UNIVERZITA KARLOVA V PRAZE

FAKULTA SOCIÁLNÍCH VĚD

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Stress testing of the banking sector

Bakalářská práce

Praha 2011

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Rok obhajoby: 2011

Bibliografický záznam

PROCHÁZKOVÁ, Jana. *Stress testing of the banking sector*. Praha, 2011. 75 s. Bakalářská práce (Bc.) Univerzita Karlova, Fakulta sociálních věd, Institut ekonomických studií. Vedoucí diplomové práce PhDr. Ing. Petr Jakubík, Ph. D.

Abstrakt

Předmětem bakalářské práce je zátěžové testování bankovního sektoru. Zátěžové testování jako metoda zabývající se detekcí finančních rizik si získalo pozornost zejména v posledních letech v důsledku výskytu nestabilit na finančních trzích. Tato práce si vymezuje dva hlavní cíle. Cílem teoretické části je podat komplexní přehled o základních principech a metodách využívaných v zátěžovém testování a objasnit motivaci aplikování zátěžových testů. Empirická část se zaměřuje na posuzování úvěrového rizika v České republice. Jejím cílem je prokázání případného empirického vztahu mezi kvalitou úvěrového portfolio českého bankovního sektoru a vývojem základních makroekonomických veličin. K tomuto účelu je využit ekonometrický model vektorové autoregrese.

Abstract

This bachelor thesis deals with stress testing of the banking sector. Stress testing as a risk measurement technique has attracted much attention especially in recent years due to the increased instabilities in financial markets. This work defines two objectives. The aim of theoretical section is to provide a complex survey of stress testing principles and methodologies and to contribute to a better understanding of why stress tests are employed. The empirical section focuses on the credit risk in the Czech Republic. It tries to estimate whether there is an empirical relationship between the quality of credit portfolio of the Czech banking system and the development in key macroeconomic variables. For this purpose the econometric model of vector autoregression has been applied.

Klíčová slova

zátěžové testování, bankovní sektor, finanční stabilita, bankovní rizika, kapitálová přiměřenost, vektorová autoregrese

Keywords

stress testing, banking sector, financial stability, banking risks, capital adequacy, vector autoregression

Rozsah práce: 88 937 znaků

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Poděkování

Za cenné rady a připomínky při zpracování bakalářské práce bych ráda poděkovala PhDr. Ing. Petru Jakubíkovi, Ph.D. Mé zvláštní poděkování patří PhDr. Ladislavu Krištoufkovi za odbornou pomoc a náměty ke zpracování empirické části práce.

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Akademický rok 2009/2010

TEZE BAKALÁŘSKÉ PRÁCE

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Garant studijního programu Vám dle zákona č. 111/1998 Sb. o vysokých školách a Studijního a zkušebního řádu UK v Praze určuje následující bakalářskou práci

Předpokládaný název BP:

Stress testing of the banking sector

Charakteristika tématu, současný stav poznání, případné zvláštní metody zpracování tématu:

In recent years the economy has been characterized by increased financial instability and low predictability of its development. Thus financial institutions have more concentrated on monitoring of financial systems as well as the resistance to shocks disrupting macroeconomic stability. One of the key instruments for assessing the vulnerability of financial institutions to potential crisis is stress testing.

Struktura BP:

Abstrakt

In this thesis I will primarily focus on stress testing of banking sector as a set of risk management tools dealing with the exposures of banks to different types of risks. The aim of this issue is to provide compact and transparent survey of bank risks, their impact on banks' portfolios as well as to introduce the basic principles of stress tests and methods. Moreover, I will discuss effectiveness and reliability of stress testing as an instrument for bank risks conducting. The first part of the thesis will cover general terms and basic types of risks such as credit risk, market risk including interest-rate risk

and exchange rate risk and finally some other risks such as liquidity risk or operational risk. The second part will be devoted to stress scenarios and stress models. I will discuss shortcomings and strong points of each model and draw a comparison between stress tests and another method (Value-at-risk). Finally I will attempt to summarize results and make conclusion.

Osnova

1. Introduction
2. The definition of stress testing, types of bank risks and other general terms
2. The purpose of stress testing and its policy implications
4. Stress scenarios and models
5. Shortcomings and strengths of models, comparison with another method of risk assessments
6. Summary of results and conclusion

Seznam základních pramenů a odborné literatury:

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Datum zadání:	Červen 2010
Termín odevzdání:	

Podpisy konzultanta a studenta:

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Introduction

The stability of financial sector has always been an important condition for a good performance of the economy and thus well-being of ordinary people. It is no wonder that financial system has been the area under the permanent control of national financial regulators. Over the last several years financial authorities have broadened the attention beyond national borders and concentrated more on the development of global financial markets. Improvement in financial intermediation combined to growing complexity of financial transactions has resulted in global interconnections of financial markets. Despite the positives of such process it is important to eliminate risks associated with a relatively easy spread of financial turbulences among other countries. One way to achieve it is developing methods for monitoring and assessing risk exposures.

This bachelor thesis deals with stress testing. This approach has attracted a closer attention particularly in recent years in connection with periods of financial turbulences and instabilities in the world. Stress testing can be characterized as a risk management technique developed for assessing financial stability and detecting potential risks to which financial institutions can be exposed. Stress tests may focus on risk profile of individual institutions or they examine the potential of systemic collapse. Given that in most financial systems the banks occupy a dominant, I will primarily focus on the principles of stress testing of the banking sector.[1]

The paper is divided into four chapters. The first three chapters comprise theoretical part. The last chapter forms empirical part. The objective of theoretical section is to produce a compact and comprehensive survey of stress testing and the description of its methodologies. It also aspires to clarify readers the rationality of employing stress tests and to contribute to a better understanding of this issue. The main aim of empirical section is to estimate if some of the selected macroeconomic variables have a significant influence on the development of credit risk in the Czech Republic.

[1] In Appendix 1 it is possible to see that the banking sector in the Czech Republic holds around 8O % of the assets of the financial market.

The first chapter is devoted to general terms and characteristics of stress testing. Apart from the definition of basic concepts, it presents both approaches to stress testing and introduces requirements put on stress tests. The chapter also involves a brief comparison of stress testing with another risk management technique (Value-at-risk).

The second chapter describes the stress testing procedure. The entire process of stress testing requires several steps to be followed. Each individual phase is described in more details as well as the methodologies commonly used in stress testing.

The third chapter is devoted to examination of risks against to which the banks are usually stress tested. The chapter deals with the issue of market risk together with the individual market risk components; it further introduces credit risk being considered as the most problematic issue of stress testing; finally operational risk is also mentioned in the chapter.

The closing chapter focuses on the empirical research of credit risk in the Czech Republic. As a measure of credit risk the share of non-performing loans to total loans has been used. Using the method of vector autoregression, the chapter examines a potential relationship between the credit risk and a set of macroeconomic variables including the industrial production; the interest rate; the exchange rate; the inflation; and the unemployment rate.

1. Stress testing characteristics

Before one starts talking about stress testing, it is necessary to have general knowledge about what stress testing signifies in the context of financial systems. Thus the following chapter will be devoted to the features of stress testing in order to understand its purpose and importance in the assessment of the financial system stability.

1.1 What is stress testing

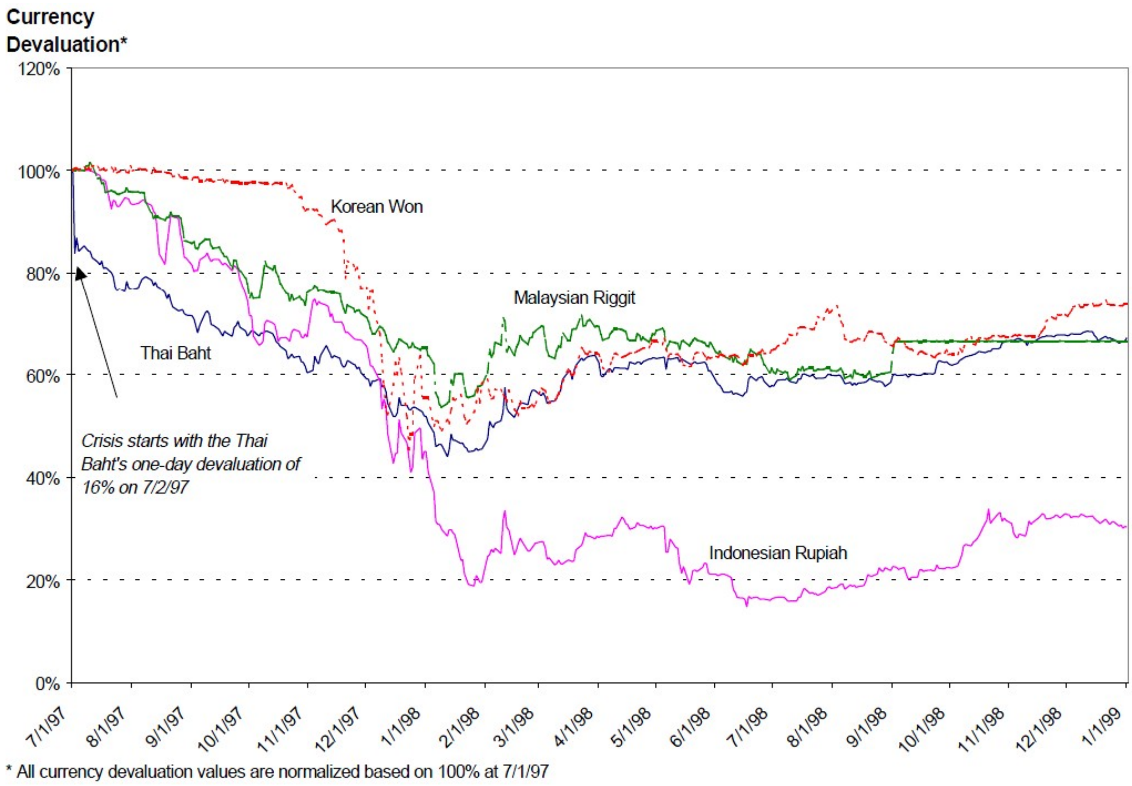
Stress testing has been defined as *"a generic term describing various techniques used by financial firms to gauge their potential vulnerability to exceptional but plausible events"* (BIS, 2000).

Stress testing performed regularly gives helpful information about the financial soundness of the banking sector and it evaluates whether the banks would be resilient enough if the economy was affected by an extraordinary event characterized by nonstandard movements of macroeconomic factors (Blaschke et al., 2001).

When talking about stress testing, the crucial element *"is the definition of the exceptional but plausible event"* (Čihák, 2004a, page 5). Such events are those occurring only sporadically. They usually have serious macroeconomic consequences on further economic performance (Illová, 2005). One can find a number of similar stress situations in the past. For instance, the Stock market crash in October 1987 was up to 20 standard deviations from a common market conditions (Breuer, Krenn, 2000). Further, the Asian crisis in 1997 experienced enormous currency devaluation which resulted in dramatic devaluation in other currencies around Asia (Wee, Lee, 1999). From those recent distress events the terrorist attacks in the United States in September 2001 were hardly predictable and caused huge problems in the ensuing world economic development. Finally, the Global financial crises 2008/2009 which entailed the collapse of large financial institutions across the world and subsequently a drop in the stock markets should not be omitted in relation to stress events.

All events mentioned have several things in common. They all are unexpected, they occur only with a low probability, and the economy needs a lot of time to cope with their consequences. Similar extreme situations are the subject of implementation of stress tests.

Figure 1: *Example of stressful event: Asian Currency Crisis 1997*



Source: Wee, Lee (1999)

1.2 Why to use stress testing

The benefits of applying stress tests can be viewed from two various perspectives. At the microeconomic level, stress tests analyze the capacity of banks to cope with uncommon strain in the economy. From the macroeconomic point of view, stress testing serves as a supervisor of the financial system stability.

1.2.1 Microeconomic perspective

One of the reasons to apply stress testing is that it indicates whether the banks hold enough capital to withstand different macroeconomic shocks. Stress testing is useful to be employ in addition to other risk management measures as they jointly evaluate the level of risk to which the banks could be exposed (BCBS, 2009).

The BCBS further states: *"Stress testing is an important risk management tool that is used by banks as part of their internal risk management and, through the Basel II* *capital adequacy framework, is promoted by supervisors. Stress testing alerts bank management to adverse unexpected outcomes related to a variety of risks and provides an indication of how much capital might be needed to absorb losses should large shocks occur"* (BCBS, 2009, page 1). [2]

1.2.2 Macroeconomic perspective

Stress testing represents one of the quantitative instruments widely used for the appraisal of the financial stability. Many regulators and central bankers have judged stress testing as an increasingly indispensable tool for measuring risks. The importance of macro stress testing lies in its functioning as an indicator of structural vulnerabilities in the financial systems. It also provides information on how resilient the banks are when unusual macroeconomic conditions occur (Čihák, Heřmánek, 2005).

1.3 Approaches to stress testing

Stress testing identifies either the risk exposures of an individual bank's portfolio or the exposures of the whole financial system to particular stressful scenarios. Based on this intention, there are two approaches to stress testing.

1.3.1 Portfolio approach to stress testing

The following approaches to stress testing will be based on papers by Blaschke et al. (2001), Jones, Hilbers and Slack (2004) and Čihák (2004a).

Stress tests were initially intended to be used at the level of individual institutions in order to measure the exposures of their portfolios to various shocks. Portfolio stress tests have been provided as a part of a firm's internal risk management department with the aim to examine how the value of an institution's portfolio changes when some macroeconomic variable is stressed. They strive to analyze potential market breakdowns, but they highlight the possible impacts on the value of an individual portfolio. Hence, stress tests carried out regularly by individual institutions have

[2] The Basel II is a set of regulations and recommendations to international banks proposed by the Basel Committee on Banking Supervision. It includes three pillars: Minimum capital requirements; Supervisory review process; Market discipline (BCBS, 2001a).

become an indispensable instrument for the assessment of an institution's financial soundness.

1.3.2 System approach to stress testing

In response to increasing mutual linkages among financial institutions, the portfolio approach to stress testing has become broadened to a group of financial institutions. Unlike the portfolio stress tests, system approach to stress testing does not take into account only the individual portfolios when assessing the financial health. The function of this class of stress tests is to have a notion about the stability of the entire financial system, or to identify aggregate risk exposures that could result in difficulties in the financial markets.

In order to have a complex picture of the ability of financial systems to resist stressful events, it is necessary to integrate both mentioned approaches into the process of stress testing. The explanation is clear. Although the broader stress tests inform about the health of the financial system as a whole which is essential for the functioning of the economy, they may disguise serious risk exposures of individual institutions. This could lead to their failures and they may be a serious source of contagion among other institutions within a given system. Hence, the system stress tests are expected to supplement those prepared by individual firms in order to complete the process of stress testing.

1.4 Requirements for stress testing

There are several requirements that are expected to be fulfilled by the regulators and those who are concerning with stress testing. Following these criteria, stress testing should serve as a reliable detector of vulnerabilities and potentially weak banks. The requirements can be formulated as follows:

- **Stress tests should be conducted regularly and timely**

One of the recipes to ensure a healthy performance of banks is to make stress testing regularly. Regular stress testing enables banks to early identify unexpected risks and they thus can better withstand them. The issue of stress testing is widely discussed especially in large international banks. These institutions may deal with weekly or even daily stress tests. Extra stress tests should be employed in periods when the economy struggles with abnormal conditions (Laubsch, 1999). However, Laubsch also remarks: *„Stress testing should not be performed so frequently and extensively as to become overwhelming and loose meaning“*(Laubsch, 1999, page 26).

In general, stress testing should be run in monthly or quarterly time horizons (Haas, 2004). For example, the Czech national bank (CNB) carries out tests on the Czech banking sector in regular quarterly intervals and the last results were published in March 2011. [3]

- **Stress tests should consider countries' macroeconomic conditions**

It is important to know that there is not a common rule in specifying what stress test should be used for testing the resilience of particular banks. All banks across the world are allowed to realize stress tests based on the recommendations of national regulators, central bankers and risk managers. However, it is always necessary to have a good knowledge about the structure of the financial system and to be familiar with the overall macroeconomic performance in which the banks operate. This understanding helps to identify what variables are the most vulnerable and thus should be stressed. It also enables to formulate an appropriate stress scenario being applied (Čihák, 2007).

- **Stress tests should include quantitative and qualitative criteria**

As mentioned in BCBS (1996), each stress test is expected to meet both quantitative and qualitative criteria. Quantitative aspects of stress testing determine the stress scenarios which could occur in a given banking sector. From a qualitative perspective, stress tests should be able to answer two basic questions:

1) How much should be a bank's capital to withstand losses due to an adverse shock?
2) What action should be taken by a bank to reduce its risk exposure and to assure a further accumulation of capital?

- **Stress tests should be integrated into decision-making process**

[3] Source : http://www.cnb.cz/cs/financni_stabilita/zatezove_testy/.

Stress testing gives information about various risks that could have an adverse impact on a bank's portfolio. Such information shall be evaluated by managers as a part of their daily decision-making (Blaschke et al., 2001).

The BCBS states recommendations for banks in the document Principles for sound stress testing practices and supervision (BCBS, 2009, page 8): *„Stress testing should form an integral part of the overall governance and risk management culture of the bank. Board and senior management involvement in the stress testing program is essential for its effective operation"*. The BCBS further suggests that *„to promote risk identification and risk control, stress testing should be included in risk management activities at various levels*" (BCBS, 2009, page 9).

- **Stress tests results should be reported periodically**

Stress tests produce meaningful information on the state of the banking sector in a case of marked deterioration in economic conditions. Therefore, stress tests are expected to be properly documented and discussed by the managing authorities who should report stress testing results periodically. They should also take them into account when setting policies and controls (BCBS, 1996).

1.5 Reasons for applying stress tests

Stress testing is often applied in connection with another risk measurement technique Value at Risk (VaR). Both instruments are used together by banks and other institutions as they participate in a complete analysis of bank risks (Laubsch, 2000).

1.5.1 VaR method

The VaR is one of the most common methods used for the bank risk management. As defined in Cipra (2008, page 483): *"The VaR methodology is based on the estimation of the worst loss that can occur with specified probability (confidence) in a given future period"*.

In other words, the VaR presents an instrument allowing to express the loss of a bank in terms of statistics. It is always determined based on two elements including probability of p % and a holding period of an asset k days. Then it holds true:

$$P\ (\Delta X(k) \leq VaR) = \ p\ \%$$
$$P\ (\Delta X(k) > VaR) = 1 - p\ \%,$$

where $\Delta X(k)$ is a change in the asset value during the holding period k (Cipra, 2008), (Breuer, Krenn, 2000).

For example, if the experts' calculations reveal that a bank's daily VaR amounts to 30 mil. crowns within the confidence level of 99 %, then there is only 1% probability that the bank's one-day losses will exceed this sum of money (Cipra, 2008).

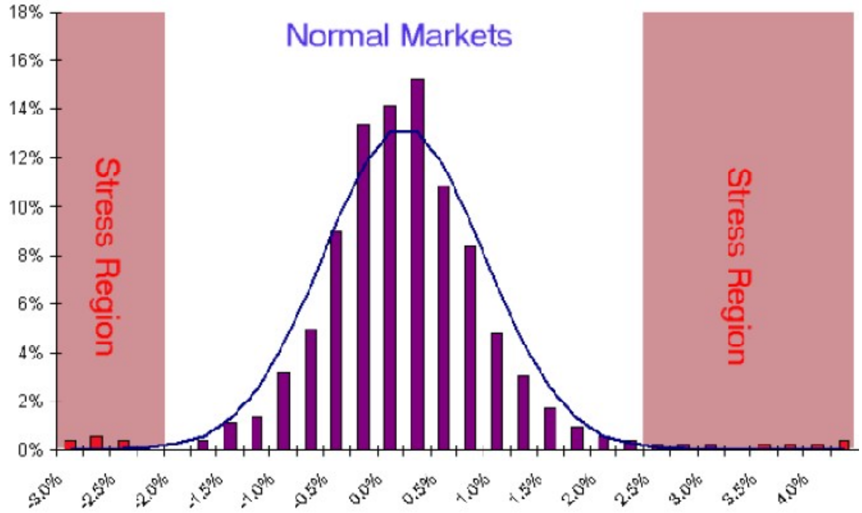
1.5.2 Limitations of VaR

Arguments for employing stress testing as a complementary tool to VaR appear in connection with certain limitations of VaR. As indicated above, the VaR methodology does not take into account large losses since they arise only with a very low probability. Another argument supporting the usefulness of stress testing lies in limited assumptions underlying the VaR calculations (Breuer, Krenn, 2000).

Firstly, VaR models work on the assumption that the risk factors are statistically distributed according to normal distribution. However, as stated in Laubsch: *"Historical analysis of markets shows that returns have "fat tails," where extreme market moves (i.e., beyond 99% confidence) occur far more frequently than a normal distribution would suggest"*(Laubsch, 2000, page 21). Given that this assumption does not seem to be entirely appropriate, stress tests should be used to complement VaR technique, since they do not work with the assumption of normal distribution and focus more on "tail events" (Laubsch, 2000).[4]

[4]According to Jones, Hilbers and Slack (2004), it refers to a less-probable situation in the economy, characterized by large movements in key market variables.

***Figure 2:** Focus of Stress Testing vs. Focus of VaR*



Source: Laubsch (1999)

The second assumption of VaR is that the market movements are not going to change extremely over time. VaR method has been designed to measure the exposures to everyday movements in certain risk factors. It reflects changes in market variables during standard market situation. However, past experiences indicated that various market breakdowns could happen. Stress testing provides an indication of the economic loss that could arise in case of market abnormalities. Since most models are not designed to measure impacts of adverse movements in nonstandard markets, stress tests should always be thought as an essential instrument for risk analysis. Employing stress tests in addition to VaR makes risk more visible, and enables managers to better cope with movements in market prices occurring on a daily basis as well as with exceptional market moves occurring rarely (Laubsch, 2000).

1.6 Stress testing as a part of the FSAP

In response to growing complexity of banking products and services, and interconnections of the banking sectors across the world, it was necessary to intensify cooperation of national and supranational institutions in assessing condition of the financial systems (Čihák, Heřmánek, 2005). In 1999, two international institutions, the World Bank (WB) and the International Monetary Fund (IMF), proceeded to the development of joint agenda, which was the Financial Sector Assessment Program (FSAP). The FSAP was constituted as a supervisor of the financial discipline of member countries, and since its foundation stress testing has been viewed as a substantial part of this supervision (Blaschke et al., 2001).

In FSAP activities the attention has been paid to two main areas which are carried out separately by both institutions.[5] The IMF deals with issues relating to stability. Its primary objective is to oversee the health of the financial systems which is associated with the detection of potential defects that might appear and thus be a serious starter of the financial crises. As a supervisor it also controls the performance of banks and non-bank institutions, finds whether internationally accepted standards are respected, and appraises the actions of policy makers while there is a systemic risk. Stress testing is one of the major tools in meeting these challenges. The WB is responsible for the matters concerning with the development of financial systems. It assesses whether the financial system operates effectively or if there is space for some improvement; controls the functioning of the payment system; and finds whether the banks and non-bank institutions respect the legal and regulatory framework in their operations.

[5] Source: http://www.imf.org/external/np/exr/facts/fsap.htm

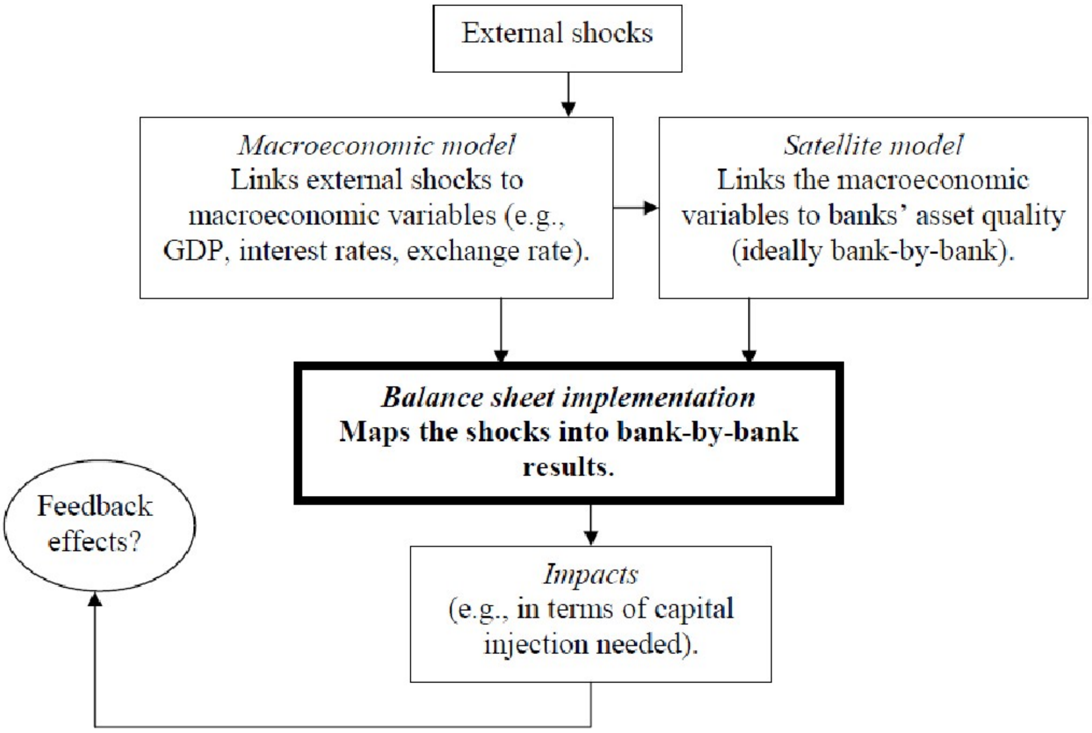
2. Stress testing procedure

Stress testing is a relatively complicated process requiring the closer cooperation of specialists from various departments within the company. For example, if the econometric model was used in stress testing analysis, then specialists in econometric modeling would be appreciated in designing stress tests. For the macroeconomic forecasts and the preparation of proper scenarios, it might be beneficial to integrate macroeconomic experts into stress testing teams (Čihák, 2004a).

Generally, the process of stress testing could be briefly described by a simplified scheme. Let us define different scenarios corresponding to a particular market states m. A number of risk factors $r_i; i = 1 \dots n$ must be specified in each stress scenario. Therefore, each scenario can be expressed as a vector $m = (r_1 \dots r_n)$ of individual risk parameters. The value of a bank portfolio V_p is dependent on the market conditions, so we can express it $V_p = V_p(m)$ as a function of m. Having defined these components, we can describe the current market situation m_{cur} and the current value of a bank portfolio $V_p\ (m_{cur})$. After the largest risk exposures are determined, we select the most appropriate stress scenario m_{stress} and recalculate the value of a portfolio. The portfolio value under new market conditions becomes $V_p\ (m_{stress})$(Krenn, 2006). The comparison of $V_p\ (m_{cur})$ and $V_p\ (m_{stress})$ shows the impact of stress and allows quantifying the amount of losses that the bank would suffer if stress scenario m_{stress} occurred (Breuer, Krenn, 2000).

As indicated above, stress testing is a process in which several steps need to be followed. Even if the sequence of steps is not strictly specified and it can be variously modified, the process should generally involve: identification of main vulnerabilities and risk exposures followed by the construction of stress scenarios; in each stress scenario the risk factors and sizes of shocks should be determined according to some criterion; the last step encompasses measuring impacts of scenarios to bank performance (Sorge, 2004)

Figure 3: *Stress Testing Framework*



Source: Čihák (2007)

2.1 Identifying vulnerabilities and risk exposures

The first step in the procedure and practically the most important one is to correctly recognize the main vulnerabilities to be a major concern of stress testing. It is hardly possible to stress test every risk factor, since too broad scope of risk factors included cause the research to be less effective. The focus of stress testing should be narrowed to key vulnerabilities and stress tests tailored according to them. However, for capturing all serious vulnerabilities, other quantitative measures should be used in addition to stress testing. There are various numerical indicators providing helpful and complementary information on risk exposures (Jones, Hilbers and Slack, 2004).

2.1.1 Macroeconomic indicators

For the complex assessment of the financial stability and then for the indication of vulnerabilities, it is necessary to have knowledge about macroeconomic environment surrounding banks. Historically the most volatile macroeconomic variables and those in disequilibrium have been prone to major shocks (Jones, Hilbers and Slack, 2004).

According to Jones, Hilbers and Slack (2004, page 8) the signals on the potential emergence of shocks may result from:

- *„The real sector, such as the growth performance of the economy relative to potential, growth rates for consumption, investment, and incomes; unemployment rates; inflationary pressures on consumer, wholesale, and asset prices. For the households and corporate sectors: measures of indebtedness, leverage, income growth, finally debt servicing ability."*

- *„The government sector, using indicators of the relative magnitude of the government deficit, debt stock, and debt sustainability; the size of the present fiscal impulse; and how the government budget is financed."*

- *„The external sector, using indicators of the magnitude of the current account deficit, official reserves, and how the deficit is financed; the relative size, maturity structure, and current composition of external debt; the extent of exchange rate misalignment and whether there are any pressures on the exchange rate."*

2.1.2 Financial soundness indicators

Financial soundness indicators (FSIs) give information about the state of the financial health of individual financial institutions and sectors in a country. Unlike the macroeconomic indicators, they are more "micro-based" (Jones, Hilbers and Slack, 2004).

In financial stability analysis, the FSIs are often used in combination with stress testing, as they mutually reinforce their usefulness in monitoring vulnerabilities in banking sectors. The main usefulness of FSIs can be seen in their comparability across different financial systems. The comparability has been reached thanks to the large contribution of the IMF which has developed internationally accepted FSIs covering "core" and "encouraged" system of definitions assessing financial soundness and vulnerabilities (IMF, 2004). The core FSIs involve especially FSIs for banking sector[6]

[6] This reflects the fact that the banking sector plays very important and dominant role in most financial systems.

and cover six main fields including capital adequacy, quality of assets, earnings, liquidity and market risk exposures. The encouraged FSIs also contain FSIs for nonbanking sectors, since their weaknesses may pose credit risk exposures for banks, so they also assist in the monitoring of vulnerabilities (Jones, Hilbers and Slack, 2004), (IMF, 2004).

There are several aspects in which stress testing and FSIs differ. While FSIs focus on monitoring of strengths and weaknesses appearing continuously over time, stress tests attempt to uncover latent risk exposures which are beyond the analysis of FSIs. Secondly, the FSIs are comparable across countries, as opposed to stress tests which are tailored to national specifics of each country. It discourages the creation of standardized methodology of stress tests (Čihák, 2005), (IMF, 2004).

2.1.3 Early warning indicators

Early warning indicators (EWIs) represent another complementary measure for monitoring and detecting weaknesses in banking sectors. Their utility lies in early detection of those banks whose soundness is deteriorating. EWIs make use the potential of those variables which are capable of isolating failing banks from those well-functioning. Among other indicators, deposit rates and credit growth are very good predictors of bank failures. Furthermore, these variables could be enlarged about interest rates on loans and interbank market rates. For example, raising interest rates on deposits indicate oncoming failures, since the weak banks have difficulties attracting deposits otherwise. If the banks experience the period of rapid growth followed by the asset quality deterioration, then the credit growth indicates probable failures of such banks (Čihák, 2004b).

EWIs are not identical to stress testing, so one can find a difference in both approaches. EWIs disclose the banks which are likely to fail in existing environment, while stress tests assess the resilience of banks to changes in their environment (Čihák, 2004b).

2.2 Designing stress tests

Once the main vulnerabilities have been identified, then the process of stress testing is developed by the specification of an appropriate stress scenario. This forms the basis of designing stress tests (Jones, Hilbers, Slack, 2004). An important step before the scenario can be constructed is the decision about the set of relevant risk factors involved in the scenario.

2.2.1 Risk factors

The portfolio value of banks is closely connected to the behavior of underlying macroeconomic variables. Hence, banks and other financial institutions face the risk of changes in these factors, as they may considerably reduce the value of their portfolios.

But it is always necessary to assess the macroeconomic risks recognized in association with the banks' exposures. If the exposures are small, then the macroeconomic risk factors resulting in shocks can also have small impacts on banks' earnings (Čihák, 2004a).

For each bank different risk factors are treated as serious. Generally, stress tests are exercised for measuring exposures to market risk (including interest rate risk, exchange rate risk, equity risk and commodity risk); credit risk; and operational risk. [7]

Based on the number of risk factors considered in stress tests, one can distinguish two basic types of stress tests; sensitivity stress tests and stress scenarios. Moreover, the maximum loss approach and the extreme value approach are two additional techniques used in stress testing analysis (Blaschke et al., 2001).

2.2.2 Single-factor stress tests

Single-factor stress tests are often called the sensitivity tests, as they measure the sensitivity of banks to shocks in single risk factors (Blaschke et al., 2001). For example, if it was examined that a bank is most exposed to interest rate risk, then the stress test takes the form of a sharp change in interest rates. Sensitivity tests are the simplest form of stress scenarios. The main advantage of such type of test can be seen that it is relatively simple for interpretation and easy to prepare. However, measuring the impacts of risk factors shocked separately may be less realistic assumption, since it is highly probable that in stressful times several risk factors will be affected by shocks (Sorge,

[7] The Basel II has set that those are the risk which need to be covered by a bank capital (BCBS, 2001a). I will pay a closer attention to these risks in the next chapter.

2004). Therefore, sensitivity tests can be used rather for a shorter time segments (CGFS, 2005).

2.2.3 Several-factor stress tests

Several-factor stress tests are simply called as scenarios, as they estimate the effects of parallel movements in a group of risk factors and thus simulate a particular stress scenario (Blaschke et al., 2001). The main reason why to prefer a scenario to single-factor stress tests is that in stress testing it is necessary to deal with all potentially significant risk exposures and also study their interactions. Then we can correctly judge how the banks cope with the consequences of stressful events. For example, a sharp rise in nominal interest rates is likely to have response to a rise in real interest rates, subsequently it could lead to the deterioration of the obligors' ability to repay. Banks will be affected by the direct effect of interest rate risk, but indirectly through credit risk as a result of correlation between risks (Čihák, 2007). Scenario stress tests can be based on two approaches (CGFS, 2005). Under portfolio-driven approach, risk managers firstly identify the vulnerabilities in existing portfolio and a plausible stress scenario is formulated in the next step. Under event-driven approach, the formulation of scenario starts with the identification of plausible events and then continues with the specification of amount of losses when such event occurs (CGFS, 2005). The advantage of scenarios is that they enable to capture the impacts of several shocks simultaneously and thus allow more realistic simulating of stressful event. However, this is at the cost of greater computational burden (Sorge, 2004).

2.2.4 Maximum loss theory

The decision about the number of risk factors involved in stress scenario depends on the specifics of each bank's portfolio. In general, all variables that could have a potential impact on the value of a bank portfolio are necessary to be included in stress testing analysis (Breuer, Krenn, 2000). Maximum loss theory (MLT) searches for the combination of movements in risk parameters that would lead to the most damaging impacts on the portfolio value (Blaschke et al., 2001). If we use again the previous marking $V_p(m)$ for the value of a bank portfolio and $V_p(m_{cur})$ for the current value of a bank portfolio, then the maximum loss that a bank could experience can be expressed as (Krenn, 2006):

$$MaxLoss_S\left(V_p\right) = sup\ \{V_p(m_{cur}) - V_p(m)\},$$

where S represents a set of scenarios exceeding a given minimal plausibility limit. $MaxLoss$ can be denoted as a bank's worst-case loss. In other words, it forms the greatest loss the bank can suffer above a given plausibility threshold (Krenn, 2006).

2.2.4.1 Factor push method

Breuer, Krenn (2000) introduce the method which enables to find what scenarios may cause the greatest loss to banks' portfolios. The idea of the factor push method is *„to change each individual risk factor by a given value in the direction that will most reduce the portfolio value"* (Breuer, Krenn, 2000, page 9).

According to Breuer and Krenn (2000), let us denote again $V_p(r)$ the portfolio value as a function of individual risk factors r. Using the fact that the change in the portfolio value usually correspond to a j -multiple of the standard deviation σ_i of i - risk factor, then portfolio values under such stressful condition can be expressed:

$V_p^1 = V_p\ (r_{1,} \dots, r_i(1 + j\sigma_i), \dots, r_n)$ for a positive change in risk factor, and

$\mathrm{V_p^2} = V_p\ (r_{1,} \dots, r_i(1 - j\sigma_i), \dots, r_n)$ for a negative change in risk factor.

Now these equations can be rewritten using the sign function:

$\mathrm{G(i) = sgn\ (V_p^1 - V_p^2)}$,

where $\mathrm{G(i)} = 1$ when it holds that the upward change in risk factor r_i brings the higher portfolio value than the downward movement, otherwise $\mathrm{G(i)} = -1$. Finally, stress scenario that the factor push method is searching for is:

$$m_{worst-case} = [(r_1 \cdot (1 - G(1) \cdot j\sigma_1), \dots, r_n \cdot (1 - G(n) \cdot j\sigma_n)].$$

(Breuer, Krenn, 2000)

2.2.5 Extreme value theory

The extreme value theory (EVT) has significantly contributed to a better understanding risk of losses resulting from the occurrence of an extreme market event.

Traditional statistical approaches such as VaR usually ignore the eventuality of catastrophic market moves and assume the everyday changes in market variables to be normally distributed (Laubsch, 2000).

The EVT has been developed as one of the stress testing techniques focusing most on the extreme situations in financial markets. These events are the major concern of many regulators and risk managers, since the exceptional trading days occurring a few times a year participate in the financial results of banks. Secondly, they are also interested in periods of crises in order to protect the financial sector from damaging events possibly resulting in systemic risk (Longin, 2000).

The EVT deals with the extreme returns and as a part of the branch of statistics it examines their statistical distribution. This is the central point of the EVT. According to the theory, extreme values have the distribution asymptotically converging to (Aragonés, Blanco, Dowd, 2000):

$$F\,(y) = \begin{cases} exp\{-\,[1+\varphi(y-\mu)/\sigma]^{-1/\varphi}\} & \text{if} \quad \varphi \neq 0 \\ exp(\,-\,e^{-(y-\mu)/\sigma}) & \quad\quad \varphi = 0, \end{cases}$$

where μ is the mean and σ is the standard deviation. The parameter φ denotes so called "tail index" which is directly proportional to the heaviness of tails. A positive tail index ($\varphi > 0$) corresponds to fat tails returns being usually found on the financial markets (Aragonés, Blanco, Dowd, 2000).

From the statistical point of view, the extremes correspond to the highest as well as to the lowest values observed over a certain period of time. The theory based on extreme values thus model the tails of statistical distribution. Financial markets are the domain where extreme price movements can be experienced during the periods of standard behavior of financial markets as well as during the unusual periods corresponding to financial turbulences. Therefore, the EVT has established the linkage between VaR statistics and stress testing, since it concerns with the normal market conditions handled by the VaR approach and simultaneously with the financial crises being the interest of stress testing (Longin, 2000).

2.3 Determining the size of shock in scenarios

Another important issue in the context of implementation stress tests is the decision about the size of shock to be applied in stress testing. Enough attention should be given to this step, since the volume of shock improperly determined may cause the outcomes of stress testing to be meaningless. Given the nature of stress tests that are designed to reveal vulnerabilities to extreme conditions, the size of shock should be similar of extreme values. However, it is necessary to be still plausible. For example, if we consider the shock such that under extreme conditions all borrowers will default simultaneously, it is highly implausible in fact and thus similar stresses should be omitted from stress testing (Bunn, Cunningham and Drehmann, 2005). Generally, there are two basic methods used for calibrating shocks.

2.3.1 Historical method

Under historical approach the size of shock in stress scenario is specified based on the past empirical disturbances in risk factors over a given time period. For example, as an incentive for measuring the resilience of banks to interest rate risk can be used a single-factor stress test based on the largest change in interest rates over the last decade (Jones, Hilbers and Slack, 2004), (Blaschke et al., 2001).

But this method also allows simulating stress scenarios including a group of risk factors. For example, several papers examining the resilience of the Czech banking sector to impacts of adverse macroeconomic shocks were based on the Czech economic conditions resulting in 1997-1999 recession. Scenarios used in these papers were the combinations of three parameters and they included an increase in interest rates, a sharp depreciation of the exchange rate and an increase in the share of non-performing loans (NPLs) (Čihák, 2004b), (Čihák, Heřmánek a Hlaváček, 2007).

The reasons for choosing approach based on historical data are that it is quite intuitive, since the events really occurred in the past and thus may appear again. On the other hand, the approach may become less relevant over time, since it is backward looking and it does not take into account market development and changes in financial structures (Blaschke et al., 2001).

2.3.2 Hypothetical method

Under hypothetical method a scenario does not reflect the extent of historical crises, but according to Berkowitz (1999, page 4) it is based on simulating plausible shocks (i) *„which we suspect are more likely to occur than historical observation suggests"*; or (ii) *„that have never occurred"*; or (iii) *„that reflect the possibility that statistical patterns could break down in some circumstances"*; or (iv) *„that reflect some kind of structural break that could occur in the future"*.

The rationality of this approach is obvious, since future economic crises may go beyond the past experiences and may include additional risks emerging through increasing cross-banking linkages (Čihák, 2004a). The advantage is that a scenario under hypothetical method is forward-looking and allows more flexible and realistic simulation of plausible events. The main weakness relating to the hypothetical approach is that it is complicated to determine the likelihood of hypothetical event, since it is beyond the past observations (Blaschke et al., 2001).

2.4 Measuring the relevance of the impacts of stress tests

The process of stress testing is completed by the reporting results of stress tests and discussion about the way of their interpretation. A key question in this step is how to express the impacts of stress tests and assess their relevance to banks. The standard way is to show the impacts in terms of capital adequacy of banks.

2.4.1 Capital and capital adequacy

Nowadays, the capital adequacy (CA) forms one of the most important instruments of banking regulation. The essence of CA lies in the fact that the banks are obliged to maintain a certain amount of capital in order to absorb potential losses and thus prevent their insolvency. With this respect, the level of CA gives a good indication of how resilient the banks are and whether they are able to withstand stressful events. Knowing of CA helps to answer two important questions (Čihák, 2007):

- Which banks are resilient enough to withstand assumed shocks and which banks will fail?

- What are the potential governmental costs associated with the failure of banks in stressful times?

2.4.1.1 Capital adequacy ratio

Typically, capital adequacy ratio (CAR) is used for answering the first question defined above. The CAR can be computed as the proportion of bank's capital to risk-weighted assets (RWA). According to the 1988 Basel Accord, a regulatory requirement for holding a minimum CAR was set at 8 % (BCBS, 1996).[8] This regulatory minimum was confirmed in the more recent revised document issued by the BCBS in 2006, it states: *„The Committee is also retaining key elements of the 1988 capital adequacy framework, including the general requirement for banks to hold total capital equivalent to at least 8% of their risk-weighted assets"* (BCBS, 2006, page 2). Hence, it must hold true that:

$$CAR = \frac{C}{RWA} \geq 8\%,$$

where C is bank capital, and RWA a the bank's risk-weighted assets (BCBS, 1996).[9]

If the effects of stress scenarios cause the decline in CAR of a bank below the minimum of 8%, then the owners' initiative is in place and they need to inject capital into the bank in order to remain in operating. In case the CAR falls below O, the bank becomes insolvent and leaves the business (Čihák, 2007).

***Table 1:** Level of CAR and Probability of the Bank's Default*

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

Source: Čihák, Heřmánek, Hlaváček (2007)

8 1988 Basel Accord is also known as Basel I including a set of minimal capital requirements for banks published in July 1988 by the Basel Committee on Banking Supervision.

9 BCBS (1996) further specifies that the amount of bank capital is given by the sum of tier1 capital and tier2 capital. The first represents shareholders' equity and retained earnings, the latter represents supplementary capital.

2.4.1.2 Governmental capital injection

The capital injection represents the amount of capital that the government needs to inject into the banks if they fail to satisfy required capital minimum. According to Čihák (2007), the governmental costs necessary to keep the banks active can be derived from subsequent accounting formula:

$$\frac{C + I_{cap}}{RWA + \sigma I_{cap}} = \tau,$$

where C denotes the bank's existing regulatory capital, I_{cap} denotes the governmental capital injection, RWA are the bank's risk-weighted assets, σ is the portion of the capital injection immediately used to increase risk-weighted assets, and τ denotes the regulatory minimum requirement CAR.

By a simple modification of the equation, the amount of the necessary capital injection can be expressed as follows:

$$I_{cap} = \frac{\tau RWA - C}{1 - \sigma\tau} \quad if\ C < \tau RWA,$$

$$I_{cap} = 0 \ otherwise.$$

(Čihák, 2007)

3. Classification of bank risks

According to Cipra (2008, page 483) *„risk is the uncertainty associated with the occurrence of a potential situation"*. In this context, the essence of bank risks is that the financial position of banks may vary significantly due to volatilities in financial markets (Cipra, 2008).

The behavior of macroeconomic variables plays here a key role. This chapter provides information about those factors of whose changes could have a negative impact on the bank portfolios. These variables thus represent potential sources of risks for the banks.

3.1 Market risk

Market risk highlights the risk of losses arising when the value of instruments in a bank portfolio changes as a result of unfavorable movements in market prices (BCBS, 1996). Both on and off-balance sheet items must be here included as a part of a bank portfolio.

Market risk is created by the interaction of individual market risk components. All these individual risks participate in the losses of a portfolio by different measures. We will deal with the issue of interest rate risk, exchange rate risk and risks arising from changes in prices of equities and commodities.

3.1.1 Interest rate risk

Interest rate risk is closely connected with a bank's exposure to adverse moves in interest rates (Čihák, 2004a). The level of interest rates has an effect on the interest income and interest expenses of financial institutions. It further affects interest sensitive assets and liabilities (as well as other off-balance sheet components) due to changes in their market value (Blaschke et al., 2001).

A bank is typically exposed to direct interest rate risk caused *„when the interest rate sensitivities of its assets and liabilities are mismatched"* (Čihák, 2007, page 31). Apart from the direct interest rate risk a financial institution might be exposed to interest rate risk indirectly. In case of increase in interest rates, the borrowers have to withstand higher costs and they may face problems with the debt repayment. Therefore, the indirect interest rate risk could be understood as a part of credit risk, as the interest rate changes influence borrowers' creditworthiness (Čihák, 2007). [10]

When the exposure to interest rate risk is examined, it is important to specify what shocks to be applied in stress testing. Either historical events or hypothetical stress scenarios can be used to define them (Blaschke et al., 2001).

The most common type of shock includes a parallel shift in a whole yield curve, further a change in the slope and the shape of a yield curve may be applied in stressful times. Assessing the impacts of these shocks enables one to determine the level of sensitivity of individual banks' portfolios to specific interest rate risk (Čihák, Heřmánek, Hlaváček, 2007).

Even thought the size of shock is not generally defined, The Derivatives Policy Group (DPG, 1995) suggests following movements:

- *„Parallel yield curve shifts of 100 basis points up and down";*
- *„Steepening and flattening the yield curves by 25 basis points";*
- *„Increase and decrease in all 3month yield volatilities by 20 percent of the prevailing levels".*

For measuring interest rate risk exposures there are three commonly used models based on the gap of assets and liabilities: the repricing model, the maturity model and the duration model (Saunders. 2000).

Using the gap in the interest rate risk managing is briefly explained in Blaschke et al. (2001). The gap methodology is based on the requirement to split a bank's assets and liabilities into buckets according to their time to repricing/maturity and the difference between assets and liabilities in a given bucket creates gap. The gap is used to evaluate the effect of a change in interest rates on the net interest income (NIE) of banks.

3.1.1.1 The repricing model

The following models will be explained based on Saunders (2000). The repricing gap signifies the difference between the interest gains earned by a bank on its

[10] More detailed credit risk analysis will be provided later.

assets and interest expenses which a bank is obliged to pay on its liabilities. *"Under the repricing gap approach, a bank calculates the gaps in each maturity bucket by looking at the rate sensitivity of each asset and the rate sensitivity of each liability on its balance sheet"* (Saunders, 2000, page 122).[11] How the repricing gap indicates the change in a bank's NIE may be expressed:

$$\Delta NII_i = GAP_i^{repr} \cdot \Delta R_i$$

where ΔNII_i is the change in NIE in bucket i, GAP_i^{repr} is the difference in the book value of assets and liabilities in bucket I, and ΔR_i signifies the change in interest rate in bucket i. If the repricing gap is negative and interest rates rise, the overall change in the NIE is also negative.

The main positive of the repricing model lies in the fact that it simply indicates a bank's income exposure to interest changes. However, it neglects the market value effect of assets and liabilities due to changes in interest rates.[12]

3.1.1.2 The maturity model

The maturity model is based on the average maturity of the assets and liabilities in a portfolio weighted by the proportion of assets and liabilities' positions on the total market value of portfolio. When the maturity of assets and liabilities mismatches, the maturity gap is created and a financial institution is exposed to interest rate risk. The maturity gap can be expressed:

$$GAP^{mat} = M_A - M_L$$

where M_A (M_L) is the weighted-average maturity of assets (liabilities). If the maturity gap is positive ($M_A > M_L$) and interest rates rise, a fall in the value of assets is

[11] Rate sensitivity denotes the time when both assets and liabilities's interest rates will be repriced.
[12] Market value effect implies that an increase/decrease in interest rates causes the market value of assets and liabilities to reduce/augment.

greater than a fall in the value of liabilities reducing the bank's net worth (equity value).[13]

The maturity model provides useful information on a bank's exposure to interest rate changes. However, matching the maturities of assets and liabilities still does not completely protect the bank against possible losses from interest rate risk, as the timing of cash flows of assets and liabilities may differ.

3.1.1.3 The duration model

The duration model works more reliably as an indicator of interest rate risk exposure, since it takes into account also the timing of cash inflows from assets and cash outflows from liabilities apart from their maturities. Duration uncovers how sensitive the prices of assets and liabilities are to shocks in interest rates.[14] It can be defined as *„the weighted-average time to maturity using the relative present values of the asset or liability cash flows as weights"* (Saunders, 2000, page 136).

The duration gap helps the bank to analyze its exposure to interest rate risk. It can be calculated as a difference between the duration of assets and liabilities:

$$GAP^{dur} = D_A - D_L$$

If a change in interest rates is considered, it is necessary to assess the difference between the change in the market values of both assets and liabilities in order to analyze the change in the bank's net worth. The duration gap is frequently used in order to immunize bank portfolio.[15] This could be reached when the gains or losses in the value of assets and liabilities are matched ($D_A = D_B$).

However, even this approach is not without shortcomings. The duration gap assumes bank exposures to parallel shifts in the yield curve and fails to recognize exposure to any other movements of the yield curve.

[13] It results from market value effect and the fact that the longer the maturity, the greater the fall in the market value.
[14] The higher the value of duration is, the more sensitive the price is to changes in interest rates.
[15] Immunizing a bank is used to protect bank equity against the interest rate shocks.

3.1.2 Exchange rate risk

Exchange rate risk arises since the value of banks balance sheet items as well as of their off-balance sheet items may also be the subject to exchange rate movements which can rule the economic results of banks (Blaschke et al., 2001).

Exchange rate risk generally occurs in two forms. Direct exchange rate risk occurs when *„a financial institution takes or holds a position in foreign currency"* (Blaschke et al., 2001, page 17). Indirect effects of exchange rate moves are associated with the impacts on the borrowers' credit quality through their potential inability to repay to banks.

For measuring foreign exchange exposure a bank's net open foreign exchange position is appropriate to be used (Blaschke et al, 2001). To calculate net open position, the standards recommended by the BCBS require two processes to be fulfilled (BCBC, 1996). Firstly, the exposure in each currency should be measured by adding items such as the net spot position, the net forward position, guarantees or other items representing profits or losses in external currencies. Secondly, the total net open position should be completed by aggregating the sum of the net short/long positions in different currencies (BCBS, 1996).

In some countries the banks can be regulated through the imposition of limits on the foreign exchange positions. These are generally determined as a certain portion of a capital. In most cases they fluctuate between 10 % and 20 % of capital which is the maximum limit (Čihák, 2007).

Exchange rate shock applied during stress testing exercises takes the form of depreciation or appreciation of exchange rates. As already mentioned before, there are no universally binding rules adjusting what size of shock should be suitable for stress testing. However, some international supervisory institutions recommended:

- According to the DPG (1995): *„Increase and decrease in the exchange value (relative to the U.S. dollar) of foreign currencies by 6 % in the case of major currencies, and 20 % in the case of other currencies";*
- *„Increase and decrease in foreign exchange rate volatilities by 20 % of prevailing levels".*

- The BCBS (1996) specifies its capital charge for exchange rate risk exposure when the increase/decrease in exchange rate reaches 8 %.

The choice of proper shock scenario to be used in stress testing is to some extent influenced by a country's recent economic situations. For example, if the country experienced dramatic depreciations in past years, the current bank portfolios could be subjected to similar stressful conditions. However, these historical scenarios should be supplemented by diverse hypothetical processes as the future recessions may differ from those previous ones (Blaschke et al., 2001).

3.1.3 Equity risk

A bank's trading book is exposed to equity risk when it holds or takes short and long positions in equities and in those instruments whose market behavior is similar. The instruments covered in stress testing to equity risk should comprise common stocks, convertible securities behaving similarly to equities and commitments to buy or sell securities in some future periods. These all items are exposed to changes in equity prices. Finally, off-balance sheet products as well as equity derivatives such as swaps, futures and options should not be forgotten in the equity risk analysis, as their value is derived from equity prices (BCBS, 1996).

There are two types of equity risks defined (BCBS, 1996). Specific market risk arises when the price of an individual equity changes. It corresponds to the bank's gross equity positions expressed as:

$$RISK_{spec} = GEP = LEP + SEP,$$

where LEP are all long equity positions and SEP are all short equity positions. The second type, general market risk, lies in the movement of the whole stock market and can be calculated as the bank's net equity position:

$$RISK_{gen} = NEP = LEP - SEP.$$

To measure the size of a bank's exposure to equity risk, the net open position is commonly used. Stress tests for general market risk are conducted more frequently than those for specific market risk. The shock to main stock market index is widely used in stress testing as well as the shock to equity prices (Blaschke et al., 2001). The size of shock recommended by the DPG (1995) is:

- *„Increase and decrease equity index values by 10%";*
- *„Increase and decrease in equity index volatilities by 20% of prevailing levels".*

Past economic performance and particularly historical stock market breakdowns may serve as a starting event for the selection of an appropriate stress scenario. But innovations and institutional changes in the stock market require modifications of these historical scenarios and their supplementing with hypothetical low probable events. The third potential method, Monte Carlo simulation, is utilized less frequently especially for its complexity and computational difficulty (Blaschke et al., 2001).

3.1.4 Commodity risk

Commodity risk is going to be the last mentioned component of market risk.

It is the risk that the changes in commodity prices can affect the value of a bank portfolio and it thus may suffer losses. Financial institutions dealing with spot trading have significant exposure to changes in spot prices, but there are also additional risks especially for those institutions that are involved in forward and derivative contracts, namely basis risk, interest rate risk, and forward gap risk (BCBS, 1996).

Even if there are many banks not involved in direct trading in commodities, all banks may be exposed to commodity risk through indirect effects of commodity price changes. To measure the net positions in commodities, historical price movements as well as new possible scenarios can be applied. A slump in prices of energy and precious metals is relevant shock for long commodity positions. A dramatic increase in energy prices is important for short commodity positions (Blaschke et al., 2001).

3.2 Credit risk

Previous survey of market risk components has shown that the adverse moves in individual market variables contribute to problems with repayment and thus form a part of credit risk.

Credit risk can be defined as the loss that the banks could experience as a result of unexpected deterioration in credit quality of clients (Čihák, 2004a). It arises when the banks' counterparties fail to repay their obligations negotiated.[16] In this case, besides a principal amount the bank losses contain also the interest from principal. Consequently, it reduces bank cash flows which could expose the banks to serious troubles. Therefore, banks pay the greatest attention to this type of risk in order to eliminate it.

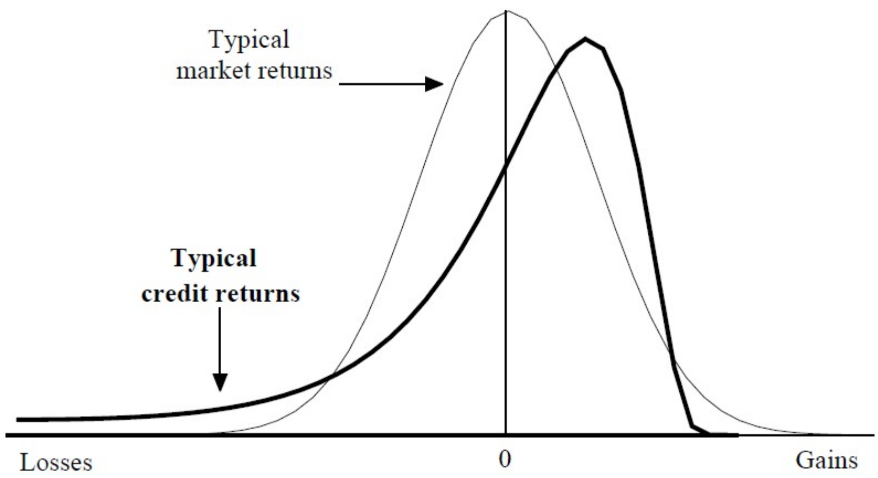
If a bank wants to measure its exposure to credit risk, there are several questions which need to be answered (Čihák, 2004a):

- What is the probability of default on each bank product on average and under extreme conditions?
- What is the significance of losses for the bank in case of default?
- What is the probability that other counterparties will default at the same time?

The approaches for modeling credit risk are different than those used for measuring market risk, since the credit risk characteristics are different. There is a number of credit instruments which are not traded or, unlike the market variables, which are not marked-to-market. Therefore, only limited data about the underlying value of a specific credit instrument is available. Further, the cases of defaults come rarely, so when they occur they are not monitored as precisely as changes in market prices. The last obstacle which makes the credit risk measuring difficult relates to asymmetric distribution of credit risk returns. It implies that small profits are made with a high level of probability and there is only little risk of high losses. These factors combined together bring great difficulties to credit risk modeling (Blaschke et al., 2001).

[16] This situation refers to the "default" of counterparties.

Figure 4: *Comparison of Distribution of Credit Returns and Market returns*



Source: CreditMetrics™—Technical Document (2007)

In general, there are two basic approaches dealing with credit risk. Mark-to-market approach claims that the banks could experience loss in their portfolios due to unexpected changes in credit quality of their obligors. Secondly, the default mode approach identifies the changes in credit portfolios if the counterparties have defaulted on their obligations (Virolainen, 2004).

3.3 Operational risk

Operational risk is another from a group of bank risks which may pose a significant threat to a bank performance. Going back to previous analysis of bank risks, it is possible to notice that all risks mentioned are associated to the development of macroeconomic environment. However, it is not a case of operational risk which is associated with defects and collapses occurring within a given bank institution.

More precisely, BCBS (2001b, page 2) describes operational risk as *„the risk of direct and indirect loss resulting from inadequate or failed internal processes, people and systems or from external events“*. As the definition suggests, it is obvious that operational risk is not exactly specified and a relatively wide range of imperfections may come under this concept.

The forms of operational risk as specified in Cipra (2008) are:

- Transactional risk; a potential loss resulting from transactional mistakes during operations (human factor errors, accounting errors, frauds);

- Operational management risk; a potential loss resulting from errors in management (inadequate control made by management, unclear specification of competencies, unfair policies and practices made by management);
- System risk; a potential loss resulting from errors in systems (errors in computer programs, poorly specified mathematical and statistical models, bad estimation of parameters).

From the perspective of risk managers, monitoring operational risk has been traditionally perceived as less useful and a greater importance has been attached to other types of risks such as market and credit risk (Jobst, 2010). Jobst explains this fact by referring to different characteristics of operational risk: *„Given that OR is not priced, incentives underlying ORM are different from those determining the hedging of credit and market risk; there is no return from greater risk, only pain and suffering. Remedies are process-driven rather than mathematical; it is difficult to quantify, especially as the demarcation line between OR and other types of risks (market and credit risk) becomes increasingly blurred "*(Jobst, 2010, page 5).

However, operational risk management has slowly entered the interest of managers particularly since the time the Basel II has emphasized that other risks apart from market and credit should be realized (BCBS, 2001b).

4. Empirical data analysis

Previous chapters were devoted to detailed description of stress testing techniques plentifully used by an increasing number of institutions for the purposes of assessing financial stability of a given entity or even the entire complex of institutions. The attention was also paid to particular risks which may potentially be the source of disruption of stability.

In this context credit risk is usually regarded as the most significant threat and it is much discussed issue in the area of stress testing. This part of the thesis aims to look closely at credit exposures in Czech banking sector.

4.1 Models of credit risk

According to Jakubík (2006b), generally two kinds of models are employed for the estimation of credit risk. From the microeconomic perspective, for banks it is important to estimate loan profile of each individual debtor. For this purpose the banks are allowed to use own internal models whose outcomes may enter the overall CAR assessment.[17] Second group, being the subject of this part, includes models of credit risk at the aggregate level. They are used for capturing the overall credit risk exposures by examining the relationship between credit portfolio and business cycle (Jakubík, 2006b).

As seen in Jakubík (2006a), this mutual relationship could be generally expressed by following function:

$$def_{t_1} = f(F_{t_2}), t_2 \leq t_1$$

where def_{t_1} denotes rate of default at time t_1 and $f(F_{t_2})$ denotes a function of macroeconomic factors at time t_2 (Jakubík, 2006a).

[17] It refers to IRB approach proposed by the New Basle Capital Accord, see Schuermann (2004).

4.1.1 Literature overview

Macroeconomic models of credit risk have become broadened in the literature of stress testing particularly in last decade.

One of the first macroeconomic models of credit risk was evolved by Wilson and several authors have adopted his approach. The model is based on modeling the probability of default in particular sectors depending on the macroeconomic conditions.

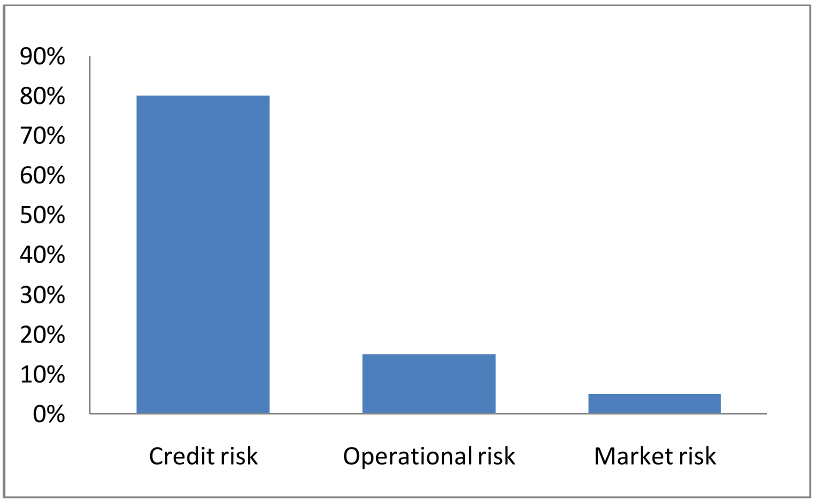
For example, Virolainen (2004) estimated default probability in six industries of corporate sector in Finland. Wong, Choi, Fong (2006) applied this concept for modeling quality of loan portfolio of banking system in Hong Kong. Virolainen identified the GDP, the nominal interest rates and the corporate indebtedness as highly significant variables explaining the corporate default. In the latter, real GDP growth, real interest rates and real property prices rang among variables with the greatest explanatory power.

Another group of papers uses the portion of NPLs to total loans (TLs) as an indicator of an aggregate credit quality. In the second step, the aggregate impact on credit portfolio is measured by simulating stress scenario on selected variables. Kalirai, Scheicher (2002) focused on the estimation of credit risk in Austrian banking system. Using a linear regression model they discovered high significance between the share of NPLs and a set of variables such as the industrial production, the real and the nominal interest rates and the money growth. Zeman, Jurča (2008) made a similar analysis for the Slovak banking sector, Sorge, Virolainen (2005) contributed to this kind of papers by the study of credit exposures of banks in Finland. Jakubík (2006a) studied the evolution of default rates depending on macroeconomic conditions in four industrial sectors of Finnish economy when two different approaches - empirical models and latent factor models - were employed. Studies devoted to stress testing credit risk in the Czech Republic can be found in Jakubík (2006b); Jakubík, Heřmánek (2007). In the first mentioned paper, using the one-factor model the statistical dependence between NPLs and variables including the GDP, the nominal interest rates and the inflation was found. The objective of the latter was to examine the development of bank loans to residents in the Czech Republic where the macroeconomic models were estimated for both household and corporate sectors. Another useful contribution to this kind of literature can be found in Jakubík, Schmieder (2008) comparing the rates of default in the Czech and the German private sector.

4.2 Credit risk in the Czech banking sector

Credit risk is a type of risk associated with the banks operating in the Czech Republic most frequently. As illustrated in Figure 5, generally three main risks are considered in the Czech banking sector. Particular attention should be paid to credit risk since it is several times higher than other risks appearing in Czech banks.

Figure 5: *Structure of Risks in the Czech banking sector*



Source: Based on consultation with Dr. Jakubík

4.2.1 Credit portfolio and its development

Although especially a massive increase in derivatives trading causes new forms of credit exposures occur (Cipra, 2008), credit risk in Czech banks is closely related to lending operations which are still predominating among banking activities.[18]

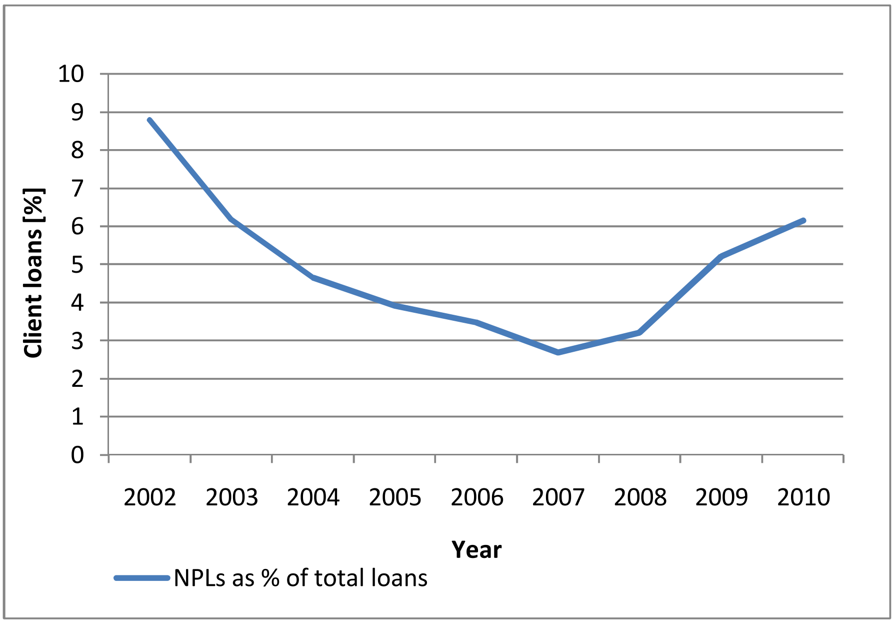
The amount of NPLs is often considered as a good indicator of the quality of credit portfolio. Information on the number of defaulted loans for the Czech Republic is available since 2002 when the development of NPLs becomes largely dependent on the economic conditions. In previous years this information was not considered reliable especially due to effects of non-standard factors such as privatization of banks.[19]

As illustrated in Figure 6, it is evident that the share of NPLs had continually downward trend after 2002. From the highest value 11,55 % achieved in the first quarter of 2002, the share of NPLs achieved its minimum in the last quarter of 2007 when it

[18] See Apendix 2 for the structure of banking sector balance sheet.
[19] http://www.cnb.cz/cs/statistika/menova_bankovni_stat/stat_mb_met/stat_mb_klasif_uvery.html

amounted only 2,68 %. However, since 2008 there was a reversal of this tendency. It is possible to observe gradual deterioration in the quality of credit portfolio of the Czech banking sector. This change probably happened as a consequence of the global financial crisis 2007/2008. The value of share of NPLs was growing slightly year-on-year and it exceeded the level of 6 % in the last quarter of 2010.

Figure 6: *Development of NPLs in the Czech banking sector*



Source: CNB, time series system ARAD

4.3 Data

The objective of the empirical section is to estimate whether there is an empirical relationship between the level of loan portfolio in the Czech Republic and the state of the economic conditions. For this purpose, the portion of NPLs to TLs has been chosen as a representative of the measure of credit risk. The economic environment in the Czech Republic is going to be characterized by a set of macroeconomic indicators including the industrial production, the nominal interest rate, the nominal exchange rate, the inflation, and the unemployment.

All the data used for the analysis were obtained from publicly available statistics published by the Czech national bank (CNB), the Czech statistical office (CSO), and the European statistical office (ESO).

Time series data on the levels of interest rate, nominal exchange rate and the data on the mount of client NPLs and TLs were collected from the time series system ARAD provided by the CNB.[20]

Statistical data on the levels of industrial production and inflation were available from statistics published by the CSO.[21]

Finally, statistics on the levels of unemployment rate were achieved from time series data published by the European statistical office (ESO).[22]

Given the fact that the information on the volume of client NPLs in the Czech Republic has begun to be published regularly since early 2002, I decided to start the analysis by collecting data from this time period. Financial statistics on all the chosen variables were available in monthly frequencies and the most recent observations available come from 03/2011.

Therefore, the analysis was realized using the monthly observations and it maps the Czech economy comprising the period from 01/2002 to 03/2011.

4.3.1 Selected macroeconomic variables

In this part I will take a look at selected macroeconomic variables in more details in order to identify their expected relationships to NPLs/TLs ratio. For the selection of macroeconomic variables, I was inspired by the works of Kalirai, Schreicher (2002) and Zeman, Jurča (2008). Following their methodology, I always chose one macroeconomic indicator as a representative belonging to a different category.

Table 2: *Selected macroeconomic variables*

Category	Variable	Notation
Cyclical indicators	Industrial production	IP
Financial market indicators	Nominal interest rate	IR
External indicators	Nominal exchange rate	ER
Price stability indicators	Inflation	INF
Household indicators	Unemployment rate	UN
Credit risk indicator	NPLs/TLs ratio	NR

Source: author

[20] http://www.cnb.cz/docs/ARADY/HTML/index.htm.
[21] http://www.czso.cz.
[22] http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home.

Industrial production was chosen as a representative of an aggregate economic activity.[23] The variable is characterized by industrial production index (IPI). I used seasonally adjusted data.

The assumption is that when the economy occurs a phase of economic recovery, the business activities are expanding and general well-being is increasing as well. Growing IP thus reduces the volume of NPLs. Therefore a negative sign between IP and NR can be expected (Kalirai, Scheicher, 2002).

Interest rate was chosen as a financial indicator. The three month interbank interest rate (PRIBOR 3M) was used for the analysis.

Similarly to Kalirai, Scheicher (2002), I assume that the level of interest rate relates to direct costs of credit for the obligors. An increase in interest rate causes that the obligors' debt burden rises as well and obligated parties are more likely to default. That is why I expect a positive sign between IR and NR.

Nominal exchange rate was chosen as an indicator which could have an impact on the Czech financial sector through foreign trade linkages (Kalirai, Scheicher, 2002). More precisely, I employ the nominal effective exchange rate for the Czech koruna determining whether the domestic currency appreciates or depreciates compared to other foreign currencies. However, as stated in the literature, the change in ER may impact NR ambiguously. The depreciation of a domestic currency positively affects the exporters whose goods become more attractive abroad. Further, the obligors' debt burden decreases in case of depreciation. These facts support a positive relationship between a depreciation and NR; however it is important to take into account difficulties arising to importers in case of depreciation of a domestic currency (Kalirai, Scheicher, 2002).

Inflation was chosen as a representative from a group of price stability indicators. As mentioned in Zeman, Jurča (2008), an increase in inflation is associated with the reduction of the real value of debt. Moreover, it also reduces the real interest rate and support a higher economic activity. These arguments show that an increased inflation should reduce the volume of NPLs. Hence, a negative relationship between NR and INF can be expected.

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[23] In literature the GDP as an indicator of economic activity is usually preferred to the industrial production. The reason for my choice is a pure fact that the data on GDP were available only quarterly. Hence, I will work with the data on industrial production, since as noted in Kalirai, Scheicher (2002), the development of industrial production usually follows the development in GDP cycle.

Unemployment rate was used as the last macroeconomic indicator taking part in the estimation of NR. It is rational to expect that people get into great difficulties to repay debt loans if they lose a job. Therefore a higher unemployment goes hand in hand with a higher amount of NPLs and the relationship between UN and NR should be definitely positive.

Table 3: *Descriptive statistics of macroeconomic variables*

Variable	Expected sign	Mean	Median	Standard deviation	Minimum	Maximum
IP	–ri	103,58	103,51	12,24	81,38	124,21
IR	+	2,53	2,39	0,88	1,20	4,55
ER	–/+	106,02	105,31	10,95	88,68	127,60
INF	–	2,30	2,00	1,85	-0,40	7,50
UN	+	6,92	7,30	1,24	4,30	8,50

Source: Author

4.4 Used methodology

For meeting the objectives of the empirical section the vector autoregression methodology has been applied.

4.4.1 Vector Autoregression

According to Cipra the vector autoregression method (VAR) can be viewed as *„a natural generalization of one-dimensional autoregressive process"* (Cipra, 2008, page 426).

A simple autoregressive model (AR) comprises of a single linear equation and a single variable where a left-hand part of the model contains the current value of a variable which is explained using its own time lags (Stock, Watson, 2001). A simple linear AR process of order p thus can be expressed as:[24]

$$X_t = \theta_1 X_{t-1} + \theta_2 X_{t-2} + \ldots + \theta_p X_{t-p} + \epsilon_t,$$

[24] P here denotes the number of time lags.

where $\theta_1, \ldots, \theta_p$ are parameters, and ϵ_t denotes white noise (Cipra, 2008).[25]

Unlike that VAR model includes a set of linear equations and variables where the current value of each variable is not only explained by its own lags but also using the current and lagged values of all variables remaining on the right-hand side of the equation. VAR method thus represents a useful mechanism how to capture dynamic relations in multivariate time series (Stock, Watson, 2001).

VAR models have gained wide applications especially in the area of macroeconomics (Greene, 2003).[26] Compared to other econometric models, the application of VAR brings the substantial advantage lying in considering all the variables to be endogenous. It actually means that each single variable contained in the model occurs in the positions of both explained and explanatory variables (Cipra, 2008).

Model VAR of order p thus can be according to Cipra written as:

$$Y_t = \alpha_1 + \varphi_1 Y_{t-1} + \varphi_2 Y_{t-2} + \ldots + \varphi_p Y_{t-p} + \mu_t,$$

where α_1 is m-dimensional intercept and μ_t is m-dimensional white noise. If we consider m time series$Y_{j,t}$, $j = 1 \ldots m$ of length $t = 1 \ldots T$, than VAR (p) can be rewritten as:

$$\begin{pmatrix} Y_{1t} \\ Y_{2t} \\ \vdots \\ Y_{mt} \end{pmatrix} = \begin{pmatrix} \alpha_{10} \\ \alpha_{20} \\ \vdots \\ \alpha_{m0} \end{pmatrix} + \begin{pmatrix} \varphi_{11}^1 & \varphi_{12}^1 & \cdots & \varphi_{1m}^1 \\ \varphi_{21}^1 & \varphi_{22}^1 & \cdots & \varphi_{2m}^1 \\ \vdots & \vdots & \vdots & \vdots \\ \varphi_{m1}^1 & \varphi_{m2}^1 & \cdots & \varphi_{mm}^1 \end{pmatrix} \begin{pmatrix} Y_{1t-1} \\ Y_{1t-2} \\ \vdots \\ Y_{1t-m} \end{pmatrix} + \cdots + \begin{pmatrix} \varphi_{11}^p & \varphi_{12}^p & \cdots & \varphi_{1m}^{1p} \\ \varphi_{21}^p & \varphi_{22}^p & \cdots & \varphi_{2m}^p \\ \vdots & \vdots & \vdots & \vdots \\ \varphi_{m1}^p & \varphi_{m2}^p & \cdots & \varphi_{mm}^p \end{pmatrix} \begin{pmatrix} Y_{1t-p} \\ Y_{1t-p} \\ \vdots \\ Y_{1t-p} \end{pmatrix} + \begin{pmatrix} \mu_{1t} \\ \mu_{2t} \\ \vdots \\ \mu_{mt} \end{pmatrix}.$$

The key assumption allowing application of VAR method is the stationarity of time series used in the model (Cipra, 2008).[27]

[25] White noise denotes the sequence $\{\epsilon_t\}$ of random variables for which it must hold $E(\epsilon_t) = 0$; $var(\epsilon_t) = \sigma^2 > 0$; and $cov\ (\epsilon_s, \epsilon_t) = 0$, for $s \neq t$ (Cipra, 2008).

[26] The model was firstly used in the work of Sims in 1980 (Stock, Watson, 2001).

[27] According to Cipra (2008), two types of stationarity can be distinguished when analyzing time series; "weak" stationarity, and "strict" stationarity. I will deal with the first one. Weak stationarity of time series means that the process is invariant towards shifts in time (up to the moments of second order); ie. means that the process is invariant towards shifts in time (up to the moments of second order); ie. $E(Y_t) = \mu =$

4.5 Construction of model

In this section I will try to examine empirical relations between financial and macroeconomic indicators using the VAR methodology. Given the objectives of empirical part the greatest attention will be devoted to estimation the impact of selected macroeconomic indicators on the ratio of NPLs/TLs.[28]

4.5.1 Testing the stationarity of time series

As mentioned above, a prerequisite for constructing VAR model is to ensure that time series used are stationary. In case the assumption was violated, we could run into difficulties with "spurious regressions" (Adkins, 2010).[29] Hence, the first thing in the analysis is to examine stationarity.

An initial idea of the presence of stationarity or non-stationarity in time series may come from looking at the data graphically (Adkins, 2010).[30] Then it is important to apply unit-root tests in order to reject or not reject the hypothesis (Cipra, 2008).

Based on graphical analysis all time series have proved to be non-stationary.[31] Non-stationarity was subsequently confirmed employing the Augmented Dickey-Fuller test (ADF test) and Kwaitkovski-Phillips-Schmidt-Shin test (KPSS test).[32] Therefore it is necessary to transform original values of time series into appropriate forms in order to obtain the desired characteristics. Hence, I will work with the first differences and logarithmic differences of original values.[33]

$const.; var(Y_t) = \sigma^2 = const.;\ cov\ (Y_s, Y_t) = cov\ (Y_{s+h}, Y_{t+h})$.means that the process is invariant towards shifts in time (up to the moments of second order); ie. $E(Y_t) = \mu = const.; var(Y_t) = \sigma^2 = const.;\ cov\ (Y_s, Y_t) = cov\ (Y_{s+h}, Y_{t+h})$.

[28] All calculations were performed using the statistical software Gretl 1.9.5.

[29] It refers to situation when coefficients estimated by regression indicate a statistically significant relationship between variables even if there is no at all (Adkins, 2010).

[30] See Appendix 5 for graphical plots of original and transformed time series.

[31] It implies the presence of the unit root in the autoregressive process (Cipra, 2008).

[32] See Appendix 6 for the results of unit-root tests for original time series.

[33] The variables used in the regression need to be transformed into the growth rates. I choose logarithmic differences for the variables IP and NEER in order to gain their monthly growth rates. For the variables NPL_RAT; IR; INFL; and UN I use the first differences. More precisely, I mean the differences of two consecutive months.

Table 4: *Transformed time series*

Variables	Transformation	Notation
NR	$NPL\_RAT_t - NPL\_RAT_{t-1}$	d_NR
IP	$ln\ IP_t - ln\ IP_{t-1}$	ld_IP
IR	$IR_t - IR_{t-1}$	d_IR
ER	$ln\ ER_t - ln\ ER_{t-1}$	ld_ER
INF	$INF_t - INF_{t-1}$	d_INF
UN	$UN_t - UN_{t-1}$	d_UN

Source: Author

After the mentioned modifications both ADF and KPSS tests reveals that the new transformed time series have already fulfilled the assumption of stationarity and they thus may enter the model.[34]

4.5.2 Estimation of coefficients and potential relations

It was already mentioned before that all the variables entering the VAR model are endogenous. It means that the model always comprises as many equations as variables we include into the VAR.

I will estimate the coefficients of the reduced form VAR where each endogenous variable is expressed as a linear function of own lagged values and the lagged values of all remaining variables.[35] In view of the fact these variables are predetermined in a given time, the Ordinary least squares (OLS) method can be used to estimate coefficients (Cipra, 2008).

The decision about the lag length chosen for the regression is important. Econometric literature offers several ways how to get optimal lag structure (Green, 2003). In practice, the lag selection is usually made based on statistical tests or information criteria such as Akaike information criterion (AIC), Hannah-Quinn criterion (HQC) and Schwarz information criterion (BIC) (Cipra, 2008). AIC revealed that 12 lags should be involved in the model. However, given the fact that the more lags included in the model the more degrees of freedom disappear, this amount is not quite optimal as my data sample is short. Remaining two criteria revealed 1 lag length as

[34] See Apendix 7 for the results of unit-root tests for transformed time series.
[35] Stock, Watson (2001) presents two other forms of VAR model including a recursive form and a structural form.

appropriate. The subsequent diagnostics of residuals however supported my suspicion that the lag length is underfitted. Therefore, the model with 3 lags has proved to be the most suitable. Using monthly data, it corresponds to a quarterly lag which could uncover interesting relationships between macroeconomic variables.

The VAR (3) model is thus composed of six linear regression equations. The regression for explained variable d_NR has following form:

$$d\_NR_t = \alpha_1 + \beta_1\, d\_NR_{t-1} + \beta_2\, d\_NR_{t-2} + \beta_3\, d\_NR_{t-3} + \gamma_1\, ld\_IP_{t-1} + \gamma_2\, ld\_IP_{t-2} + \gamma_3\, ld\_IP_{t-3} + \delta_1\, d\_IR_{t-1} + \delta_2\, d\_IR_{t-2} + \delta_3\, d\_IR_{t-3} + \varepsilon_1 ld\_ER_{\,t-1} + \varepsilon_2 ld\_ER_{\,t-2} + \varepsilon_3 ld\_ER_{\,t-3} + \zeta_1 d\_INF_{t-1} + \zeta_2 d\_INF_{t-2} + \zeta_3 d\_INF_{t-3} + \eta_1 d\_UN_{t-1} + \eta_2 d\_UN_{t-2} + \eta_3 d\_UN_{t-3} + \mu_1$$

Regressions for all remaining explained variables ld_IP_t,d_IR_t, ld_ER_t,d_INF_t, d_UN_t can be constructed in the same way.

Figure 5 records the results of six linear regressions carried out within the VAR (3) model. The figure contains the values of coefficients and p-values which are enough to satisfy the interpretation. If the level of significance of 1% is taken into account, it is possible to notice that five variables proved to be significant. Considering 5% level of significance, the number of significant variables increased to fifteen, and at 10% level of significance there are even twenty significant variables. With respect to the objectives of the empirical part, I will mainly deal with the first two columns showing the relationship of selected macroeconomic variables to the NPL ratio.

The output of VAR (3) model revealed that the month-on-month growth rate of NPL ratio is influenced by the lagged values of three variables including d_NR, ld_IP, and d_UN.

Statistically significant relationship with the own lagged value indicates that an increase in NPLs does not occur suddenly and unexpectedly and a certain persistence associated with defaults is clearly evident.

Significant relationship between the NPL ratio and industrial production confirmed that the amount of NPLs fluctuates depending on the stage of economic cycle, as the industrial production is probable to follow the development in economic conditions. An increase in industrial production leads to a decrease in NPL ratio and this change will have an effect on NPL ratio with the lag of two months. This result is really in line with my expectations as the higher general well-being has a positive effect on the clients' ability to repay.

The last variable appearing statistically significant relative to NPL ratio is the unemployment rate. Even in this case my intuition was confirmed. A month-on-month rise in unemployment will be reflected in an increase in NPL ratio with the lag of two months. A negative relationship is not surprising and does not need a deeper economic clarification since higher unemployment goes hand in hand with higher problems to repay.

None of the remaining variables has proven to be significant in explaining the development of NPL ratio.

In addition to investigating the relationship between NPL ratio and macroeconomic variables, the output of VAR (3) model enables to observe interesting relations among other variables. However, as noted previously, I will consider such broader analysis beyond the scope of this work and I will leave it to a reader.

Table 5: *The Output of VAR (3) model*

	d_NR		ld_IP		d_IR		ld_ER		d_INF		d_UN	
	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
d_NR(t-1)	0,2422 **	0,0181	0,0143	0,1037	-0,0510	0,4149	0,0033	0,6600	0,3070	0,2497	0,0816	0,1106
d_NR(t-2)	-0,0569	0,5973	-0,0015	0,8730	0,0488	0,4656	0,0047	0,5563	-0,1562	0,5823	0,0115	0,8314
d_NR(t-3)	0,3620 *	0,0004	-0,0210 **	0,0153	0,0500	0,4130	-0,0081	0,2660	0,0056	0,9827	-0,0005	0,9921
ld_IP(t-1)	-1,3977	0,2561	0,0461	0,6645	-0,0078	0,9918	-0,0136	0,8804	2,9773	0,3581	-1,2772 **	0,0409
ld_IP(t-2)	-3,4322 *	0,0075	0,1766	0,1078	-0,2848	0,7148	0,1148	0,2173	2,0587	0,5349	-0,2753	0,6638
ld_IP(t-3)	1,2746	0,3089	-0,0539	0,6191	-0,5382	0,4874	-0,0137	0,8816	3,1659	0,3374	-0,6903	0,2739
d_IR(t-1)	-0,1107	0,5299	0,0075	0,6231	0,5029 *	0,0000	0,0280 **	0,0330	-0,0191	0,9672	-0,1686	0,0598
d_IR(t-2)	0,0931	0,6224	-0,0091	0,5788	-0,2560 **	0,0310	-0,0342 **	0,0158	0,2338	0,6390	-0,0191	0,8406
d_IR(t-3)	-0,1225	0,4553	-0,0100	0,4829	0,0134	0,8950	0,0212 ***	0,0814	-0,0837	0,8463	-0,0201	0,8071
ld_ER(t-1)	-0,0629	0,9663	-0,0957	0,4596	-1,9539 **	0,0367	0,0981	0,3728	-0,2615	0,9469	-0,2375	0,7517
ld_ER(t-2)	0,3210	0,8305	-0,0356	0,7844	0,2320	0,8029	0,0152	0,8909	-1,7389	0,6601	-0,1179	0,8759
ld_ER(t-3)	-0,9631	0,5120	0,2850 **	0,0271	0,5669	0,5333	0,0288	0,7897	3,3102	0,3929	-0,3226	0,6624
d_INF(t-1)	0,0218	0,6004	0,0014	0,6972	0,1145 *	0,0000	0,0049	0,1099	0,1882 ***	0,0882	0,0024	0,9095
d_INF(t-2)	0,0481	0,2967	0,0066	0,1025	0,0419	0,1435	-0,0053	0,1170	0,1396	0,2509	-0,0180	0,4375
d_INF(t-3)	-0,0544	0,2521	-0,0032	0,4400	0,0005	0,9861	0,0038	0,2806	-0,0401	0,7481	0,0334	0,1634
d_UN(t-1)	-0,2374	0,2882	0,0049	0,8005	-0,3530 **	0,0121	-0,0067	0,6816	-0,3194	0,5869	0,4908 *	0,0000
d_UN(t-2)	-0,1852	0,4606	0,0033	0,8799	0,2742 ***	0,0801	0,0332 ***	0,0751	0,2208	0,7383	0,2522 **	0,0481
d_UN(t-3)	0,3930 ***	0,0615	-0,0047	0,7939	-0,1421	0,2721	-0,0118	0,4420	-0,1984	0,7177	-0,1492	0,1569
Const.	-0,0029	0,9010	0,0015	0,4516	-0,0093	0,5174	0,0023	0,1697	-0,0292	0,6303	0,0047	0,6851

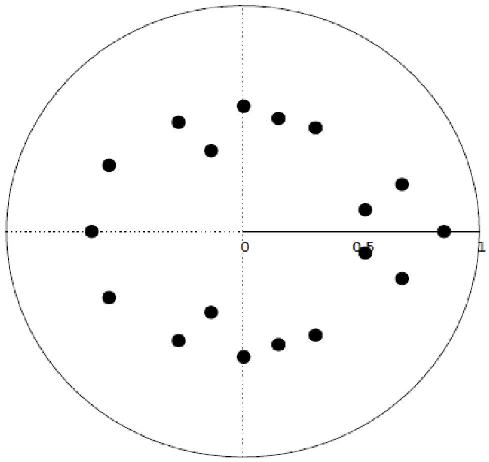
Source: Author

4.6 Verification of assumptions

Once the model is estimated, another important step involves verifying if it satisfies the assumptions for VAR model.

Cipra (2008) attaches a high importance to check whether the estimated model is stationary. Requirement on stationarity demands the inverse roots of the AR polynomial to be situated inside the unit circle. By looking at the graphical plot, it is evident that the estimated VAR (3) model does not fail in satisfying this condition.

Figure 7: *Inverse Roots of Autoregressive Operator*



Source: Author

Important information about whether the model is correctly specified is contained in the analysis of residuals. I used Ljung-Box Q-test to check if the residual components in individual regressions show the presence of autocorrelation. The results of Q-test are summarized in Table 6.

Table 6: *Test of autocorrelation of residuals*

Residuals	Ljung-Box	P-value
uhat_NR	18,480	0,102
uhat_IP	7,654	0,812
uhat_IR	14,996	0,242
uhat_ER	4,530	0,972
uhat_INF	39,567	0,000
uhat_UN	17,592	0,129

Notes: Null hypothesis: there is no autocorrelation in residuals.

As the results suggest, due to high levels of p-values the null hypothesis cannot be rejected in five of six regressions. The occurrence of autocorrelation in residuals is confirmed only in the regression estimating inflation. In this case, the hypothesis of no autocorrelation in residuals was rejected at 5% level of significance.

In order to complete the analysis of residuals, I also carried out Jarque-Bera test for the examination of normality of residuals.

Table 7: *Test of normality of residuals*

Residuals	Jarque-Bera	P-value
uhat_NR	102,384	5,86E-23
uhat_IP	3,314	1,91E-01
uhat_IR	14,450	7,28E-04
uhat_ER	0,994	6,08E-01
uhat_INF	8,004	1,83E-02
uhat_UN	7,713	2,11E-02

Notes: Null hypothesis: residuals are normal.

With respect to very low levels of p-values the normality of disturbances needs to be rejected at 5% level of significance for the regressions estimating NPL ratio, industrial production, inflation, and unemployment.

Conclusion

Theoretical section of the bachelor thesis has been designed to introduce a reader the concept of stress testing and to explain its general methodological principles. Stress testing represents a general term for a set of risk measurement techniques employed for the assessment of the condition of the financial systems and the detection of potential vulnerabilities to low probability and high intensity events. Stress tests usually focus on the banking sectors which reflect a key role of banks in most financial systems. Either risk exposures of individual entities or the systemic risk posing a threat to the entire system may be the subject of stress testing. In order the running stress tests to be effective and working reliably as a detector of financial disruptions, there are several requirements on stress testing which need to be satisfied. Other techniques used for quantifying risks such as VaR approach works under limiting assumptions and stress tests thus should be used at least to complement them.

The process of stress testing is a multi-stage procedure in which each stage has its significant position. The most important phase is a proper direction of stress testing requiring the identification of main vulnerabilities. This step is followed by a specification of a number of risk factors involved in stress scenario and then by simulating shocks. The size of shock is usually determined based on the most extreme changes in risk factors historically observed or even a new plausible stress scenario can be defined. The process of stress testing is completed by measuring the impacts of plausible shocks on the financial position of banks.

After composing theoretical background of stress testing, we have turned our the attention to empirical data analysis. Empirical section was focused on the estimation of credit risk in the Czech Republic, as such risk is permanently considered as the most significant issue of stress testing not only in the Czech Republic. Using the vector autoregression model we tried to examine the development of credit portfolio of the Czech banking sector in dependence on the economic conditions. A central point of the empirical analysis was a testing the hypothesis that there is any empirical dependence between the measure of credit risk and the selected macroeconomic variables. As a measure of credit risk the share of non-performing loans to total loans was applied. The analysis comprises the period starting from 01/2002 up to 03/2011.

The outcome achieved from the vector autoregression model has confirmed some expectations about the interdependencies between the credit portfolio and macroeconomic variables. From selected macroeconomic variables the industrial production and the unemployment rate have been proved as statistically significant. Both indicators influence the credit risk measure by an expected direction. A negative relationship has been proved between the share of non-performing loans and the industrial production. On the contrary, a positive relationship has been discovered between the share of non-performing loans and the unemployment rate. Both outcomes thus have been in line with our expectations.

Despite the fact we can confirm the expectations about the empirical interdependency between the credit risk in the Czech Republic and some macroeconomic factors, it is important to take into account the fact that all remaining variables in the regression have not been proved statistically significant even if in reality they could be.

The author realizes potential limitations of chosen econometric methodology resulting in imperfections in results. The efforts to eliminate these shortcomings form the basis for further research in this area.

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