

Methodology of Diagnosing Financial Crises by Using a System of Signaling Economic Indicators and Digital Analytical Tools

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Abstract—The global financial crisis, caused by the pandemic, has taken on a scale unparalleled in previous crisis periods. Our assessment of the impact of this crisis on the economy is associated with high uncertainty of economic consequences. The most vulnerable to this crisis were countries with a high level of debt obligations and limited opportunities for the financial and credit system. At the same time, the stable financial and credit system of the state guarantees: the development of the potential of the country in improving the quality of life, the reliability of economic and social institutions, and effective redistribution of capital. Digitalization of the economy has provided new opportunities for the diagnosis of a financial crisis state and to monitor its precursors. This article is devoted to the research and development of effective methods for diagnosing and predicting financial crises in Russia with the help of a special system of economic indicators and digital analytical tools. The state of the country's economy for 1997-2019 was studied in detail. In addition, the source information base was data from the Federal Service of State Statistics of the Russian Federation, the Ministry of Finance of the Russian Federation, and the Central Bank of the Russian Federation. The authors identified the most

important groups of factors causing high financial and economic risks with the use of signal approach, nonparametric methods, mathematical statistics, and econometric modeling. As a result, a system of signs-indicators of crisis phenomena typical for the Russian economy has been developed. Also, a multifactor model is proposed which allows to track the influence of factors that determine the onset of crisis phenomena. Finally, the implementation of developed methods allows us to obtain information on trends in the sphere of financial and economic instability and ultimately assess the likelihood of a financial crisis.

Keywords—*financial crisis, economic instability, financial markets, signaling approach, econometric modeling*

I. INTRODUCTION

Financial crises are associated with periods of social tension, political risks, and loss of economic growth. The main task of a modern government in creating conditions for sustainable economic development is timely prevention and competent management of risks caused by crisis phenomena

in the economy. In addition, the specificity of financial crises is that their causes are often irrational (the impact of external macroeconomic factors on financial markets; financial bubbles; the occurrence of difficult to predict events with significant economic implications and named the "black swan", such as the COVID-19 pandemic, etc.). Thus, the financial crisis of the world economy caused by the pandemic had a great impact on the dynamics of world financial markets, which contributed to an increase in instability and the achievement of critical levels of liquidity in the financial sector. Opposition to these consequences led to an understanding of the need for infrastructural changes in the financial and credit system, as well as the actualization of research and development in the field of early diagnosis and prevention of crisis phenomena in the economy [20].

Globally synchronized shutdowns and the collapse of financial markets have reinforced each other and led to an unprecedented stop in economic development in virtually every country in the world. These reasons make the global recession caused by Covid -19 unique. Despite this, researchers are turning to the analysis of the consequences of past pandemics, and global financial crises using a unique method for the assessment of possible economic losses [4].

In this regard, the current stage of development of the financial and economic activity of states is characterized by an urgent need, in order to ensure economic stability. In recent decades, the scientific community has developed a number of methods aimed at predicting financial crises, known as early warning systems for crisis events. Studies of financial cycles [15; 18] suggest that crises follow periods of credit expansion and sustained asset price growth [1; 19].

G. Kaminsky et al. [14] proposed one of the most effective methods for predicting periods of economic instability, designated as the «signaling approach». Moreover, researchers Demirguc-Kunt A., Detragiache E. [7] Hardy D., and Pazarbasioglu C. [12] worked in this direction almost simultaneously. This approach is that the onset of a financial crisis is usually associated with exceeding the threshold values of the developed system of indicators. However, when we are applying this approach in practice. We face the problem of choosing the weights of these indicators and their threshold values. In order to solve this problem, the signal approach suggested to maximize the ratio of signal strength to their random errors.

Later on, a number of researchers [26; 27] improved the early warning system. They are adapted the system to forecast financial crises in different countries. Research by Bussiere and Fratzscher [6] has further reaffirmed the need to choose between sensitivity and false warning signals when using an early warning system for financial crises. In addition, when predicting financial crises on the basis of the signaling approach, one often has to face the problem of late publication of the necessary statistical data. If so, the consequence of this is a late and irrelevant forecast.

Another direction for diagnosing financial crises is the study of the vulnerability of the country's financial system based on a specially formed system of indicators [10; 19; 25]. In particular, the researchers Illing and Liu in their work [10]

proposed calculating the financial stress index as a measure of the stability and resilience of the financial system to various factors and events. This index shows the extent to which the financial system of the country is able to withstand the "stress" generated both within the country and by the international financial markets [19].

However, the phenomenon of a sharp rise in prices in the financial market and their subsequent decline were analyzed in a series of works devoted to the problem of the valuation of financial assets (for example, [24]). According to R. Shiller [24], the prices of financial assets that create a "financial bubble" increase the tension of the country's financial system. In this regard, the further development of asset pricing theory, together with modeling stock price movements and market volatility models [9; 11, 21] appear promising direction for the prediction of financial crises.

At the same time, the use of digital methods used in Internet trading opens the way for analyzing large amounts of information about financial markets in real time. This allows us to track various processes taking place on the market. Today financial market monitoring carried out with modern trading platforms and digital methods and new price trends can be traced earlier.

A large number of scientific works are devoted to the study of detailed exchange information using specialized software. Thanks to them, we have the opportunity to study the microstructure of the financial market (for example, [8; 13; 17]). Digital techniques in the financial markets have allowed the study to find an explanation for many economic phenomena observed in these markets. For example, the effect of a "long memory" of time series [5; 16], the impact of capital flows on the market price in relation to the projected liquidity [3; 13] and others.

In works [22; 23], the authors proposed and tested certain methods for predicting the instability of the Russian financial market, based on the analysis of detailed exchange information using specialized software. During the study, it was found that these methods also allow to identify facts of manipulation on the financial market on the basis of online diagnostics of exchange capital flows. The authors developed an approach for diagnostics of market processes, which are creating financial instability of the national financial system [22]. They used methods for studying non-equilibrium economic processes, and mathematical statistics.

A review of the scientific literature has led to the conclusion that the two components of financial markets - dynamism and riskiness - are becoming very important areas of research in forecasting crisis phenomena. At the same time, the financial crisis may be due entirely unforeseeable circumstances and have a negative impact on the economic activity of the country and the welfare of the population in the medium and long term. In this regard, complex studies aimed at comprehensive diagnostics of the state of the financial and credit sphere in order to provide early warning of financial crises are of particular importance. The ability to correctly interpret and accurately measure the degree of risk during the spread of financial crises, as well as to form adequate

protective economic measures, is an urgent scientific and practical problem in the modern world economy.

The purpose of this article is a comprehensive study and development of effective methods for diagnostics and forecasting of financial crises in Russia using a special system of economic indicators and digital analytical tools for processing financial information.

II. MATERIALS AND METHODS

It is widely known that the financial crisis is a natural phenomenon, which not only causes problems for the economy of the government but also can be a stimulus for further development. However, when we are ignoring the reasons leading to the emergence of crisis phenomena. It always has the most serious consequences.

In this regard, the initial task of the study was to clarify the causes of the crisis in the Russian economy. For this reason, the state of the country's economy for 1997-2019 was studied in detail. Information base of research were the data of Federal Service of State Statistics, Ministry of Finance, the Central Bank of the Russian Federation, the world's financial markets. Information from the Moscow stock exchange processed with special software. Special attention paid to the following large-scale crises of the Russian economy.

The first of them fell on 1998-1999. One of the most severe economic crises in the history of the country. The main causes of default are a significant increase in Russian government debt because it was generated by the collapse of the Asian economies a liquidity crisis and low world prices for raw materials, which formed the basis of Russian exports.

The next financial crisis in Russia fell on 2008-2009. Its occurrence is associated with a number of factors: the general cyclical nature of economic development; problems of the credit market due to the mortgage lending crisis; high prices for raw materials (including oil); overheating of the stock market.

In 2014-2015 the currency crisis characterized by the weakening of the Russian ruble against foreign currencies caused by the rapid decline in world oil prices, on the export of which the revenues of the Russian budget largely depend, as well as the introduction of economic sanctions against Russia.

We also note that the financial crisis of 2019-2020 caused by the COVID-19 pandemic was not considered in detail in this work, but is a subject for further research.

The identification of the most significant factors of crisis conditions in the Russian economy was carried out on the basis of the methods used in the development of early warning systems for crisis situations: qualitative analysis, which was supported by the study of statistical characteristics of time series of financial instability indicators; methods of nonparametric statistics and signaling approach; econometric modeling.

The use of qualitative analysis involved a graphical comparison of the dynamics of economic indicators of the pre-crisis, crisis, and post-crisis periods.

The selection of signal indicators of financial instability was carried out on the basis of non-parametric statistics methods, which make it possible to identify in advance the vulnerability of the economy to the financial crisis and assess the likelihood of financial instability.

In order to assess the close relationship between selected signal indicators and the dynamics of Russian stock indices, we used econometric regression.

The study based on the works [7; 12; 14], so the key idea of the signaling approach is that when a crisis occurs, some economic indicators behave in an unusual way. This unusual behavior begins to repeat itself systematically and then manifests itself in a wide range of economic and financial indicators.

Source database for qualitative analysis were the following groups of indicators.

1. The indicators defining the real economy and public finances (the ratio of exports to imports, the current account balance of payments, the producer price index, industrial production growth, inflation rate, GDP growth rate, the ratio of budget deficit to GDP ratio, etc.)
2. Indicators reflecting the state of the country's debt market (coefficients of debt dependence, debt load per person, external debt load; the growth rate of external and internal state debt of the Russian Federation, etc)
3. Indicators characterizing the monetary system (money supply; refinancing rate; the ratio of M2 money supply to gold and foreign exchange reserves and GDP; the growth rate of gold and foreign exchange reserves).
4. Indicators reflecting the state of the stock and foreign exchange markets (growth rate and dynamics of the Russian stock indices RTS and MOEX; growth rate and dynamics of world stock indices; exchange rates EUR/RUR; USD/RUR, etc.).

Further (similar to the methodology of Kaminsky et al. [14]), the indicators most significant for predicting crisis phenomena in the economy were selected and the optimal threshold value was determined. For this purpose, all indicators were divided into four groups (Table 1).

TABLE I. DISTRIBUTION OF INDICATOR VALUES WITH SIGNALS OF A FINANCIAL CRISIS

Signal presence (absence)	The presence of a crisis (absence)	
	<i>The crisis is fixed inside the signal window</i>	<i>There is no crisis inside the signal window</i>
There is a signal	W	X
No signal	Y	Z

Obviously, the more indicator values fall into cells W and Z, the more effective it will be. For each indicator, threshold values and an unconditional probability of financial instability were determined. The unconditional probability defined as the ratio of observations, for which the signal inside the window followed by the financial instability to all observations (1):

$$P(A)=(W+Y)/(W+X+Y+Z) \quad (1)$$

Indicator $P(A)$ characterizes the probability of onset of the financial crisis without reference to indicator values.

The conditional probability of a crisis situation determined as the ratio of significant signals (W) to the total number of signals ($W + Y$) (2):

$$P(A/B)=(W)/(W+Y) \quad (2)$$

It is advisable to use the indicator if the conditional probability $P(A/B)$ is higher than the unconditional $P(A)$. This condition is necessary for choosing the optimal threshold value of indicators.

For this reason, the composite index of financial stability is the sum of n selected indicators of financial stability, each of which can be assigned a degree of significance (specific weight).

In that case, the described signaling approach to forecasting crisis phenomena can be completed with a binary choice model, which is a dependent variable that takes the value 1 during the period when the crisis occurred, and 0 - the crisis did not occur.

Our study ends with the construction of multivariate models in relation to Russian stock indices based on the analysis of the probability of the onset of crisis phenomena. They are depending on the values of the selected signal indicators, as well as on the relationship between these indicators and stock indices.

When we are forming a multifactor model for forecasting crisis phenomena (3), the principles of arbitrage models were applied. Factors that characterize three key vectors were considered - macroeconomic indicators (V_{i1}), indicators of world stock markets (V_{i2}), indicators of the world foreign exchange market (V_{i3}). The model takes into account the risk-free rate of return in the market (r_f), the sensitivity of Russian stock indices to the effects of various factors related to the indicated vectors, as well as the possible model errors (ϵ_i).

$$\Phi = \rho_\phi + \sum_{i=1}^v \beta_{i1} \zeta_{i1} + \sum_{\varphi=1}^u \beta_{\varphi2} \zeta_{\varphi2} + \sum_{\kappa=1}^x \beta_{\kappa3} \zeta_{\kappa3} + \epsilon_i \quad (3)$$

During construction of the multifactor model was accompanied by a ranking of selected indicators of forecasting crisis phenomena on the basis of an analysis of the statistical criteria between indicators. In the case of a close relationship between the indicators, a correction factor (group level) was set equal to 1; in the case of a moderate relationship between indicators, the correction factor (group level) was set at 2/3; with a weak relationship between the indicators, a correction factor of 1/3 was used. This technology is consistent with the ideas of M. Blum [2], who proved that the betas of financial assets change over time, which leads to the use of correction factors for beta index.

III. RESULTS

Dozens of countries lost 10 -35% of national financial assets in the 1970-2000s because of financial instability. The

International Monetary Fund registered more than 150 currency and 54 debt, banking crises in more than 50 countries during the period 1975-1997. In the Russian financial market, the frequency of crisis periods is usually no more than 5-10 years. In the course of the research, it was possible to establish that the development of financial crises in Russia has the same characteristics as in other countries of the world (Table 2).

TABLE II. CRISIS IMPACT ON THE FINANCIAL SECTOR OF THE RUSSIAN ECONOMY

Financial sector institutions	Characteristics of the financial crisis
Financial sector and financial markets	Reduction of loans, chain bankruptcies, transition to a loss-making model of banking activity, predominance of speculative financial activity over investment, depreciation of securities, massive losses in the derivatives market, banking panic, etc.
International finance	The mass withdrawal of capital from the country, uncontrolled depreciation of the national currency, uncontrolled increase in public external debt, the failure to pay the state and commercial organizations, the transfer of systemic risk to the international market.
Money turnover	A rapid uncontrollable rise in prices, a flight from the national currency, introduction of hard foreign currency into domestic circulation, mass appearance of money substitutes.
Public finances	Sharp reduction of gold and foreign exchange reserves and state stabilization funds, appearance of budget deficit, reduction of tax collection, reduction of budget financing, growth domestic public debt.

Further, we conducted a qualitative analysis of more than 27 indicators indicated in the previous section. As a result, a list of indicators-precursors of impending financial instability was formed in accordance with the described methodology, which implies the use of a signaling approach based on nonparametric statistics methods and a binary choice model.

11 of the indicators showed a high probability (more than 90%) of financial instability, with positive results over the maximum possible period (36 months). It should be noted that the calculation results have shown almost complete coincidence with values of the unconditional and conditional probability of the crisis period in relation to signal indicators. After comparing, the results obtained for the Russian economy with the results of studies conducted in relation to Western countries. A formed system of signal indicators confirmed its importance for predicting financial crises and periods of economic instability.

Methods of mathematical statistics and econometric modeling made it possible to form a multivariate model for assessing the financial stability of the Russian economy. Table 3 provides an example of the parameters of the model built in relation to the Russian RTS index.

TABLE III. FACTOR MODEL PARAMETERS ESTIMATION OF FINANCIAL STABILITY OF THE STOCK MARKET, FORMED IN RELATION TO THE RTS INDEX

Indicators	The coefficient of determination (R^2)	The correction factor (the group level)	Corrected group level on the RTS sensitivity coefficient to the variability of the signal indicator (b_{ij})
<i>Macroeconomic indicators</i>			
Money supply (%)	0.5	0.67	1.44
Gold reserves (%)	0.4	0.33	0.43
Consumer price index (inflation) (%)	0.3	0.33	-2.09
Refinancing rate (%)	0.1	0.33	-0.80
Unemployment rate (%)	0.1	0.33	-0.59
Brent oil price, %	0.3	0.33	6.27
GDP (%)	0.6	0.67	1.26
External public debt (%)	0.0	0.33	-7.54
Ratio of M2 money supply to GDP	0.0	0.33	-1.99
Export-to-import ratio (%)	0.1	0.33	-4.70
Ratio of M2 money supply to gold and foreign exchange reserves	0.4	0.33	0.55
<i>World stock indices</i>			
Hang Seng (%)	0.1	0.33	0.90
France CAC 40 (%)	0.0	0.33	-1.87
Germany DAX (%)	0.0	0.33	-11.26
Dow Jones 30 Industrials (%)	0.0	0.33	1.29
<i>World currency</i>			
EUR/USD (%)	0.3	0.33	0.27

Because of approbation of the constructed multifactor model for forecasting financial instability was tested on the Russian MOEX and RTS indices for the period from 1998 to 2019. It was found that the constructed models demonstrate a fairly high closeness between the predicted and actual values of the profitability of Russian stock indices. They are reflecting the state of the financial market generally. For example, the predicted value of the RTS index growth rate at the end of 2019 in accordance with the developed model was 19.45%, while the actual value at 01.12.2019 totaled 23.11%. Developed multi-factor model makes it possible not only to predict the correct direction of the relative change in the stock index, but also its value. We can say that the use of multi-factor models based on a combination of signal approach, mathematical methods and non-parametric statistics, enhances the diagnostic of financial instability on the Russian financial market.

IV. DISCUSSION

The system of 27 indicators was tested in the process of diagnosing signs of crisis during the period 2018-2019. The study showed that in 2018-2019 17 indicators confirmed the presence of signs of crisis phenomena. Thus, the probability of a crisis in 2020 was estimated to be quite high. Most analysts and scientists also pointed to an impending decline of the world economy in 2019-2020, due to both economic and

political reasons. The world stock indices NASDAQ, Dow Jones experienced high volatility in 2018-2019. The COVID-19 pandemic was the catalyst for the beginning of a severe financial crisis around the world, including Russia.

The study of the crisis phenomena of the Russian financial market with the methods of mathematical and nonparametric statistics made it possible to establish the effectiveness of the combined use of the signaling approach and econometric modeling for diagnosing and forecasting periods of instability in the Russian economy. Our results are to a certain extent consistent with the results described in the scientific works of Kaminsky, G. et al.; Demirguc-Kunt A., Detragiache E.; Hardy D., Pazarbasioglu C. [7; 12; 14]. In the course of the study, the most significant groups of factors causing high financial and economic risks were identified. Consequently, a system of indicators of crisis phenomena characteristic of the Russian economy was developed. One of the major findings that the implementation of the developed methodology not only provides some information about the emerging trends in the field of financial and economic instability but also indicates the likelihood of a financial crisis.

V. CONCLUSION

The instability of economic development and the volatility of capital markets in the past two decades has stimulated the search for new opportunities for forecasting crises and decreasing their consequences. Diagnostics of the state of the country's economy using digital analytical tools make it possible to obtain rather sensitive and operational indicators - "signs" of crisis phenomena. We can significantly increase the efficiency of forecasting periods of economic instability by using them in automatic mode.

In recent years, a number of studies have confirmed the prospects for using the signaling approach in combination with a binary choice model and econometric modeling methods for predicting the onset of crisis phenomena in the Russian economy. We have developed a multi-factor model, which allows us to monitor the impact of the most critical factors on crisis phenomena.

Approbation of this model carried out in relation to the Russian indices of MOEX and RTS shows a rather high correlation between the forecast and actual relative changes of Russian stock indexes.

The scientific significance of the research results lies in the fact that the proposed methods are great for diagnosing the crisis phenomena. As a result, they contribute to the development of scientific approaches for the analysis and forecasting of the price dynamics in financial markets and periods of their increased volatility.

In practice, the results can be used in the activities of state authorities and mega-regulators of the economy in the development of crisis and stabilization policies. In addition, institutional investors can use it in the formation of effective strategies for the management of capital invested in financial assets.

Acknowledgments

The reported study was funded by RFBR according to the research project No. 18-010-00909.

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