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Credit Risk and Stress Testing of the Czech Banking Sector

Kreditní riziko a stresové testování českého bankovního sektoru

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1 Introduction

In the globalization world the financial crises can spread easily between countries. Cross-border contagion can threaten countries with the week banking sector. From this point of view, the stress test exercise should be regularly processed in order to detect financial system fragility. The important part of such exercise is the evaluation of the credit risk under certain macroeconomic scenario. For this reason it is very important to know the link between credit risk and macroeconomic environment. Using these tools for monitoring purpose, reformative measures can be adopted by regulator to prevent the potential financial crises in the country in advance. Due to these facts, macroeconomic credit risk modeling is the new challenge for the economic research.

Our recent experience with the effects of economic downturn on banks' loan portfolios in the Czech economy in the late 1990s provides an opportunity to investigate the link between macroeconomic development and credit portfolio quality. These findings can help to improve the stress test calculation employed by the Czech National Bank for the purpose of financial stability. Despite a very good shape of the Czech economy at this moment, the central bank needs to have reliable tools to detect potential instability within the economy.

From financial stability point of view, credit risk of the banking sector portfolio should be investigated. Rapid credit growth in the Czech Republic creates pressure for the improvement in credit risk management at the present time. Loans to households' growth rate reach 30% on average during last years. After deep recession in the end of the nineties and consequential credit crunch period, credit growth to corporate sector was recover since 2002. Despite of significant growth, level of the private credit in the economy is still far to EU-15 average. The estimation of the sectoral credit risk models together with stress test can be useful tool for the central bank. These models can provide better knowledge about

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potential instability of the banking sector. Different unfavorable, but plausible scenario can be tested in this manner. Although sectoral models can better explain credit risk in the economy, sectoral data is difficult to obtain. Especially in the case of Central and Eastern European transitional economies, time series are still short with a lot of structural breaks. It makes empirical analyses hard.

This paper follows methodology used by Jakubík (2006a). It extends the study of Jakubik (2007), who estimated macoreconomic credit risk model for the Czech aggregate economy. Besides the credit risk modeling, the paper focuses on difficulties with data of sectoral default rate. It shows how to deal with incomplete data in order to distinguish credit risk for the household and corporate sector. It is structured as follows. Section 2 introduces related studies. Section 3 describe available data, one-factor model as a selected approaches to credit risk modeling and its estimation for the corporate and households sectors. Section 4 presents using of the estimated models for the stress test purpose. The last section concludes and discusses possible further research topics.

2 Related Study

In the context of the New Basel Capital Accord, there are studies investigating cyclical effects in credit risk models on the bank capital requirement. Catarineu-Rabell, Jackson, Tsomocos (2003) investigate the impact of different forms of implementation of the rating system on the bank capital requirement. Verónica Vallés (2006) discuss difficulties with the implementation of Basel II. She focus on the through the cycle rating system and its construction for the emerging economies with financial information affected by macroeconomic crisis. A survey of the literature on cyclical effects on default probability, loss given default and exposure at default can be found in (Allen, Saunders 2003). There are studies investigated which factors drive the corporate credit risk in the economy. Elizalde (2005) studies the importance of credit risk correlation in bond market prices. By decomposing the firms' credit spreads on different credit risk factors is able to compute the importance of each credit risk factor on the evolution of the firms' credit risk, identifying their credit risk correlation. The other studies use the idea of decomposition of the credit risk on the common observable factors for all firms in the economy and firms' specific unobservable factor. This is also assumption of the popular one-factor model belonging to class of latent factor models. The firms' specific factor is unobservable, but the assumption about its distribution is made. This model is employed for example by Rösch (2005), Hamerle, Liebig, Scheule (2004) or Jakubík (2006a).

From the regulators point of view credit risk on the aggregate level is important. The most of the central bank employ some kind of sensitivity analyses or stress test exercise for the financial sector. They try to estimate sectoral credit risk in the economy. Sorge, Virolainen (2006) illustrate the main analytical approaches to macro stress test in the literature and estimate macroeconomic credit risk models for stress test purposes using data for Finland. In order to model corporate credit risk they use bankruptcy data as well as loan loss provisions. Wagner, Marsh (2006) study credit risk transfer in the economy with endogenous financing. They find the transfer of credit risk from banks to non-banks to be more beneficial than credit risk transfer within bank sector. The results of the economic research on the issue credit risk and stress testing is highly demanded by central banks. Boss, Krenn, Puhr,

Summer (2006) gives an overview of the general ideas used by Austrian central bank for the monitoring of systematic risk in the economy. They integrated credit risk into the stress test exercise. They used bankruptcy data as a proxy for default rate for 13 industry sectors. Time series of default frequencies is explained by macroeconomic risk factor changes. The estimated equation enable them translate macroeconomic risk factor changes into probabilities of default for each industry sector. Bario, Furfine, Lowe (2001) covered the relationship between credit risk, financial cycles and financial stability. They found limited number of macroeconomic variables to predict episode of financial turbulence. Danmarks Nationalbank analyzed the financial vulnerability of the Danish household sector (Danmarks Nationalbank (2007)). Macro stress test of Danish households simulates the effect of higher unemployment and interest-rate increases on the households' ability to service their debt. Macroeeconomic credit risk model is also employ in stress test exercise of Bank of England. Pain (2003) found the empirically relationship between banks' provision and macroeconomic indicators as a GDP growth rate, real interest rates, credit growth or concentration of the domestic loan portfolio.

Further related studies to the issues of credit risk and stress testing can be found e.g. in Jakubík (2007).

3 Credit Risk in the Czech Economy

From the central bank point of view it is necessary to assess the change in the credit risk of a loan portfolio in relation to change in the macroeconomic environment within a stress test exercise. To this end, a macroeconomic credit risk model for the Czech aggregate loan portfolio was developed by Jakubík (2006b).

One disadvantage of the aggregate model is that it cannot capture the different sensitivities of corporate and households sectors to change in the macroeconomic environment. The structure of the loan portfolio has changed considerably over the past five years in the Czech economy. The share of loans to households in banks' total loan portfolio increased from 10% in 2001 to almost 40% at the end of 2006. It is thus apparent that the household sector is becoming increasingly significant in the total loan portfolio. For this reason, it would be appropriate to estimate the macroeconomic credit risk model separately for the corporate and household sectors. The main obstacle to the estimation of such models is the non-availability of data on the dependent variable.

The aggregate risk model for the Czech economy was estimated on quarterly data on inflow of non-performing loans (NPLs).[1] However, such data is only available on an aggregate basis and cannot be obtained separately for the household and corporate sectors. The sectoral breakdown shows NPL stocks, not flows. To obtain flows, one has to estimate the decrease in NPLs as a result of write-offs, sales or enforcement of such classified liabilities of banks. The following relationship applies to the stock of NPLs, the default rate and the rate of gross NPLs decrease.

$$NPL_2 = NPL_1 - u\,NPL_1 + df\,(Loans_1 - NPL_1) \tag{1}$$

1 NPLs are loans with a classification of three or higher, i.e. substandard, loss and doubtful.

where *NPL* is the stock of NPLs in the relevant period, *u* the rate of gross NPLs decrease, *df* the default rate and $Loans_1$ volume of outstanding loans at the beginning of the period under review. This enables us to derive the following relationship (2) for the default rate.

$$df = \frac{\Delta NPL + u\,NPL}{Loans_1 - NPL_1} \tag{2}$$

Depending on the frequencies monitored, equation (2) can be used to compute the quarterly or annual default rate.[2] Except for the rate of gross decrease, all the variables in relationship (2) are usually known. Volumes of total loans and NPLs are available for the Czech economy broken down by sector. The rate of decrease was only available for aggregate loans. This figure is highly volatile, mainly due to non-recurring massive write-offs at the end of the 1990s and at the beginning of the new millennium as a result of clean-ups of large banks' balance sheets. It can be assumed that most of the problem loans related to corporations rather than households and that the rate of decrease for the household sector is relatively stable over time. The period of write-off, sale or enforcement of NPLs to households was chosen to be two years as an expert estimate. If we work with the annual default rate, the corresponding rate of decrease is 0.5.[3] Based on this assumption, the default rate of households in the economy can be derived using relationship (2).

The question is how to deal with the corporate sector. Using of the equation (2) is not appropriate for the corporate sector due to unstable behaviour of the rate of gross NPLs decrease. However having an aggregate data on the gross inflow of NPLs and default rate for the households sector we can derive gross inflow of NPLs for the corporate sector. Nevertheless the time series of the sectoral loans are available, we can estimate corporate default rate as a ratio of the gross NPLs inflow and outstanding loans at the given time.[4] For the better figure of the corporate sector credit risk, we can use credit register to compare our estimation and real figure. However the central credit register contains data only since November 2002. We use this data only for the latest values. However we checked that our estimate well fit to credit register data.

3.1 One-factor Model

The one-factor model is the popular version of the latent factor model which belongs to the class of the Merton structural model. This model appear in many papers, for example in (Rösch 2005), (Lucas, Klassen, Spreij, Straetmans 1999) (Cipollini, Missaglia 2005), (Jakubík 2006a), (Jakubík 2006b), (Jakubík 2007). The model is able to good explain credit

2 *An alternative approach to approximating annual default rate is to use bankruptcy data. This approach was used for example by Virolainen (2004) or Bos, Krenn, Puhr, Summer (2006).*

3 *Parameter u in the equation (1) may not in fact be constant over time. Nonetheless, we believe that the level of 0.5 is relatively realistic and consistent with anecdotal evidence.*

4 *Data on the gross inflow on NPLs for the corporate sector were calculated as a difference between this variable for the aggregate economy and households sector. This number was finally adjusted, because there are still others sector in the economy as a government, entrepreneurs and financial sector. We used the share of the corporate sector on the total NPLs for the adjustment.*

risk in the economy due to its nonlinearity. This section briefly describes the model and way how to use this concept for the macroeconomic credit risk modeling.

A random process with a standard normal distribution is assumed for the standardised logarithmic return on assets of a firm. The discrete normal logarithmic return satisfies the following equation for each firm in the economy.

$$R_{it} = \sqrt{\rho} F_t + \sqrt{1-\rho} U_{it} \tag{3}$$

R denotes the logarithmic return on assets for each firm *i* at time *t*. *F* corresponds to the logarithmic return in the economy independent of firm *i* at time *t*, which is assumed to be a random variable with a standard normal distribution. This variable represents the part of the return which is not specific to the firm and can thus satisfy the general conditions for profitability of firms in the economy. *U* denotes the return specific to the firm, which is again assumed to be random with a standard normal distribution. The two random variables are also assumed to be serially independent. Given these assumptions, the logarithmic return on assets of each firm *i* at time *t* also has a standard normal distribution. The model is based on the Merton approach, according to which a default event occurs if the return on a firm's assets falls below a certain threshold. Formally,

$$P(Y_{it} = 1) = P(R_{it} < T), \tag{4}$$

where Y denotes a random variable with the two potential state (1/0 – borrower *i* defaults/non-defaults at time *t*). Different macroeconomic indicators can be considered if the applied variant of the model assumes that the value of this threshold changes depending on changes in the macroeconomic environment. The value can be modelled as a linear combination of macroeconomic variables (x_{jt}). The final version of the model is described by the equation (5) in the case that macroeconomic indicators are included into the model (Ψ denotes the distribution function of the standard normal distribution).

$$p_{it} = P(R_{it} < T) = P(\sqrt{\rho} F_t + \sqrt{1-\rho} U_{it} < \beta_0 + \sum_{j=1}^{K} \beta_j x_{jt}) = \Psi(\beta_0 + \sum_{j=1}^{K} \beta_j x_{jt}) \tag{5}$$

The conditional default probability on realization f_t of random unobservable factor at time *t* corresponding to the default probability (5) is given by formula (6).

$$p_i(f_t) = P(U_{it} < \frac{\beta_0 + \sum_{j=1}^{K} \beta_j x_{jt} - \sqrt{\rho} f_t}{\sqrt{1-\rho}}) = \Psi\left(\frac{\beta_0 + \sum_{j=1}^{K} \beta_j x_{jt} - \sqrt{\rho} f_t}{\sqrt{1-\rho}} \right) \tag{6}$$

If we furthermore assume a homogenous portfolio of firms in the economy whose returns on assets correspond to process (3), the average default rate in the economy is then – based on the law of large numbers – equivalent to the probability of default of a firm. Given the assumption of homogeneity of firms in the economy, it is more appropriate to estimate the model on the basis of sectoral data.

In order to estimate the model (5), a relationship with a conditional number of defaults of firms depending on the realisation of the random variable *F* representing the latent factor was used. The conditional number of defaults depending on the realisation of the random factor is a random variable which, under the given assumptions, has a binomial distribution, with the parameters of conditional probability $p_i(f_t)$ given by equation (6) and the number of firms N_t.

$$D(f_t) \approx Bi(N_t, p(f_t)) \tag{7}$$

The model can be estimated by maximising a likelihood function containing a random latent factor, which was assumed to have a standard normal distribution. Full description of the one-factor model and way how to estimate it can be found for example in Jakubík (2007). We employed this concept in this paper. [5]

3.2 Macroeconomic Credit Risk model for the Corporate Sector

As was described at the beginning of the chapter Credit Risk in the Czech Economy, the proxy for the credit risk in the corporate sector can be calculated. The credit register, which is operated by the Czech National Bank and contains credit data of the corporate sector, can be used for the more precise calculation of the corporate credit risk in the economy.[6] However this register is operated only since October 2002. We used data from the credit register since 2003 to check our proxy credit risk time series. This data confirmed good construction of the proxy variable.

Key macroeconomic determinants for the development of the corporate sector are interest rates, exchange rates, price of the inputs, and growth rate of the domestic economy and the economy of the key business partners.[7] These indicators also affect default rate in the corporate sector. 90% of the newly granted loans to the Czech corporate sector are with short fixation less then one year. It means that increase of the interest rate cause raise the price of firms´ financial sources at the one year horizon ceteris paribus. More expensive sources decline the ability of the firms to meet their financial obligations. Consequently, corporate default rate increase. Appreciation of the exchange rate can also affect positively default rate of the corporate sector.[8] Stronger exchange rate raises price of the goods in foreign currency. Firms are becoming les competitive. In general the price of goods in foreign currency at the world market is given. Hence the ratio between cost and sales is changed and profit of firms decline. It can lead in the higher default rate in the corporate sector. The increase of the price of firms' inputs can also affects companies in the negative way. On the contrary,

5 *Although this model was originally derived for the bankruptcy data, it can be applied for the loans data as well - see Jakubík (2007).*

6 *The register contains data on legal entities and individual entrepreneurs and can be used to obtain information on the payment discipline of banks' clients.*

7 *Key macroeconomic determinants of the profitability of the non-financial corporations are discussed for example in CNB (2007).*

8 *The relationship between profitability and real effective exchange rate was empirically confirmed e.g. by CNB (2007).*

growth of the market price of firms' outputs can affects firms in the opposite way. From the debtor point of view, the increase of the price level in the economy means decrease of the real value of the obligation. Although permanent inflation leads to the additional cost and harms the economy, in the short run the inflation improves the financial situation of the debtors and decrease probability of the companies' default. The period of the economic boom has positive effect on the corporate sector. Demand for the goods and services produced by the non-financial firms increases. Consequently the profit of companies increases and corporate default rate decreases. The same effect on the corporate credit risk has the growth of the economies of the key business partner. How strongly corporate sector is influenced by foreigner economies depends on the openness of the domestic economy. Vulnerability of the corporate sector also depends on its indebtedness. Higher debt of the company corresponds to the higher financial leverage and higher potential profit or lost. Such a company is more vulnerable to the unexpected macroeconomic shock and its default probability is higher.

In order to estimate credit risk model for the corporate sector we took into account all macroeconomic indicators mentioned above. We were looking for the model which would be able to explain corporate sector credit risk and capture the effect of the key macroeconomic determinant changes. Such a model could be used for the stress test scenario of the Czech banking sector. We used credit data to derive a proxy variable for the credit risk modelling. This variable was derived from the gross inflow of the NPLs for the aggregate economy and households default rate calculated according the equation (2). Such derived time series of the corporate default rate was available from 1997 Q1 to 2007 Q1. However due to the others considered macroeconomic indicators, the final model was estimated for the time period from 1998 3Q.

We employed one-factor model in all analyses. The best performance was obtained for the model where GDP, exchange rate, inflation and indebtedness of the corporate sector were included as macroeconomic indicators. The model was estimated for quarterly time series from 1998 Q3 to 2006 Q4. Resulting estimated model corresponds to equation (8). The estimate of the coefficients is shown in Table 1.

$$df_t = \psi(c + \beta_1 gdp_t + \beta_2 e_{t-2} + \beta_3 \pi_{t-1} + \beta_4 debt_{t-4}) \tag{8}$$

Table 1 – Default rate model for the corporate sector

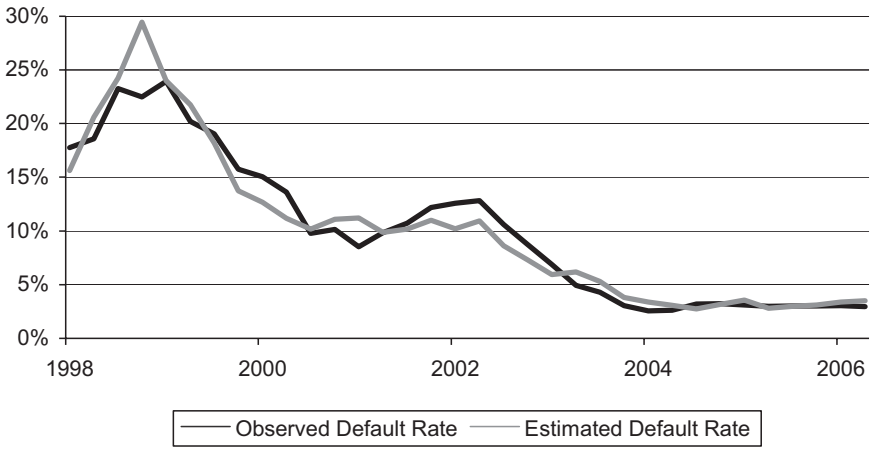
Description of variable corresponding to estimated coefficient	Notation	Estimate	Standard error	Pr>|t|
Constant	c	-2.822	0.484	<.0001
Gross domestic product (β_1)	gdp	-7.765	1.247	<.0001
Real exchange rate (β_2)	e_{t-2}	0.983	0.441	0.0327
Inflation (β_3)	π_{t-1}	-6.389	0.788	<.0001
Loans-to-GDP ratio (β_4)	$debt_{t-4}$	3.497	0.314	<.0001
Latent factor	ρ	0.007	0.002	0.0004

All the estimates were significant at least at the 5% confidence level. According the estimated model, corporate default rate in the Czech economy depends negatively on the non-lagged growth rate of the annual real gross domestic product. The growth rate of the Czech economy improves the situation of the firms and their default probability decrease. Our empirical analysis demonstrates the influence of the exchange rate on the credit risk. We used real effective exchange rate of the Czech koruna deflated by consumer price index lagged by two quarters. Stronger real exchange rate of the domestic currency affects corporate credit risk positively. Impact of the inflation on the firms' default rate was confirmed. In the case of inflation, the annual rate of growth of the average quarterly price consumer index lagged by one quarter was the most significant. A positive effect of the inflation on the situation of debtor was empirically shown. A real value of outstanding debt decreases with the inflation. We consider the debt indicator as a ratio of loans to GDP lagged by four quarters. As the loans we used total outstanding banking loans to the non-financial corporate sector. Latent factor which is the part of the estimation was still significant. However its coefficient is not part of the final model expressed by equation (8). Obtained result implies that corporate default rate in the economy is also affected by other factors then the macroeconomic indicators included.

However only the macroeconomic indicators mentioned above were included into the final model, also the others were considered. We employed for example real and nominal interest rates, real gross domestic product growth rate in the EU-15, EU-25, EA-12 and Germany or unemployment rate. Although some of them had significant prediction power for the corporate defaults rate, due to the correlation with the included indicators they did not contribute to the prediction power of the whole model.

Figure 1 demonstrates the performance of the estimated one-factor model for the Czech corporate sector. It confirms ability of the model to explain corporate default rate in the economy.

Figure 1 – Performance of the Estimated Model for the Czech Corporate Sector



Due to nonlinearity of the model, standard methodology for quality measurement of estimate can not be applied. Nevertheless a number of the less common indicator can be used. One of the tests of model quality is a test of the hypothesis that all the coefficients

except the constant term are zero (H_0: $\beta_1 = \beta_2 = \beta_3 = \beta_4 = 0$). This hypothesis can be tested by likelihood ratio $-2ln\lambda = -2ln(L_c/L_u)$, where L_c denotes likelihood function of the constrained model and L_u likelihood function of the unconstrained model. This ratio is an asymptotic chi-squared distributed variable with 4 degrees of freedom due to four macroeconomic indicators included into the estimated one-factor model. The test rejected null hypothesis at the confidence level less then 1%. Instead of the standard coefficient of determination which can not be used due to nonlinearity, the pseudo-coefficients of determination were employed. All these coefficients are based on the likelihood functions of the restricted and unrestricted model. They should be in the interval [0;1]. Our results close to 1 pointed out the good quality of the estimated model.

$$R_E^{\,2} = 1 - \left(\frac{\ln L_U}{\ln L_C} \right)^{-\frac{2}{n}\ln L_C} = 0.97$$

Estrella (1998) (9)

$$R_{CU1}^{\,2} = 1 - \left(\frac{L_C}{L_U} \right)^{\frac{2}{n}} = 0.96$$

Cragg-Uhler (1970) (10)

$$R_{CU2}^{\,2} = \frac{1 - \left(\frac{L_C}{L_U} \right)^{\frac{2}{n}}}{1 - L_C^{\,\frac{2}{n}}} = 0.96$$

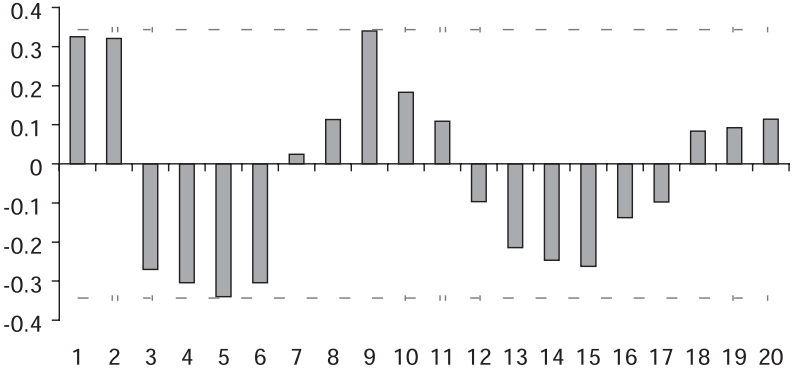
Cragg-Uhler (1970) (11)

$$R_{VZ} = \frac{2(\ln L_U - \ln L_C)}{2(\ln L_U - \ln L_C) + n} \frac{2\ln L_C - n}{2\ln L_C} = 0.81$$

Veall-Zimmermann (1992) (12)

The residuals of the model (8) were tested for autocorrelation using the Q-statistics. These values demonstrate absence of the autocorrelation in the residuals at the 5% confidence level (see figure 2).

Figure 2 – Autocorrelation function of the residuals



Furthermore the heteroskedasticity was investigated by Breusch-Pagan test. We ran the following regression.

$$\varepsilon_t^{\,2} = c + \beta_1 gdp_t + \beta_2 e_{t-2} + \beta_3 \pi_{t-1} + \beta_4 debt_{t-4} + \nu_t \tag{13}$$

We tested following null hypothesis H_0 against alternative hypothesis H_1. H_0 means that square residuals do not vary with any of the original regressors.

$$H_0 : \beta_1 = \beta_2 = \beta_3 = \beta_4 = 0$$
$$H_1 : \beta_j \neq 0 \quad j \in \{1,2,3,4\}$$

We were not able to reject the null hypotheses. The present of the heteroskedasticity was not proved. It seems that estimated standard errors of the coefficients are not biased. Overall the estimation of the model (8) is not probably biased due to the properties of the residuals.

3.3 Macroeconomic Credit Risk Model for the Household Sector

In order to estimate credit risk model for the household sector in the Czech economy we follow one-factor model methodology. The same approach as for the corporate sector was applied. The resulting model was estimated for the annual default rate time series from 1997 Q3 to 2006 Q3.[9]

The ability of the households meet their financial obligation depends mainly on the income to instalment ratio. The households usually have a regular income as a salary, pension or some kind of rent. Besides that, they can own financial assets, real or personal estates. If their disposable income decreases under the certain threshold, they have to sell owned assets. If they already have nothing to sell they fall to the default. From the point of banks, it is easier to assess payment ability of the households then firms. One of the key macroeconomic determinants for the households default is unemployment rate which significantly affects the households' income. In the case that the key breadwinner of the heavy indebtedness household is fired from the job the household is usually not able to compensate his income and fall to the default under the condition that all owned assets are already sold. Gross domestic product is usually correlated with the households' income and therefore can be used as a proxy for it. Instalment of the debt depends on the interest rates in the economy. Default probability of the indebted household increases with increase of the interest rate under the consideration that interest rate for the loan is not fixed. Besides the indicators influencing the income to instalment ratio, principal of the debt can be also affected. Increase in the price level declines the real value of the debt. Hence, the inflation decreases the default probability of the households.

9 *The quarterly time series of the annual default rate was generated from the monthly series of the annual default rate calculated using relationship (2) by averaging the three monthly figures corresponding to the relevant quarter. Although the default rate obtained using equation (2) was available from 1994, the time series on which the model was estimated had to be shortened as a result of some lags in the model and due to the shorter series of the other macroeconomic indicators included in the model.*

A whole range of macroeconomic indicators were considered for the estimate. The model chosen as the statistically best model, in line with the economic theory, was one containing the unemployment rate and the real interest rate.[10] The unemployment rate was lagged by four quarters, which corresponds to the lagged impact on payment discipline in the event of loss of employment.[11] The statistically best results were achieved with a lag in the real interest rate of three quarters. This result expresses the lagged impact of an interest rate change on debtors resulting from interest rate fixation. The real interest rate was calculated by deflating the annual PRIBOR by the CPI. Latent factor which is the part of the estimation was still significant as well as in the case of the model for the corporate sector (8). Obtained results imply that default rate of the households sector in the economy is also affected by other factors then the considered macroeconomic indicators. The resulting estimated model corresponds to equation (14). The estimate of the coefficients is shown in Table 3.[12]

$$df_t = \psi(c + \beta_1 u_{t-4} + \beta_2 r_{t-3}) \tag{14}$$

Table 2– Default rate model for the household sector

Description of variable corresponding to estimated coefficient	Notation	Estimate	Standard error	Pr>|t|
Constant	c	-2.224	0.071	<.0001
Unemployment (β_1)	u_{t-4}	3.695	0.846	<.0001
Real interest rate (β_1)	r_{t-3}	1.808	0.596	0.0043
Latent Factor	ρ	0.004	0.001	0.0004

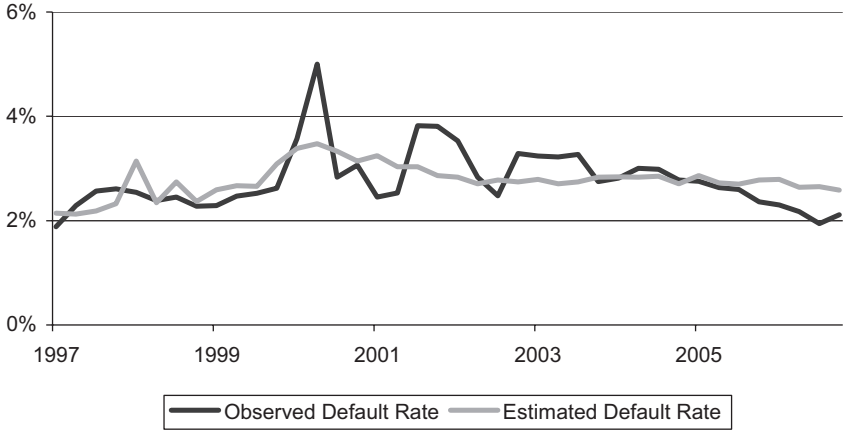
The hypothesis that all the coefficients except the constant term are zero (H_0: $\beta_1 = \beta_2 = 0$) was tested by the likelihood ratio $-2ln\lambda = -2ln(L_c/L_u)$. This ratio is an asymptotic chi-squared distributed variable with 2 degrees of freedom. The test rejected null hypothesis at the confidence level less then 1%. However pseudo coefficients of determination show worse performance of the model compare the corporate sector. It could be caused by the lower prediction power of the macroeconomic indicators to explain households default. Another reason could be instability of the parameter u in the equation (2) which was assumed to be constant.

10 *Also considered for the estimation of the model were nominal interest rates, inflation, the interest rate gap, the real GDP growth rate, the output gap, the ratio of interest paid to income or disposable income, etc. Disposable income was modelled using average wages and household consumption, while interest paid was modelled as the product of the credit volume and the annual PRIBOR increased by a certain interest rate spread.*

11 *The loan is initially repaid from savings or the redundancy payment; payment discipline is affected only after that.*

12 *Danmarks Nationalbank employs unemployment and interest-rate within the macro stress test of Danish households (Danmarks Nationalbank (2007)).*

Figure 3 – Performance of the Estimated Model for the Czech Household Sector



$$R_E^{\,2} = 1 - \left(\frac{\ln L_U}{\ln L_C} \right)^{-\frac{2}{n} \ln L_C} = 0.38$$

Estrella (1998) (15)

$$R_{CU1}^{\,2} = 1 - \left(\frac{L_C}{L_U} \right)^{\frac{2}{n}} = 0.37$$

Cragg-Uhler (1970) (16)

$$R_{CU2}^{\,2} = \frac{1 - \left(\frac{L_C}{L_U} \right)^{\frac{2}{n}}}{1 - L_C^{\,\frac{2}{n}}} = 0.37$$

Cragg-Uhler (1970) (17)

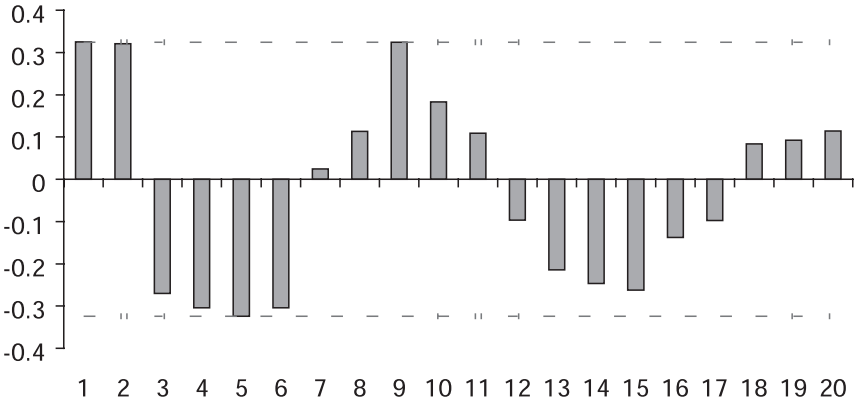
$$R_{VZ} = \frac{2(\ln L_U - \ln L_C)}{2(\ln L_U - \ln L_C) + n} \frac{2 \ln L_C - n}{2 \ln L_C} = 0.34$$

Veall-Zimmermann (1992) (18)

The residuals of the model (14) were tested for autocorrelation using the Q-statistics. These values demonstrate absence of the autocorrelation in the residuals at the 5% significance level (see figure 4).

Furthermore the heteroskedasticity was investigated in the same way as in the case of the corporate credit risk model (8). In contrast to model (8), the estimated model (14) records the heteroskedasticity of the residuals. Due to this result the standard errors of the estimated coefficients can be biased.

Figure 4 – Autocorrelation function of the residuals



4 Use of Models in Stress Testing

The Czech National Bank (CNB) employs the stress test exercise of the Czech banking sector for the purpose of financial stability. This methodology was gradually elaborated since 2004 by Čihák (2004), Čihák Heřmánek (2005), Čihák, Heřmánek a Hlaváček (2007). The basic stress tests based on extreme value from the past were complemented by interbank contagion test. These tests were followed by model scenarios within in-built estimated macroeconomic factors from the CNB's quarterly forecast and estimated growth in non-performing loans from the macroeconomic credit risk model for the aggregate economy developed by Jakubík (2007). This model enables to link development of the non-performing loans and macroeconomic environment. However different sensitivity of the households and corporate sectors was not able to capture. Although the aggregate model records good quality of the estimation, the forecast can be biased due to rapid growth of the loans to household and increasing share on the total banks' portfolio in the present time. The estimated sectoral credit risk models can better capture the real credit risk in the economy. We can test affect of the macroeconomic changes separately for the households and corporate sector. Both of these models can be incorporated into the current stress test methodology of the Czech National Bank. The models can evaluate the effect of the macroeconomic scenario on total non-performing loans to the corporate and households sector.

In order to forecast credit risk for the corporate sector, we have to set the inputs of the model (8). These include the non-lagged real GDP growth rate, real effective exchange rate lagged by two quarters, annual inflation lagged by one quarter and aggregate corporate loans to GDP ratio lagged by four quarters. These values can be set either expertly or as a percentage deviation from the CNB's quarterly macroeconomic forecast (see CNB (2003)). All these indicators are the part of the CNB's forecast except loans to the corporate sector. In the case that stress test exercise assume one-year horizon, we do not need to predict this variable due to four lags in the model. For longer horizon some kind of the credit growth model could be applied. The models based on the panel regression are used most frequently for the loan portfolio growth rate. This sort of models was also applied to the countries of Central and Eastern Europe, for example by Cottarelli, Dell'Ariccia, Vladkova – Hollar (2003) or Duenwald, Gueorguiev, Schaechter

(2005). The vector error correction model (VEC) is generally used for estimates for individual country as well as for aggregate data for several countries – e.g. Hofman (2001) or Schadler, Murgasova, Elkan (2005). In many studies the volume of loans in the economy is expressed as a ratio of loans to the private sector to GDP and is often estimated on the basis of a set of macroeconomic variables. Other studies try to model directly the rate of growth of the absolute volume of loans in the economy as for instance Fabrizio, Igan, Mody, Tamirisa (2006) who modeling credit growth for the countries of Central and Eastern Europe.

Table 3 – Sensitivity Analysis of the Credit Risk Model for the Corporate Sector (annual default rate in response to the value of exogenous variables)*

			GDP Growth Rate (in %)					
Inflation (in %)	*Real Effective ER*	*Loans to GDP (in %)*	1	2	3	4	5	6
1	0.9	15	6.01	5.14	4.37	3.70	3.11	2.61
		35	19.64	17.56	15.63	13.84	12.20	10.70
		50	37.07	34.18	31.37	28.68	26.09	23.63
	1.0	15	7.28	6.26	5.36	4.57	3.87	3.26
		35	22.48	20.22	18.10	16.13	14.30	12.62
		50	40.84	37.85	34.94	32.11	29.38	26.77
	1.1	15	8.73	7.57	6.52	5.59	4.77	4.04
		35	25.53	23.10	20.81	18.65	16.64	14.77
		50	44.70	41.64	38.64	35.71	32.85	30.10
3	0.9	15	4.63	3.93	3.31	2.78	2.32	1.92
		35	16.30	14.46	12.76	11.21	9.80	8.53
		50	32.36	29.62	26.99	24.49	22.11	19.88
	1.0	15	5.67	4.84	4.10	3.47	2.91	2.43
		35	18.84	16.81	14.93	13.20	11.61	10.16
		50	35.96	33.10	30.34	27.68	25.14	22.73
	1.1	15	6.88	5.91	5.05	4.29	3.63	3.05
		35	21.60	19.40	17.34	15.42	13.65	12.02
		50	39.70	36.74	33.86	31.06	28.38	25.80
5	0.9	15	3.52	2.96	2.47	2.06	1.70	1.40
		35	13.35	11.75	10.29	8.96	7.77	6.70
		50	27.91	25.36	22.94	20.65	18.51	16.51
	1.0	15	4.35	3.68	3.10	2.59	2.16	1.79
		35	15.58	13.80	12.16	10.66	9.30	8.08
		50	31.31	28.61	26.03	23.57	21.25	19.07
	1.1	15	5.34	4.55	3.85	3.25	2.72	2.27
		35	18.05	16.08	14.26	12.58	11.05	9.65
		50	34.87	32.04	29.32	26.70	24.21	21.85

Note: The sensitivity analysis uses non-lagged real GDP growth, CPI inflation lagged by one quarter, real effective exchange rate lagged by two quarters and corporate loan-to-GDP ratio lagged by four quarters.*

Table 3 shows the sensitivity of the corporate credit risk to the change in real GDP growth rate, real effective exchange rate, inflation and corporate loans to GDP ratio. The coefficients of the equation (8) cannot be interpreted as the commonly used elasticities of impacts of the relevant macroeconomic factors on credit risk, due to recalculation by the cumulative distribution function of a normal distribution. For this reason the effect of the change in one macroeconomic indicator depends on the value of the others indicators. This fact points out

the table 3. For example the effect of slow down in GDP growth from 5% to 3% depends on the actual corporate loans to GDP ratio, real effective exchange rate and inflation.

The CNB's quarterly macroeconomic forecast for unemployment rate, 12-month PRIBOR and CPI can be used to predict credit risk in the household sector according to the equation (14). However the model (14) does not record so good statistical performance as the model (8) for the corporate sector.

Table 4 shows the sensitivity of households' credit risk to the change in the unemployment rate and real interest rate in the economy. We observe low sensitivity of the model to the exogenous macroeconomic shocks. It can be caused by lower sensitivity of the households sector to the macroeconomic environment as well as inaccurate estimation of the proxy variable for the households' credit risk in the economy according to equation (2).

Table 4 – Sensitivity Analysis of the Credit Risk Model for the Households Sector (annual default rate in response to the value of exogenous variables)*

	Unemployment Rate (in %)			
Real IR (in %)	5	7	10	15
0	2.07	2.47	3.18	4.75
1	2.16	2.57	3.31	4.93
2	2.26	2.68	3.45	5.11
4	2.46	2.92	3.73	5.50
6	2.67	3.16	4.04	5.92
8	2.91	3.43	4.36	6.36

*Note: * The sensitivity analysis uses unemployment rate lagged by four quarters and real interest rate lagged by tree quarters.*

5 Conclusions

Credit risk modelling is an important part of the stress test exercise. We investigated different sensitivity of the corporate and households sector credit risk to the change of macroeconomic environment in the Czech economy. In order to improve banking sector stress test, sectoral macroeconomic credit risk models can be incorporated into the exercise. While the performance of the estimated model for the corporate sector records very good quality, the performance of the model for the households sector was worse. Further work in this area could be done. Data from the credit register for individuals would be possible to use in the future for the credit risk modelling for the households sector. Nevertheless this research study is important step to capture different impact of the macroeconomic change on the sectoral credit risk. One-factor model was employed in all analyses. This methodology enables to capture nonlinearities of the credit risk determinants. All these results can contribute to detect potential fragility of the banking sector and prevent the financial crises.

Abstract

This paper deals with sectoral credit risk in the Czech economy. It follows structural Merton's approach. Latent factor models are employed within this framework. The credit risk

models for the corporate and household sectors in the Czech Republic were estimated in this manner. They are able to capture the effects of macroeconomic changes on the sectoral credit risk in the economy. The results of this study can be used for the improvement of the Czech banking sector stress test. The models enable the stress tests to be linked to the Czech National Bank's official quarterly macroeconomic forecast.

JEL Classification / JEL klasifikace
G21, G28, G33

Souhrn
Tato práce se zabývá sektorovým kreditním rizikem v české ekonomice a vychází z mertonovského strukturálního přístupu. Pro modelování kreditního rizika jsou použity latentní faktorové modely. Na datech české ekonomiky byly odhadnuty makroekonomické modely kreditního rizika pro sektor podniků a domácností. Tyto modely jsou schopny zachytit dopad změn makroekonomického prostředí na sektorální kreditní riziko v ekonomice. Výsledky této studie mohou být použity k zpřesnění stresového testování českého bankovního sektoru. Modely umožňují navázání stresového testování na oficiální čtvrtletní prognózu České národní banky.

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Vystudoval ekonomii na Fakultě sociálních věd Univerzity Karlovy v Praze, statisticko-pojistné inženýrství na Fakultě informatiky a statistiky VŠE v Praze, inženýrskou informatiku na Fakultě jaderné a fyzikálně inženýrské ČVUT v Praze. Ph.D. v oboru finance obhájil na Fakultě financí a účetnictví v Praze. V průběhu své odborné praxe vystřídal několik bankovních institucí, v současné době působí jako vrchní ekonom ČNB v Praze. Je členem představenstva a výkonného výboru České společnosti ekonomické, Centra základního výzkumu pro dynamickou ekonomii a ekonometrii a členem Evropské ekonomické společnosti."

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