8 %	15 %
8–10 %	5 %
> 10%	0.5 %

4.2 Results of Interbank Contagion Tests

In the simple test, for most banks the effect of their loss of solvency on the rest of the banking sector was negligible (impacts of up to one percentage point on the sector's CAR). For some banks, the impact of insolvency of each individual bank on the sector's CAR was three percentage points on average. Nevertheless, for all of these banks the CAR after the simple test stayed above the required minimum of 8 %. The banking sector reached equilibrium after the second iteration in the simple test.

Although the results of individual banks' contagion tests could not be published due to legal confidentiality restrictions, the averages for major bank groups illustrate the systemic importance of individual banks in each group. In *Chart 5* we used information on the 35 sub-tests measuring impact on the total sector CAR arising from the failure of each individual bank. We then calculated averages from these tests along the different groups of banks. Thus the column "large banks" shows the average of results of the five sub-sets calculated for large banks, the building-societies column represents the average of results for six sub-tests conducted for building societies, and so on. The tests confirm the high systemic importance of large banks, and suggest that systemic importance decreases quickly with the size of the bank. The tests indicate that systemic importance of the building societies is even lower than for the small banks (reflecting the fact that the building societies mostly enter the interbank market as lenders rather than borrowers). In contrast, the systemic importance of foreign bank branches as a group is relatively high, similar to medium-sized banks, confirming the appropriateness of incorporating those institutions in the contagion test.

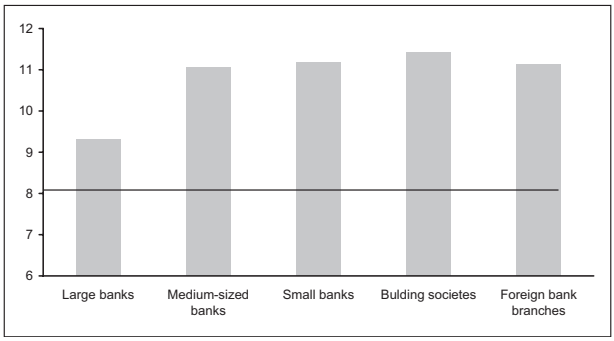
In the combined test with the Scenario II shocks incorporated (i.e., using the more stressful set of shocks to external risk factors), the resulting CAR would be 9.2 % and the loss due to interbank contagion would be 0.5 percentage point in the CAR. The maximum loss of the banks in default could reach 0.6 % of the total capital in the banking sector (*Table 4*). The contagion among the banks in the system stops after the third iteration.

5. Macro Stress Test Using Consistent Model Scenarios

The shocks and scenarios used in the previous sections were not derived from formal models; they were assumptions based on historical values. In this section, we focus on model-based macro stress tests, in which the shocks to the indi-

[18] Similar mapping is typically a part of supervisory early warning systems, and can be estimated based on past instances of failures. The values used in Table 3 are expert estimates based on foreign practice. A similar method to interbank exposure testing is described for example in (IMF, World Bank, 2005b).

CHART 5 Impact of Interbank Contagion on Systemic CAR
(Simple Test; averages along bank groups)



Note: Systemic CAR along bank groups, result of simple test interbank contagion test.
Source: Calculation based on CNB data from June 2006.

vidual external risk factors (interest rates, exchange rates, changes in asset quality) are interconnected through a macroeconomic model. The macro stress test is based on (i) testing macroeconomic variables and related outputs from the official CNB macroeconomic forecasting model and (ii) the macroeconomic credit-risk model. As an illustration, shocks to different scenarios of development of the sector's financial stability are tested on data on the portfolios of individual banks as of the end of 2005.

The model scenarios were generated in three steps (*Chart 6*). In the first step, consistent macroeconomic scenarios were obtained from the CNB's forecasting model (QPM[19]). These scenarios capture the development of key macroeconomic variables (such as the GDP growth rate, inflation rate, interest rates, and exchange rates) in the near future under "normal" circumstance (in the baseline scenario) and stressful circumstances (i.e., under an external shock or combination of macroeconomic shocks). In this way, two key inputs to the stress testing were obtained, namely interest rates and exchange rates.

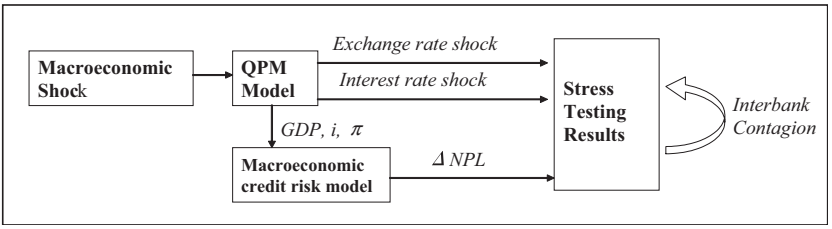
In the second step, the macroeconomic credit-risk model was used to estimate the evolution of NPLs in banks' portfolios based on the development of macroeconomic indicators.[20] As the main output of the macroeconomic credit-risk model is the quarterly change in NPLs, and given that the stress testing works with growth in NPLs over a one--year time horizon, it was necessary to annualise the results of the credit-risk model.[21]

In the third step, results from the individual bank's responses to the shock were used to run the interbank contagion tests, using the "combined test" methodology described in Section 4.1.

The baseline model scenario uses the official CNB forecast of April 2006 and serves as an estimate of the likely development of the Czech economy in 2006

[19] QPM stands for Quarterly Prediction Model. For a basic description of the methodology of this model, see (CNB, 2003). Results of the prediction model are discussed in the CNB's quarterly inflation reports (CNB, 2000–06).
[20] This model is described in (Jakubík, 2006) and in (CNB, 2005).
[21] This annualisation was performed as follows: The annual change in NPLs was estimated for four successive estimates of the quarterly default ratio, which were then summed. The dampening effect of monetary policy could thus manifest itself in the shock scenarios in the second to fourth quarters.

CHART 6 Architecture of the Incorporation of the Model Consistent Scenarios Tests



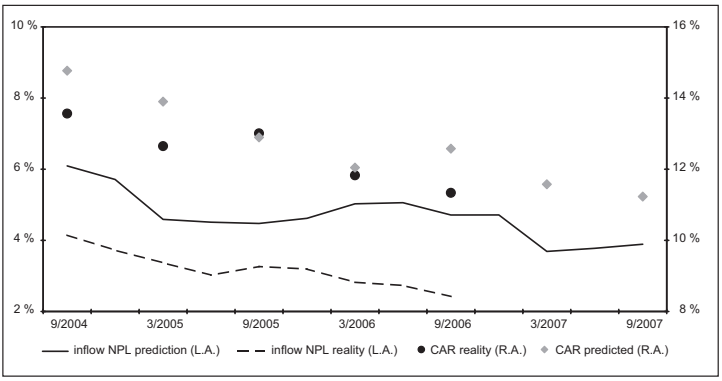
and 2007. Besides the baseline model scenario, three alternative scenarios (A, B, and C) were proposed which reflect less probable, but still plausible shocks. The shocks in these scenarios take into consideration the history of real economic growth and its links to other macroeconomic variables.

TABLE 4 Summary of Results of the Combined Stress Test for the Interbank Contagion, June 2006

Stress test	**Actual values** [x]	**Scenario I**		**Scenario II**	
Method	**(pre shock)**	**Method 1: Exposure (A_b+A_o-P)**		**Method 1: Exposure (A_b+A_o-P)**	
Anticipated level of loss given default (LGD)	**20 %**	**40 %**	**100 %**	**40 %**	**100 %**
Capital adequacy ratio (CAR) before contagion	11.5	11.0	11.0	9.7	9.7
CAR after-contagion					
Average (weighted)	11.5	10.9	10.8	9.4	9.2
Average (non-weighted)	18.0	14.5	14.3	6.7	5.7
Median	11.5	10.3	10.3	7.9	7.3
Number of banks and foreign banks branches	35	35	35	35	35
with CAR < 0%	0	2	2	6	7
with CAR < 8%	0	13	14	18	18
with CAR < 10%	5	17	17	23	23
Share of banks and branches with CAR < 0 % (in default)					
total banks' and branches' net exposure in the sector's assets	x	0.1	0.1	0.3	0.5
loss on banks' and branches' net exposure in the sector's capital [X]	x	0.0	0.0	-0.7	-0.6
loss banks' and branches' net exposure in the sector's assets [X]	x	0.0	0.0	0.0	0.0
total share of banks' and branches' assets in the sector's assets	x	0.9	0.9	4.2	5.1

Notes: [X] This is a sum of losses of creditor banks (and branches) on debtor banks' (net) exposures in default.
A_b – exposure of the banking portfolio (assets)
A_o – exposure of the trading portfolio (assets)
P – loans and deposits received (liabilities)

CHART 7 "Predictions" According to Baseline Scenarios
(CAR and inflow of the NPLs)



Note: CAR is being calculated semi-annually, when we have full information on the bank sector portfolio. The prediction of inflow of the NPLs is available quarterly

5.1 Baseline Scenario

The baseline scenario was derived from the April 2006 CNB forecast[22], which expected real GDP growth of 6.1 % in 2006 and 5.4 % in 2007. Inflation was projected to be below 3 % in 2006 and edge up to 3.4 % in 2007. Growth in regulated prices, changes to indirect taxes, and a rise in inflation expectations were to be the major factors contributing to the rise in inflation. Consistent with the forecast was an initial period of interest rate stability followed by a gradual rise in interest rates.

The baseline scenario does not contain any risks that would pose an immediate threat to the financial sector and its stability. Low interest rates, the positive outlook for investment activity and GDP growth will further boost growth in lending to households and corporations. The low interest rate differential will prevent growth in debt in foreign currencies.

Due to the nature of stress testing, even the baseline scenario should not be taken as a prediction of development of the CAR and NPLs in the next year. Simulations of the macro stress tests on baseline predictions of the QPM model from the last 3½ years show that both the actual CARs and the actual NPL inflows were better than the projections from the stress-testing model (*Chart 7*). The reasons for this were twofold. Firstly, the actual GDP developments turned out to be better than the original CNB forecasts and inflation was on average lower, meaning that the interest rate paths were mostly revised downwards in the examined period. Secondly, the stress-testing sheet focuses on (gross) inflows into the stock of the NPLs to asses the influence on the CAR, thereby omitting the outflow of the NPLs. This is only partly compensated by taking into account the accumulation of "baseline" profit. Even the baseline scenario thus reflects the conservative ("prudent") analytical approach that underlies stress testing.

[22] A detailed description of the CNB macroeconomic forecast is given in the CNB Inflation Report (2006), available at www.cnb.cz.

TABLE 5 Differences of Alternative Scenarios from Baseline Scenario for the Year 2006

Type of scenario	Period	Scenario A	Scenario B	Scenario C
Real GDP growth (% y-o-y)	1Q 2007	-1.6	-1.4	-3.2
Inflation rate - CPI (% y-o-y)	3Q 2006	0.4	0.2	0.0
Interest rate (percentage points)	2Q 2006	1.6	-0.8	-0.6
Exchange rate (percentage points)	2Q 2006	4.5	-7.3	2.1

Source: CNB

5.2 Alternative Scenarios

In addition to the baseline scenario three alternative scenarios were created. The difference of these scenarios from the baseline scenario is summarised in *Table 5*. Periods for different variables in Table 5 reflect the way the different variables and their predictions enter stress testing. GDP growth and inflation enter stress testing via the macroeconomic credit-risk model with lags according to this model; interest-rate and exchange-rate enter stress testing directly in the first predicted quarter.[23]

5.2.1 Alternative Scenario A

Alternative scenario A analyses the potential response of the domestic economy to a significant global negative shock.[24] Such a shock might hypothetically occur in a situation where global imbalances associated with a loss of confidence in the main economic zones are suddenly corrected and interest rates of the main world currencies, i.e. the dollar and the euro, rise rapidly. The scenario also includes a large downturn in global economic activity and inflation, further intensified by a strong monetary restriction. The downturn in the economic activity of the Czech Republic's major trading partners would have a relatively sizeable impact on its macroeconomic situation and exports. GDP growth rates in 2006 and 2007 would be about 1–2 percentage points lower than in the case of the baseline scenario, and interest rates would be considerably higher.

The impact of alternative scenario A on the stability of the financial system would to some extent depend on the distribution of the decline in GDP across the individual sectors of the economy. In any event, however, it would influence the ability of economic agents to service their debts. The increase in interest rates would amplify this effect and would have an adverse impact on banking portfolios.

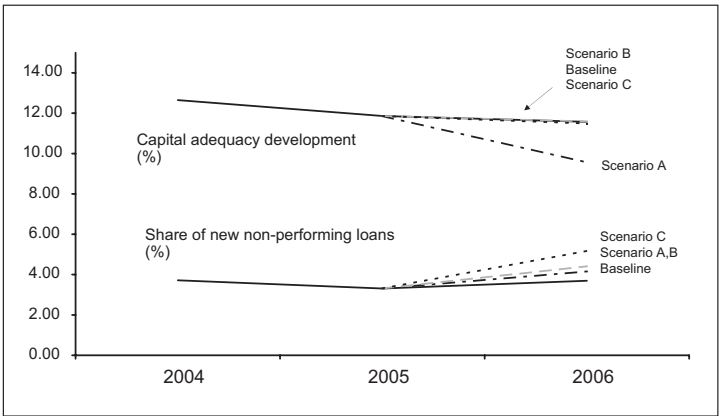
5.2.2 Alternative Scenario B

Alternative scenario B combines the effect of developments in the nominal exchange rate and inflation. This scenario assumes a sudden exchange-rate appre-

[23] As already mentioned in Chart 6, interest rates in fact enter stress testing two times. In the first stance the change of interest rates influences banking portfolios directly through the standard interest-risk channel. To model this impact we use the prediction of interest rates for the first quarter after the shock. Afterwards the change of the interest rates also influences credit risk, which is modeled by the macroeconomic credit-risk model (see (Jakubík, 2006)). This model uses the current value of interest rates and thus the differences of the alternative scenarios from the baseline are equal to zero.

[24] The global negative shock should be generated in a global economic model describing a realistic and consistent trajectory for foreign interest rates, inflation, economic activity and, where appropriate, the cross--exchange rate. In this scenario, this is not the case. For reasons of simplicity and in order to achieve a really strong shock, a significant shock to euro-area interest rates, German GDP and inflation is assumed.

CHART 8 Results of Scenarios of Macro Stress Testing



Note: The share of new non-performing loans (NPLs) is related to the given volume of loans at the end of 2005.

Source: CNB

ciation and a negative supply shock (e.g., a poor harvest or other shock to the supply of goods and services) that would, ceteris paribus, result in rising prices. However, the stronger exchange rate would cause a slight decline in inflation and GDP growth compared to the baseline scenario. The monetary policy response would be to cut interest rates to a very low level.

In contrast to scenario A, the impact of scenario B is more favourable. The decline in GDP growth is only temporary, and although disposable income falls, easing of the monetary policy reduces the loan repayment burden, at least insofar as it allows debtors to swap their rates for lower ones. The decline in interest rates also means less pressure on banks' portfolios, although it might lead to lower interest margins and hence might also reduce banks' profitability.

5.2.3 Alternative Scenario C

Alternative scenario C reflects the potential risks associated with a possible drop in domestic demand and assumes a gradual decline in GDP growth between Q2 2006 and Q1 2007. A drop in domestic demand, and hence also in economic activity, might be caused, for instance, by a sharp decline in corporate investment activity in a situation of investment outflows due to cost optimisation. This would lead to an increase in unemployment and a fall in household consumption. A strong fiscal restriction might also foster a drop in domestic demand.

A negative shock to GDP growth would cause the output gap to widen and inflation to fall. The monetary-policy response would be a substantial easing, which would help to revive economic activity, in particular in 2007. The lower interest rates compared with other countries would also foster a slight depreciation of the exchange rate, which, in turn, would further ease the monetary conditions.

Scenario C provides an imperfect picture of the impact of an outflow of direct foreign investment on the Czech economy, since any major outflow would likely have more permanent implications for the structure of the economy, potential output, and

export performance, which monetary policy would be unable to reverse in just one or two years. However, it may serve as the first step in the analysis of the Czech economy´s dependence on foreign direct investment for the purposes of assessing the impact on financial stability.

5.3 Test Results for the Model Scenarios

The CAR in the baseline scenario would be 11.6 % in 2006 calculated on the December 2005 banking sector data (11.3 % on the June 2006 data). The share of NPLs in the given volume of claims would be 3.7 %. The CAR would be two percentage points lower in scenario A, at the same level in scenario B and 0.1 percentage point lower in scenario C than in the baseline scenario for 2006. The new NPLs of the banking sector in the pessimistic scenarios A, B and C would be 4.2 %, 4.4 % and 5.2 % respectively at the one-year horizon (see *Chart 8*).

6. Conclusions and Directions for Further Research

In all the scenarios presented in this article, the post-test CAR of the banking sector would be 9.2 % or higher (*Table 6*). Some banks would fall below the required 8% minimum CAR in some of the scenarios. However, even in the most stressful scenarios (Scenario A and Scenario II), the capital injection needed to make sure that every bank satisfies the regulatory minimum would be 0.7 % of GDP or even less.

The banking sector as a whole therefore seems to be resilient to the effects of the assumed macroeconomic and prudential shocks, even though there is variation among banks with regard to their sensitivity to shocks, especially to interest rates and interbank contagion. The banking sector was capable of withstanding both *ad hoc* scenarios based on historical experience as well as scenarios based on a formal macroeconomic model.

The stress tests conducted in this article have also shown some limitations of this approach. The exercise has shown some challenges linked to the relatively "static" nature of the stress-testing method, which might create some tensions when being integrated with more dynamic and advanced approaches (for example with macroeconomic credit risk model or with official CNB's macroeconomic model QPM). The stress-testing method does not fully take into account the reactions of the involved economic agents (financial institutions, depositors, and regulators), including problems such as herding behaviour or crowded trades.

Stress testing performed by central banks or supervisors has significant limits as a prediction tool. It could just give basic information about the potential effects of macroeconomic shocks on banks' portfolios and thus give some rough supportive guidelines to actions needed to maintain stability. Macroeconomic stress testing also lacks some important data available to the individual financial institutions and thus would never replace microeconomic stress tests conducted by banks themselves. However macroeconomic stress tests provide additional information about the spread of the different shocks across the financial system.

Many of the above-mentioned obstacles and problems are in nature of the stress testing. However the exercise has shown some possibilities of improvement of this tool in future. These include:

TABLE 6 Summary of Results of Stress Tests, June 2006: Banking Sector
(data are in %, unless stated otherwise)

Scenario type	Historical Scenarios		Macroeconomic Model Scenarios			
	Scenario I	Scenario II	Baseline	Scenario A	Scenario B	Scenario C
Pre-shock CAR [a]	***11.5***	***11.5***	***11.5***	***11.5***	***11.5***	***11.5***
large banks	10.3	10.3	10.3	10.3	10.3	10.3
medium-sized banks	15.8	15.8	15.8	15.8	15.8	15.8
small banks	14.1	14.1	14.1	14.1	14.1	14.1
Results for the chosen scenario type						
Overall impact of shocks (percentage points)	-2.3	-5.2	-2.0	-5.1	-1.6	-1.8
Interest rate shock	-1.6	-3.3	0.0	-2.6	1.3	1.0
Exchange rate shock	1.1	1.5	0.0	0.3	-0.5	0.2
Credit shock	-1.6	-3.0	-1.9	-2.4	-2.2	-2.8
of which indirect impact of exchange rate shock	-1.1	-1.4	0.0	-0.3	0.0	-0.1
Interbank contagion [b]	-0.1	-0.4	-0.1	-0.4	-0.1	-0.1
Profit allocation (percentage points) [c]	1.7	2.9	1.7	2.9	1.3	1.4
After-shock CAR	***10.9***	***9.2***	***11.3***	***9.3***	***11.3***	***11.2***
large banks	10.3	9.1	10.3	8.6	10.3	10.3
medium-sized banks	13.9	11.8	14.9	13.6	14.9	14.3
small banks	13.5	12.5	13.3	12.5	12.8	12.8
Capital injection (percentage of GDP) [d]	0.1	0.6	0.0	0.7	0.0	0.1
Share of banks with negative capital after shock [f]	1.0	4.4	0.0	4.4	0.0	0.0
Impact on dividends and royalties [g]	-68.6	-100.0	-57.5	-100.0	-36.7	-40.8

Notes: [a] CAR means capital adequacy ratio defined in accordance with the relevant regulations of the Czech National Bank, (in particular those governing capital adequacy of banks and other prudential business rules)

[b] Test integrated with the interbank contagion for Method 1, anticipated level of loss given default (LGD) 100% and chosen probability of the banks' failure (default) on the basis of the CAR.

[c] Scenarios assume that in the absence of shocks each bank would generate profit (or loss) at the level of the average figures for the previous 5 years and that it would use possible profit as the first line of defence against the declining CAR.

[d] The capital required for each bank in order to have at least an 8% after-shock CAR.

[e] Market share of banks with negative capital after the impact of assumed shocks (as a percentage of total assets).

[f] As a percentage of dividends and royalties of previous calendar year.

Scenario I and Scenario II are based on the chosen hypothetical and historical shocks (see part 2 of this article). They also include the impact of the interbank contagion.

Scenarios: baseline, A, B and C are based on the macroeconomic prediction model of the Czech National Bank and the credit risk model (part 5).

1. Increasing the length of the stress-testing horizon. The build-up and resolution of financial imbalances often lasts several years.[25] An increase of the stress-testing horizon could therefore make the modeling more realistic; however, it would also

[25] e.g., Caprio and Klingebiel (2003)

raise demands to account more endogenous links between macroeconomic development and the financial system as well as among different market players within the financial system.

2. Incorporation of an improved credit-risk model with separate household credit and non-financial enterprise credit portfolios. The current macroeconomic credit-risk model works well, but the household and non-financial enterprise credit portfolios are likely to be determined by different factors.[26] The enterprise credit portfolio could be segmented further according to the industry classification, which could improve the predictive power of the credit-risk model.
3. Inclusion of modeling of the loan growth (along major sectors and industries), which is often identified as the leading indicator of a financial crisis. Current stress testing is rather static in a sense that it considers the current structure of assets and liabilities of the banking system. Given the rapid growth of loans [27] (especially loans to households) this structure is likely to change with potential to heighten the credit-risk sensitivity of banking balance sheets.
4. Improvement of modeling of the creation of profit and its distribution. In the current version of stress testing, the profits form the first buffer of the banks in the case of a negative shock. For the stress-testing horizon, the "baseline" profits are considered to be equal to the average profit of the bank over last five years.
5. Extension of stress-testing practices to non-bank financial institutions, such as insurance companies and pension funds. Although the financial system is dominated by banking institutions (banks comprise about 75 % of total financial-sector assets), financial innovations, emergence of new instruments and financial disintermediation lead to an increase of the significance of this sector. The increased significance of complex financial groups also raises questions about possible contagion from these non-banking financial institutions to banks.

[26] For example, the credit risk of loans to households is more likely to be dependent on unemployment, wage growth or demographic developments. The risk of the loans to non-financial enterprises should be more dependant on its relation to the foreign economy, e.g. on the exchange rate.

[27] On the issue of the rapid credit growth in Central and Eastern Europe in recent years, see for example (Cotarelli, Ariccia, Vladkova-Holar, 2005) or (Kiss, Nagy, Vonnák, 2006). These papers try to determine whether the recent credit growth in many CEE countries is in line with their macroeconomic convergence, or whether it is excessive.

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