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METHODS OF ASSESSING CREDIT RISKS OF BANK FINANCIAL TOOLS ON DIFFERENT TIME HORIZONS

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Problem statement

Lending to corporate borrowers has traditionally been considered one of the main types of banking operations, so close attention is paid to the study and development of methods of assessing credit risk in the scientific and practical literature [Sorge, Marco, 2011; Kayser, 2013; Marlin, 2017], [Kostrov, Karminsky, 2014; Fedorova, Dovzhenko, 2016; Morgunov, 2017; Grishunin, et al., 2020]. Nevertheless, the challenges of improving them remain relevant [Yang, 2017; Prorocowski, 2018; Leone, et al., 2019; Porretta, et al., 2020; Barniv, et al., 2021; Karminsky, 2015; Pomazanov, 2020]. A significant role, in this case, is played by the development of approaches and methods for building internal models to assess the probability of PD default, the value of losses in the case of LGD (Loss Given Default), and the value of credit claims – exposure at default EAD. The indicators were first established by the Basel Accords and are related to the use of Internal Ratings-Based Approach (IRB Approach) models to assess credit risk [BCBS, 2011], [Kozarevic, et al., 2017; Camfferman 2015; Cohen, 2017]. The growing interest of banks in this approach is largely due to such factors as:

1. Regulatory development after the 2008-2009 financial crisis. Implemented in 2018 in most countries of the world (including Russia) International Financial Reporting Standard IFRS 9 "Financial Instruments" (hereinafter – IFRS 9) obliged banks to improve the existing approaches to the forecasting of bank reserves (reflected in bank reports as an indicator of expected credit losses, ECL) [Financial Stability Forum, 2009; Beatty, Liao, 2011]. The requirements for classifying financial instruments and assessing impairment have changed [Downes, et al., 2016]. Thus, financial instruments for which significant increase in credit risk (SICR) and impairment indicators are identified (non-performing assets, NPL) must be formed reserves for the entire life cycle. This means that now the assessment of the probability of PD, the value of losses in case of LGD, and the value of credit claims EAD should consider the maturity structure of financial instruments (i.e., calculated for the entire lifetime, not only for 12 months, as it was established by the Basel Accords) [Prorocowski, 2018, Montesi, 2019]. Also, the estimates must reflect the PD as of the reporting date, which requires a Point in time estimate, instead of the through-the-cycle approach suggested by the Basel Accords. Thus, the development of a methodology to build models following regulatory requirements is relevant [Reitgruber, 2015; Novotny-Farkas, 2016; Miu, Ozdemir, 2016]. For the Bank of Russia in the last 5 years, the issue has not lost its urgency: the regulator names the task of bringing together the approaches to prudential provisioning with the IAS as one of the perspective directions of development of banking regulation and supervision in 2023-2025 [Bank of Russia, 2022].

2. A significant impact of regulatory changes on the financial performance of credit institutions. Moody's [Moody's, 2018] shows that the use of simplified approaches to taking into

account the maturity structure when analyzing the credit quality of financial instruments leads to greater volatility of banks' financial results (as a consequence of profitability indicators). As a rule, investors and other stakeholders pay close attention to the profitability of banks and are wary of volatility[1] Western risk management concepts require verification of Russian data [Lobanov, Chugunov; 2019], therefore, conducting empirical research on this topic is interesting for modern financial risk management, as well as improving the methods for assessing credit risk for commercial banks and regulators.

3. Consequences of the pandemic and increased sanctions pressure from unfriendly countries against Russia in the form of reduced household incomes and reduced cash flows of companies. As a result, banks' credit risks and expenditures on loan reserves increased [Bank of Russia, 2021]. This problem is even more acute for European banks, which were forced to form additional reserves due to the application of management adjustments (post-model adjustments). They represent a reasonable stress test (i.e., there is an increase by a given coefficient) of model-calculated values of the probability of default (PD) and the value of losses in the case of LGD for counterparties and instruments related to the most crisis-hit industries. In [Mohamed, 2021] the impact of management adjustments to reserves on the sustainability of the banking system was assessed. The study shows that the application of the method of reasonable adjustments makes up for the risks unaccounted for by the models, caused by economic shocks[2].

Thus, changes in international financial reporting standards have formed the basis for the application of the "expected loss" model [Prorocowski, 2018]. Therefore, firstly, according to the rules, at the time of granting loans and other bank products exposed to credit risk, financial institutions must calculate expected credit loss (ECL) [Cohen, Edwards, 2017] for the lifetime of financial instruments (i.e., also for time horizons of more than 12 months). This significantly changes the traditional approaches to credit risk assessment used by commercial banks. Secondly, since 2018 the approaches to calculating bank reserves have changed [Onali, Ginesti, 2014; Chawla, et al., 2016]. Banks need to use the "expected credit losses" approach in their models [Beatty, Liao, 2011]. Expected credit losses are interpreted as the value of all losses in case of a debtor's default at any point in time during the life of financial instruments. This significantly affects the measurement and recognition of credit losses [Bushman, Williams, 2015]. As a result, over the past few years, the interest of researchers and regulators to the topic of forecasting expected credit losses for the life of financial instruments has increased both in Russia and European countries, as the use of advanced methods can optimize the increased

[1] See Appendix 4
[2] Ibid.

reserves of banks and increase the stability of the banking system. This creates a new field of research at the intersection of various scientific disciplines: financial risk management, banking, and corporate finance (described in more detail in the section).

Degree of validity and reliability

During the preparation of the dissertation methods of fundamental and applied research, works of leading foreign and Russian scientists and experts in the field of credit risk modeling were used. The empirical results of the study obtained by the author correspond to the goals and objectives set in the dissertation. It developed methods and models of credit risk assessment for the duration of financial instruments (including long time horizons), as well as their testing and verification.

The validity of the scientific provisions and results, conclusions, and scientific-theoretical and practical recommendations obtained in the dissertation work follows from the use of well-known methods and econometric models, which were used in the research work "Approaches to Building Default Probability Models for Financial Instruments of Project Financing at Long Time Horizons"[3], prepared by the author for the Analytical Credit Rating Agency (ACRA). The results of the work have been repeatedly discussed at international and domestic scientific conferences, as well as in the articles of the author. The conclusions of the dissertation in chapter 1 are based on theoretical work in the field of credit risk modeling. The conclusions of the dissertation work in chapters 2 and 3 are substantiated by factual data and supported by the reasoned application of modern financial-analytical, statistical, and econometric methods, which allowed to confirm the purpose and objectives of the study, as well as to build models for assessing expected credit losses, including PD models for more than one year.

Degree of problem development

In the Russian and foreign literature, there are several contemporary works devoted to research in the field of various credit risk assessment metrics affecting the formation of bank reserves [Onali, Ginesti, 2014; Chawla et al., 2016; Prorocowski, 2018; Cohen, Edwards, 2017; Karminsky, 2015; Pomazanov, 2018]. Thus, a number of domestic authors investigate different approaches to the construction of rating models of corporate clients, give their comparison [Kostrov, Karminsky, 2014], and describe ways of their application [Karminsky, 2015]. The analysis of models based on market and macroeconomic indicators [Belousova, et al., 2018], models based on accounting indicators [Pomazanov, 2004, 2020], and financial statements [Karminsky, et al., 2012]. A comparative analysis of empirical methods of modeling credit ratings is presented in [Grishunin, et al. 2020]. These papers provide an overview of fundamental

[3] https://cfjournal.hse.ru/article/view/12366/13236

models for assessing the probability of default, discussing their advantages and disadvantages, and classifying the available models. The review forms the basis for the practical use of such models in solving risk management problems [Totmianina, 2011]. Researchers have attempted to develop default probability models for project finance transactions [Kayser, 2013; Sorge, Marco, 2011; Karminsky, 2015].

Approaches to modeling the probability of default of corporate borrowers of Russian banks are presented in [Totmianina, 2014; Fedorova, Dovzhenko, 2016; Morgunov, 2017] based on binary choice models, including macroeconomic indicators. Within the framework of one-factor modeling approaches to the selection of risk-important financial and macroeconomic indicators, the simultaneous use of which in the credit risk management system complicates the processes of modeling and forecasting of enterprise activity, in this connection two approaches to the selection of the most risk-important indicators were suggested: 1) conducting statistical tests for descriptive ability and 2) step-by-step selection of factors from each class of indicators.

The problematic component of the above models is the forecasting horizon limited to a period of up to 12 months. Attempts to build simplified models for a long time horizon are presented in [Venables and Ripley, 2002; John Klein and Melvin, 2003]. The need to determine the cumulative probability of default arose with the introduction of the international standard IFRS 9 [Porretta, et al., 2020; Pomazanov, 2018], and hence the development of empirical models with an extended time horizon based on statistical data from the Russian market to calculate expected credit losses for the life of financial instruments, which affects both the financial performance of individual banks and the financial stability of the banking sector as a whole [Hashim, et al., 2016; O'Hanlon, 2016].

The premise of regulatory requirements affecting loan loss provisioning was outlined in [Beattie, et al., 1995; Wahlen, 1994], a precursor to the concept of expected losses (EL) [Wall, Koch, 2000]. Different approaches and conclusions are presented in [Liu, et al., 1997; Ahmed, et al., 1999], where there is no consensus on the relationship between the creation of additional reserves and the profitability of its shares. Also, the influence of macroeconomic factors is not unambiguous [Laeven, Majnoni, 2003] and there is empirical evidence that banks all over the world start to make additional provisions for loan losses on problem loans only after the occurrence of crisis events and the beginning of the decline phase in the economy [Onali, Ginesti, 2014].

Another group of analysts reviewed the trends in loan loss provisions in Spain [Pérez, et al., 2006]. Researchers have concluded that the amount of loan loss provisions is significantly influenced by the stage of the economic cycle [Hol, et al., 2006]. Quagliariello [Quagliariello, 2007] shows for Italian banks that the formation of loan loss provisions depends on the stage of

the economic cycle, but with a certain lag. In [Quagliariello, 2008] the influence of macroeconomic effects on the financial stability of the bank was studied. The creation of macro models is one of the most important tasks in the methodological work on extending the time horizon of models of expected credit losses [Gavalas, Syriopoulos, 2014; Chawla, 2016]. Therefore, the dissertation studied and systematized the main types of models and approaches to solve the studied problem, and the results obtained by the author were compared with the position of scientists on the importance of the impact of macroeconomic indicators in assessing credit risk and the forecasting of bank reserves.

An important approach to provisioning is dynamic [Mann, Michael, 2002]. Dynamic provisioning allows deferring the recognition of credit risk premiums by creating a reserve for expected losses. If there is no default, the full reserve, which is a risk premium, will be liquidated at maturity [Gebhardt, 2008]. The works [Hrvoje, et al., 2018; Marshall, 2018] examine and compare current concepts of expected losses and develop models of credit risk taking into account the lifetime of financial instruments [Novotny-Farkas, 2016; ESRB, 2017; Dabbene et al., 2017; Edwards, 2016; Skoglund, 2017; McPhail, 2014; Shafii et al., 2016], including for Islamic finance.

This large number of multidirectional studies examining approaches and methods of forecasting bank reserves indicates the importance of this topic as the number of reserves formed also affects other important indicators of banks, including profitability and market capitalization.

Thus, the systematization of approaches to the provisioning, as well as the creation and testing of modern methods using advanced econometric and statistical models will lengthen the time horizon for assessing the credit risk components. In this regard, the author highlights a number of research gaps, the elimination of which will also contribute to the scientific literature:

1. Lack of empirical research on the development of methods for estimating the probability of default for more than 12 months using advanced statistical methods of analysis based on Weibull distributions.

2. Lack of empirical studies on the application of alternative methods and models for assessing the PD for more than 12 months with the help of rating migration matrices on Russian data.

3. The need to develop methods that consider macroeconomic factors to assess credit risk indicators at the reporting date (point in time) instead of the through-the-cycle approach proposed by the Basel Accords.

4. The need for empirical research to improve methods for assessing the value of losses in the event of LGD, and the value of credit claims EAD throughout the life of financial instruments.

Object and subject of the study.

The object of the study are financial instruments of Russian commercial banks (primarily loans and documentary obligations).

The subject of the research is the development of methods and models for assessing credit risk within the life cycle of financial instruments for risk management purposes.

Purpose and objectives of the study.

The study aims to develop methods for extending the time horizon of credit risk forecasting, as well as to improve the assessment accuracy of expected credit losses within the lifetime of financial instruments of Russian banks.

It is necessary to solve the following main tasks to achieve this objective:

1. To study and systematize regulatory approaches to the assessment of credit risk throughout the life cycle of financial instruments in the context of changes in the requirements of international standards.

2. To carry out a synthesis of approaches to assessing credit risk based on the systematization of scientific knowledge and regulatory requirements, as well as modern risk management techniques throughout the life cycle of financial instruments.

3. To develop methods for PD estimation on the life of financial instruments, for which parametric distributions, in particular Weibull distributions, can be used.

4. To develop alternative methods and models for assessing the PD on the life of financial instruments based on migration matrices.

5. To propose approaches for assessing the value of credit claims exposed to EAD for the life of financial instruments, allowing to consider credit risk on financial instruments with a set limit (e.g., credit line, overdraft), as well as off-balance sheet claims (such as guarantees and letters of credit) with their specifics.

6. To develop approaches to estimate the value of losses in the case of LGD to account for collateral on the corporate loan portfolio of the bank.

7. Evaluate the predictive power of the developed models and their robustness.

Methodological basis of the study

In this work, the author reviews the scientific papers, systematizes the approaches used to solve the forecast problems on a long-time horizon, and carries out their comparative analysis. Methods of statistical analysis and econometric modeling, the method of approximation of historical default levels employing migration matrices, and built parametric models based on Weibull distributions are used.

The macroeconomic modeling used the autoregressive distributed lags model (ADL model), linear and log-linear regressions, using the capabilities of the scenario approach. Also,

linear scaling methods, the Bayesian approach, the reference point approach, and Vasicek's formulae were used in the work.

Such methods and tools of financial mathematics as discounting, compound interest, and the sliding window method were used to model the value of credit claims at the time of EAD. For the LGD loss model, the author segments homogeneous groups according to different characteristics of the loan portfolio, in particular the level of collateral coverage.

As part of this dissertation research, a unique database was compiled, including various parameters and characteristics of loans to various categories of corporate clients, combined into homogeneous portfolios, and an extensive pool of macroeconomic data was formed, the sources of which were statistical materials from the Central Bank of the Russian Federation, the Federal State Statistics Service, SPARK and RUSLANA databases; internal statistics from a large Russian bank, including:

- database of merchant loans, with more than 36,000 observations on 1,500 borrowers since November 2011.
- database of credit products of financial companies, including about 3,000 observations since 2009.
- database on specialized lending (project finance), which has had 2,500 observations since 2009.

In addition, data were collected to build a macroeconomic model for each of the portfolios, as well as EAD and LGD models.

In this work, the author used current information from other sources, including the sites of Russian and foreign rating agencies, as well as Russian commercial banks.

The theoretical implication of the work lies in the development of concepts and approaches to the construction of models for assessing credit risk throughout the life of financial instruments, including in relation to Russian reality.

Scientific novelty and the author's contribution to the literature.

1. Completely new approaches to the assessment and forecasting of expected credit losses over the entire life cycle of financial instruments have been formed. The methods previously described in the scientific literature were mostly limited to a forecast horizon of up to 12 months or were based on a normal distribution.

2. A comparative analysis of the effectiveness of approaches to building models based on parametric distributions and migration matrices has been carried out for the first time, which ensures the positioning of each model depending on the availability of historical and statistical data, as well as the inclusion of macroeconomic factors.

3. Improved methods for assessing the PD, losses in the case of LGD, as well as the value of claims at EAD risk throughout the life of financial instruments are substantiated, which provides an opportunity to assess the credit risk parameters of Russian banks in contrast to foreign models of risk management.

4. Approaches for estimating the point-in-time probability of default are developed, complementing the through-the-cycle approach proposed by the Basel Accords. Several types of econometric models were investigated to solve this problem and the Vasicek model was chosen as the most effective one.

5. An original methodology, based on an integrated approach to the evaluation of reserves to cover expected credit losses, contributing to the development of methods for assessing credit risk in the face of changing requirements of international standards, is proposed.

The main results of the study and the provisions defended

1. Methods for PD estimation over the life of financial instruments, based on bank data and survival models with no limit on the life of financial instruments. This allows (in contrast to the previously used approaches) to reasonably form fewer reserves, and therefore improve the bank's financial result. A limitation of this approach is the presence of available statistics on defaults over a sufficiently long period.

2. An alternative approach, based on the Merton model, to estimate the probability of default over the lifetime of financial instruments as applied to project finance and lending to financial institutions. The robustness of the model is confirmed and the conclusion about its applicability to Russian commercial banks is made.

3. Development of a macro model to estimate the component of expected credit losses at the point-in-time (PIT calibration), the implementation of which is one of the key regulatory tasks and the most important step in creating a methodology for calculating expected credit losses.

4. Assessment of the value of credit claims exposed in the case of EAD, as well as losses in the case of LGD for the whole life of financial instruments, as one of the key components for calculating the expected credit losses of commercial banks, which is of both scientific and practical importance.

The results obtained on the first item of the provisions

The sample for the construction of cumulative levels of default since November 2011 was prepared, as well as the formation of a register of borrowers. Estimated marginal default probabilities for each period of life of financial instruments with the derivation of the integral ECL estimation for the whole life of financial instruments.

Calculation results of empirical cumulative default levels. The author analyzed the bank's data from 01.11.2011 to 01.10.2016 (60 dates), which were combined into the rating groups presented in Table 1. The need for grouping is due to the insufficient number of observations in individual rating grades.

Table 1 – Number of observations by rating grade/group

Rating group	**Rating grade**	**Number of observations in the rating grade**	**Number of observations in the rating group**
3	1+	-	2,059
	1	-	
	1-	-	
	2+	1	
	2	-	
	2-	195	
	3+	149	
	3	485	
	3-	1,229	
4+	4+	2,450	2,450
4	4	2,791	2,791
4-	4-	3,784	3,784
5+	5+	4,120	4,120
5	5	4,237	4,237
5-	5-	4,268	4,268
6	6+	3,460	7,557
	6	2,461	
	6-	1,636	
7	7+	823	1,250
	7	295	
	7-	132	
89	8+	66	716
	8	519	
	8-	44	

Rating group	Rating grade	Number of observations in the rating grade	Number of observations in the rating group
	9	87	

Source: author's materials.

Figure 1 and Table 2 show the empirical cumulative default levels for the Trade segment.

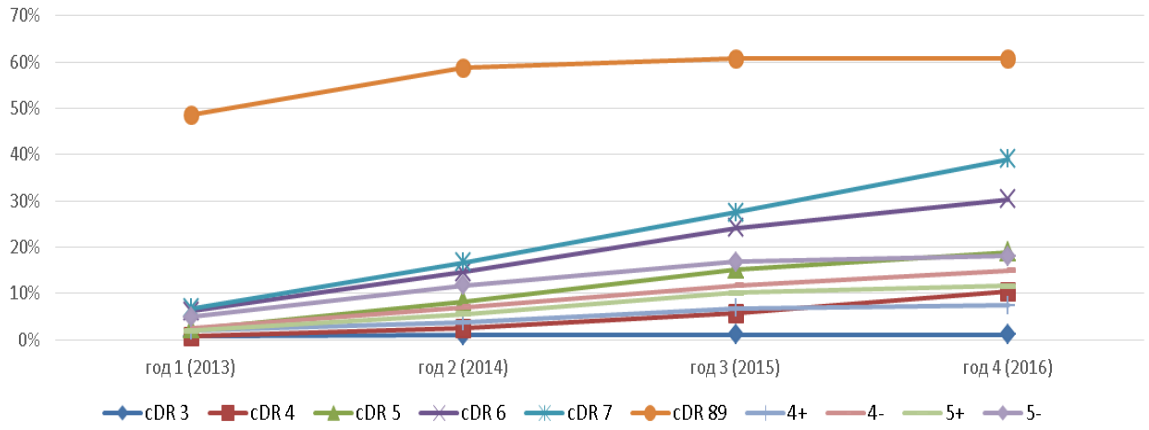

Figure 1 – Empirical cumulative default levels, Trade segment.
(Source: author's materials)

Table 2 – Empirical cumulative default levels for the Trade segment

Rating group	Year 1	Year 2	Year 3	Year 4
3	0.68%	0.96%	1.07%	1.07%
4+	1.90%	3.84%	6.84%	7.40%
4	0.67%	2.46%	5.64%	10.42%
4-	2.41%	7.08%	11.71%	14.95%
5+	2.01%	5.58%	10.17%	11.69%
5	2.33%	8.32%	15.19%	18.99%
5-	4.99%	11.79%	16.78%	18.06%
6	6.23%	14.57%	24.19%	30.37%
7	6.77%	16.67%	27.57%	39.04%
89	48.64%	58.73%	60.70%	60.70%

Source: author's materials.

The author constructed the long-term cumulative probability profiles "through-the-cycle" (hereinafter – TTC PD) based on the Weibull distribution, as well as calculated the values of the two-parameter Weibull distribution function and the modified Weibull distribution for the Trade segment.

Based on the parameters obtained, multi-year PD curves (TTC) were plotted separately for each rating group (see Figure 2).

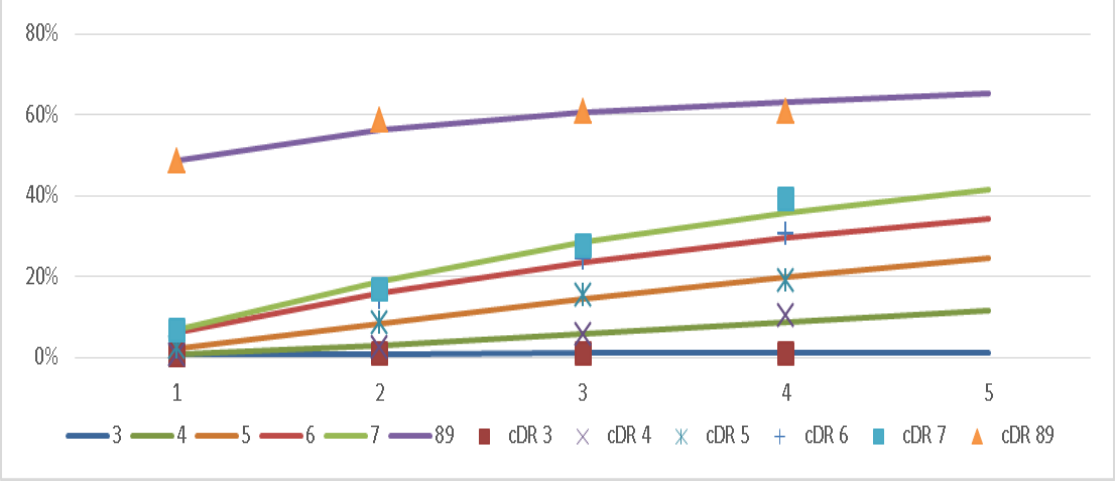

Figure 2 – Cumulative probabilities of default for the Trade segment. (Source: author's materials)

Figure 3 graphically shows the comparison of the two methods using the example of the rating group "5-" (in the Trade segment it has a fairly high concentration of borrowers).

Since the coefficient of determination for the two-parameter Weibull distribution is slightly lower than the coefficient for the modified Weibull distribution (0.96<0.98), it was decided to choose the modified two-parameter Weibull distribution.

For rating groups 3, 4-, 5+, 5, and 5-, with a borrower concentration of 57.7%, the coefficient of determination for the two-parameter Weibull distribution is lower than the coefficient for the modified Weibull distribution. Thus, after comparing the results of the two methods for the remaining rating groups, a decision was made in favor of choosing the modified two-parameter Weibull distribution.

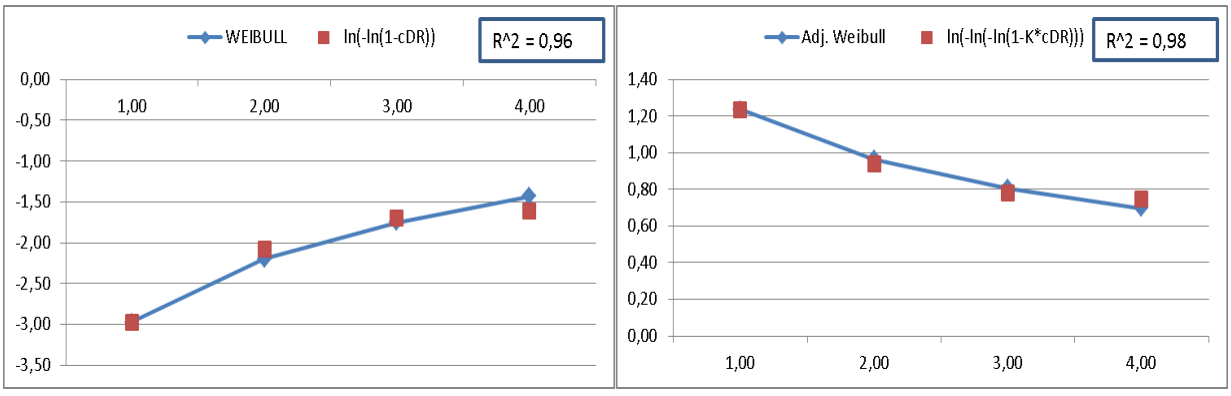

Figure 3 – Comparison of the two-parameter Weibull distribution approach with the modified Weibull distribution approach on bank data (rating group "5-"). (Source: author's materials)

The results obtained on the second item of the provisions

An approach to modeling Lt PD based on migration matrices constructed from pooled internal data on changes in ratings was also considered.

Forecast modeling was performed by autoregressive distributed lags (ADL-model). The quality of the approximation was assessed using the determination factor.

Graphically comparing the actual dynamics of the share of loans with overdue payments in the total volume of loans to financial institutions with the forecast dynamics is as follows (Figure 4).

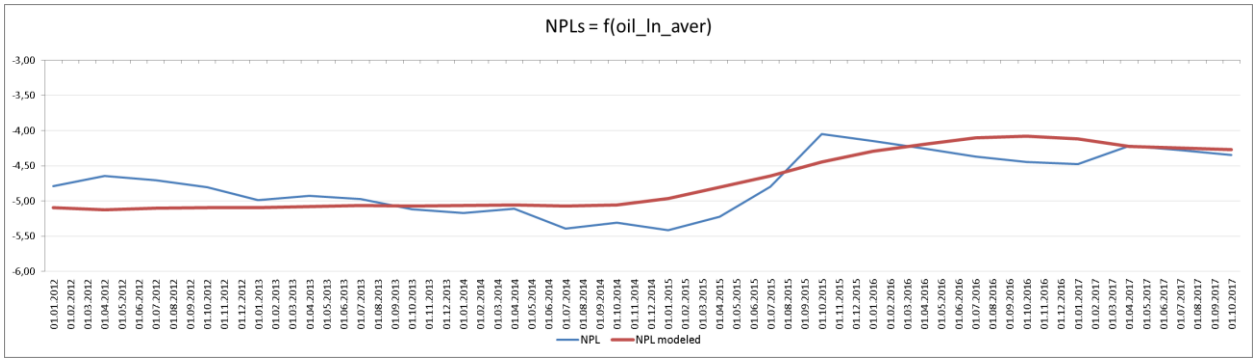

Figure 4 – Comparison of the actual dynamics of the share of loans with overdue payments in the total volume of loans to financial institutions. (Source: author's materials)

Determination factor of the final regression is 99.7%. The final regression has the following form:

$$ln\left(\frac{NPL_t}{1-NPL_t}\right) = -1.08 * \ln(\sum_{i=4}^{n} \frac{oil_{t-i}}{4}).$$

Checking the model quality: the accuracy of the built model is good, as the average value of the relative error does not exceed 2.66%. The quality check also took into account the fact that the model correctly reflects the direction of change of DR – decrease or increase, on the sample data for validation.

Choice of scenarios of economic situation development: forecasts of Brent oil prices in the Bank were taken as basic, optimistic, and pessimistic scenarios to take into account the forecast macroeconomic information for 2 years.

Below are calculations of the optimistic and pessimistic forecast of the Brent oil price and the corresponding forecast of the NPLs level (the share of loans with overdue payments in the total volume of loans to financial institutions) (Table 3).

Table 3 – Scenario values of changes in the Brent oil price and the NPLs level

Brent oil price scenario	Indicator	2018	2019
Basic (50%)	Oil price ($/bbl)	57.0	58.1
	$NPLs_{New}$	1.23%	1.25%

Brent oil price scenario	Indicator	2018	2019
Optimistic (25%)	Oil price ($/bbl)	77.8	90.7
	$NPLs_{New}$	1.17%	0.90%
Pessimistic (25%)	Oil price ($/bbl)	50.0	25.8
	$NPLs_{New}$	1.33%	1.44%
NPLs weighted on the scenario probability	**$NPLs_{New}$**	**1.24%**	**1.21%**

Source: author's materials.

Based on the migration matrices, the author built a model of default probability for the life of financial instruments (including on long time horizons) for the "Specialized Lending" segment (project finance loans issued for the construction of residential real estate in the logic of project finance, passed the business model test and SPPI-test as part of the preliminary classification of the financial instrument).

The study revealed that the calculated estimates do not lead to a significant overestimation of the amount of expected credit losses (ECL) and best reflect the specifics of the project finance portfolio, so they can be used to calculate the ECL in the Russian commercial banks.

The results obtained on the third item of the provisions

The point-in-time calibration (PIT calibration) is based on the Bayesian formula.

Linear correlation coefficients (Pearson correlation) were calculated when building models between the variables to account for macroeconomic information. The results were analyzed to select the macroeconomic factors with the highest value of a linear relationship with the level of default.

The calculation results showed a strong linear relationship between the level of default of the analyzed assets and the five selected macroeconomic variables.

In addition, the following factors are selected based on the graphical analysis: 1) annual GDP growth; 2) annual average dollar exchange rate growth; and 3) the index of change in average annual Brent crude oil prices. These indicators show a high correlation with the level of defaults, a well-defined linear trend, and good interpretability in terms of influence on the level of defaults.

The model was built in several stages.

Stage 1 – a one-factor model was constructed. Due to the presence of factors that have a high correlation with the dependent variable, one-factor models were built: linear, log-linear regression, and Vasicek. The models showed the highest predictive power:

1) Vasicek with the variable "growth of the US dollar exchange rate" (dollar_aver_lag4): R^2 = 88.8%;

2) Vasicek with the variable "annual GDP growth" (gdp_1): R^2 = 88.3%;

3) log-linear regression with the variable "growth of the US dollar exchange rate" (dollar_aver_lag4): R^2 = 87.4%.

It was determined that the model based on the growth factor of the average US dollar exchange rate is less interpretable than the model with the variable "GDP growth rate". Also, taking into account the results of the graphical analysis, Vasicek's model with variable GDP growth rate was chosen as the best model by the analysis results of all single-factor models.

In stage 2, a two-factor model was built. To test the feasibility of adding a second factor to the model to strengthen its predictive properties, the strongest two-factor models were built with the following limitations in mind. The log-linear regression model (R^2adj = 92.7%) with the variables dollar_aver_lag2 (increase in the average annual dollar exchange rate) and rdi_2_lag3 (average annual index of real disposable income) showed the highest predictive power. The predictive power of this model is slightly higher than the one-factor model with the variable gdp_1 (R^2 = 88.3%), but adding additional factors to the model did not significantly increase its predictive power and is therefore not appropriate.

In stage 3, back-testing of the model was conducted. The results of one-factor models with the variable "GDP growth rate" on the test sample (back-testing) were checked using the following approach: allocation of a separate training sample for model development, as well as a test model to check its quality. For the final model, the following criteria had to be met:

- ✓ the model should have the highest determination factor.
- ✓ the relative decrease in R^2 on the test sample should not exceed 5%.

The results of the comparison of analysis approaches are presented in Table 4.

Table 4 – Results of the choice of approach to the construction of the final model

Model	**R^2 by sample:**	
	Training sample	**Test sample**
Vasicek	89.3%	86.7%
Log-linear regression	86.1%	83.6%
Linear regression	77.1%	73.7%

Source: author's materials.

According to the analysis results, the most adequate effect of the annual GDP growth rate on the level of default in the "Trade" and "Production and services" segments are reflected by Vasicek's model. The model has high efficiency on the training sample, R^2 = 89.3%. On the test

sample, the model effectiveness is slightly lower, R^2 = 86.7%. A 5% decrease in efficiency on the test sample can be considered acceptable.

In stage 4, the parameters of the model were evaluated. The parameter ρ value was estimated based on the condition of maximizing the overall determination factor R^2 of the model. The stability of the predictive power of the model was monitored by the R^2year indicator. This approach has maximized the overall R^2 up to 88.3% and achieved high predictive power of the model since 2013, $R^2 \geq 87{,}7\%$.

The proposed macroeconomic model provides high stability of forecast values depending on the level of incoming macroeconomic factors. This is ensured by the choice of the function type of dependence of the level of DR on GDP by Vasicek's model, which is close to a linear function at medium and high DR, but at the same time provides a gradual asymptotic approach of DR to zero when GDP growth is forecast at 3% or more. According to the test results, the predictive power of the model (in the form of the determination factor R^2) is stable over the years, which shows a small value of the standard deviation of the determination factor R^2, equal to 5.2%. The TTC Lt PD was also adjusted to account for the macro forecast.

The results obtained on the fourth item of the provisions

The approaches proposed by the author to the EAD evaluation on the life of financial instruments (including on long time horizons) were developed on the data of a Russian commercial bank. The author also presents the results of calculating the intermediate stages of the study (steps). The author considers several approaches to developing an EAD model of instruments recorded on a bank's balance sheet, including simplified and advanced approaches to building EAD models.

Two models are also adapted to estimate the EAD of off-balance sheet instruments: the EAD model for on-balance sheet financial instruments (applied to the on-balance sheet portion of the liability) and the credit conversion factor (CCF) model applied to the off-balance sheet portion of the liability.

The author also created a model to estimate the level of loss given default (hereinafter – LGD) for the contracts of corporate borrowers, taking into account the structure of maturity and forecast macroeconomic information. By creating such a model, the following results are achieved:

- the quality of LGD estimates at the level of each individual borrower is improved based on the model of loan portfolio segmentation by LGD level to consider the current structure of the loan portfolio for the life of financial instruments (including long-time horizons);
- calculation of LGD for the whole life of financial instruments is provided, taking into account future economic conditions for the life of financial instruments (including on long time horizons).

The LGD model is based on a Russian commercial bank's internal statistics on repayments of problem loans and applies to all contracts opened as of a particular reporting date and issued to corporate borrowers, which are evaluated on a portfolio basis as part of the ECL assessment.

The LGD model for corporate borrowers, which are evaluated collectively, is based on a portfolio segmentation model by LGD level. This model involves identifying segments of the loan portfolio with similar characteristics in terms of collateral coverage and determining for each of the segments the average level of loss given default (LGD).

The LGD segmentation model for corporate borrowers is based on the allocation of homogeneous groups according to various characteristics of the loan portfolio, in particular the level of collateral coverage, based on the established statistical relationship between the level of these characteristics and the average level of default losses on borrowers in the respective groups. When segmenting the portfolio, the cluster analysis method is used, the target function of which is the actual values of LGD for the borrowers with partial or full repayment of the debt and/or debts considered settled or uncollectible (continuous delinquency over 2 years).

To determine the level of loss given default (LGD) for corporate borrowers' financial instruments with objective signs of impairment, which are estimated using the expected credit loss lifetime model, the level of loss given default (LGD) is determined at the beginning of each annual period after the default based on the analysis of the cumulative recovery level profile for the respective periods.

Thus, the segmentation model is applicable to determine the level of default loss at each stage of the ECL model:

1) for estimating expected credit losses for the horizon of 12 months and over the life of financial instruments for which there is no objective evidence of impairment (Stages 1 and 2 of the ECL model), segmentation model by level of LGD at the time of default is applied;

2) for estimating lifetime expected credit losses for financial instruments with objective evidence of impairment (Step 3 of the ECL model), other models described in the work are applied.

The validity of the scientific provisions, conclusions, and recommendations formulated in the dissertation is determined by the theoretical and methodological base of the study, based on the works on "risk management", "accounting", "credit and investment analysis", "banking", etc. The results were obtained using modern methods of econometrics and economic-statistical modeling based on a unique empirical database. The results obtained can be verified by other researchers in future works. The analysis results allow concluding that the scientific provisions, conclusions, and recommendations formulated in the dissertation are valid.

The practical implication of the study results lies in the fact that, according to the provisions of IFRS 9, commercial banks "at no particular cost" should bring their models into conformity with its requirements. Currently, a large number of medium and small banks need ready-made models and solutions. This study will allow them to solve this problem and, as a consequence, increase the sustainability of the banking system in Russia in crisis. Also, the results of the study can be used by the Bank of Russia in solving the problem of convergence of approaches to prudential provisioning with IFRS [Bank of Russia, 2022].

Structure of the work. The dissertation consists of an introduction, four chapters, a conclusion, a list of references, and appendices. The total volume of the work is 219 pages of the main text, and 38 pages of appendices; the list of references includes 174 titles, more than a third of which were published in the last 10 years. The list of English-language articles consists mainly of papers published in highly ranked journals (first and second quartiles).

Approval of scientific results. The dissertation research results were provided in the form of the following presentations, and reports were discussed at international and Russian conferences and seminars:

1) "Methods of Credit Risk Assessment in the Context of Variation of International Financial Reporting Standards Requirements" at the Ph.D. Seminar of Gazprombank's Basic Department "Economics and Banking Business" of the Moscow State Institute of International Relations of the Ministry of Foreign Affairs of Russia on "Risks and Risk Management".

2) "Methods of managing the credit risk of corporate clients under conditions of the variability of requirements of financial reporting standards" at NIS "Empirical Studies of Banking Activity", National Research University Higher School of Economics.

3) "Constructing a probability of default model during the lifetime of a financial asset" at the 19th April International Scientific Conference on Economic and Social Development (April 10, 2018, Russian Federation, Moscow).

4) "Constructing a probability of default model during the life cycle of a financial asset" at the 20th April International Scientific Conference on Economic and Social Development (April 9-12, 2019, Russian Federation, Moscow).

5) "Credit ratings as a long-term assessment of credit quality of project finance transactions in renewable energy" at the International Wind Energy Forum RAWI Forum 2020 – Main Forum of Russian Wind Industry (February 19-20, 2020, Russian Federation, Moscow).

6) "Migration matrices as a tool for calculating the probability of default for the entire life of an asset" at the Analytics for Management and Economics Conference (AMEC, September – December 2020).

7) "Long-term assessment of the value of corporate credit claims of banks at the time of default" at the meeting of the Permanent Research Seminar No. 2020-00 "Empirical Studies of Banking Activity" (seminar leader prof. A.M. Karminsky), HSE School of Finance (June 17, 2020).

List of works published by the author on the topic of the dissertation research

1. Vasilieva A., Frolova E. Methods of Calculation of Expected Credit Losses Under Requirements of IFRS // Journal of Corporate Finance Research. 2019. Vol. 13. No. 4. P. 74-86. – DOI: https://doi.org/10.17323/j.jcfr.2073-0438.13.4.2019.74-86.

2. Vasilieva A., Frolova E. Development of the 'Inner Assessment Model' of Long-Term Default Probability for Corporate Borrowers in the Trade Segment of the Economy in accordance with IFRS 9 // Journal of Corporate Finance Research. 2020. Vol. 14. No. 1. P. 91-114. – DOI: https://doi.org/10.17323/j.jcfr.2073-0438.14.1.2020.91-114.

3. Vasilyeva A.F. Approaches to Modelling Exposure at Default for the Entire Life of the Asset // Financial Journal. 2021. Vol. 13. No. 4. P. 91-109. – DOI: https://doi.org/10.31107/2075-1990-2021-4-91-109.

4. Vasilieva A. Approaches to Building Default Probability Models for Financial Instruments of Project Financing at Long Time Horizons // Journal of Corporate Finance Research. 2021. Vol. 15. No. 4. P. 66–87. – DOI: https://doi.org/10.17323/j.jcfr.2073-0438.15.4.2021.66-87.