

**NEUROMODELING OF FEATURES OF CRISIS CONTAGION
ON FINANCIAL MARKETS BETWEEN COUNTRIES
WITH DIFFERENT LEVELS OF ECONOMIC DEVELOPMENT**

Dmytro Lukianenko

Kyiv National Economic University named after Vadym Hetman
54/1 Peremogy Ave., Kyiv, 03680, Ukraine
ORCID: 0000-0002-3475-2126, E-mail: lukianenko@kneu.edu.ua

Inna Strelchenko

Ukrainian State University of Chemical Technology
8 Gagarina Ave., Dnipro, 49005, Ukraine
ORCID: 0000-0001-5179-4304, E-mail: iistrelchenko@gmail.com

The study examines the problem of modeling the effects of the spread of crises between countries with different levels of economic development. The main focus is on the study of the spread of crisis contagions from the economy of the source country to the economies of the recipient countries. The authors conducted a fundamental analysis of the basic theoretical concepts, causes and mechanisms of crisis in the world economy. The relevant study was carried out in the context of certain types of financial crises.

A methodological approach to modeling the processes of crisis contagion through financial and trade transmission channels has been developed and substantiated. In particular, a method of classifying economies according to the level of behavioral similarity of individual indicators of resilience within two years after the end of the latency period is proposed. The practical implementation of the technique in the form of a cyclic algorithm in the MATLAB system is performed. Approbation of the created software is performed on the data of the world financial crisis of 2008-2009.

The obtained distribution of world economies and the calculation of statistical characteristics for each cluster made it possible to identify nine scenarios of economic development under the influence of cross-border processes of crisis. The influence of the type of exchange rate regime on the dynamics of the exchange rate during two years after the end of the latent period is analyzed separately. The analysis of the exchange rate in clusters showed that there is a certain relationship between the type of currency regime and the consequences of the crisis in domestic financial markets.

Keywords: *financial crisis, channels of crisis spreading, latency period, macroeconomic indicator, rank coefficient of concordance, neural network, Kohonen map*

JEL Classification: C45, F36, G01, G15, G17

Introduction

Ability to timely identify growing structural imbalances of financial markets is one of the challenges of modern economic theory and policy. The global integration of national economies provides, on the one hand, the dynamization of lending, investment, and foreign exchange, diversification of cash flows, and on the other hand - the expansion of the derivatives and speculative capital, unevenness and asymmetry in the distribution of financial resources and income.

On the way to solving the problem of predicting the consequences of the spread of crisis infection from the country of origin to the recipient countries the issue of developing a generalized model of crisis formation remains unsolved. After all, within the existing classifications of world economies used by such international organizations as the IMF or the World Bank, it is not possible to identify similar features in the dynamics of key macroeconomic indicators during crises in financial markets. Substantiation of the principle of classification of world economies according to the type of response to the spread of crisis phenomena allow to develop and propose scenarios of possible behavior of individual indicators that characterize the resilience of the economic system to the processes of multichannel financial crises spreading.

There is no single concept that explains the speed and direction of financial crises spreading. Financial crises have different mechanisms of initiation and cross-border transmission depending on the region and the level of socio-economic development of the country. However, today has been formed a clear division of the crisis phenomena transmission channels into external (cross-border) and internal (between the financial and real sectors of the economy of one country).

The phenomenon of the international chain contagion of crises is known as the “spillover effect”, which reflects the relationship of all countries with a market economy. The effect occurs when a crisis “flows” from one country to another, and they, in turn, affect a third country. In [1], two approaches were proposed to explaining the reasons for the development of financial crises. The first explains this phenomenon by trade integration and the similarity of macroeconomic parameters of countries: the crisis “flows” between countries when the main macroeconomic indicators change. The second approach

associates the spread of financial crises with financial integration, external effects and changes in the behavior of investors or other financial agents. At the same time, a crisis in one country can cause a crisis in others, even if their macroeconomic indicators are quite satisfactory. A crisis spreads because either “market sentiment” or investors’ interpretation of economic information changes.

In [2] the contagion was defined as the spillover effects taking place above and beyond the linkages explained by fundamentals, or as the extreme amplification of spillover effects. Ahrend and Goujard [3], Buch and Goldberg [4] and Claessens [5] in their works have documented that global banks have played a significant role in the international transmission of global financial shocks, including during the world financial crisis in 2008-2009. In these cases Cetorelli and Goldberg [6] and Buch and Goldberg [4] discuss the impact of cross-border lending by foreign banks on domestic credit. Billio et al. [7] showed that banks are the main transmitters of shocks, while researching the connectedness between hedge funds, insurance companies, brokers, and banks using principal component analysis and Granger causality networks. However, such approach has a static character and does not allow the comparison of shocks in time.

Allen and Gale [8] define “contagion” as a consequence of excess spillover effects, exemplifying that a financial crisis in one region may spread to other regions. So, the contagion risk measurement became one of the most important concerns on the daily agenda.

De Bruyckere et al. [9] used excess correlations to measure the secondary effects of bank/sovereign risk during the European debt crisis, and they found significant empirical evidence of a relationship between bank and sovereign credit risks.

Laeven et al. [10] find that large banks create more systemic risk when they engage in extrinsic activities. In addition, the default of a large bank is more devastating for the banking system. Similar conclusions were reached by Varotto and Zhao [11]. They agreed that bank size is an important determinant of contagion risk.

There is also no consensus on determining the date of the beginning of the crisis and the methodology for its fixation. Most approaches use a system of indicators to solve this problem.

Babecký et al. [12] find that growth of domestic private credit, increasing FDI inflows, rising money market rates as well as increasing world GDP and inflation were common leading indicators

of banking crises. Currency crisis onsets were typically preceded by rising money market rates, but also by worsening government balances and falling central bank reserves.

Ferrari and Pirovano [13] presents a methodology to calculate thresholds in an early warning framework for extracting signals useful to predict the occurrence of banking crises. Behn et al. [14] find that in addition to credit variables, other domestic and global financial factors such as equity and house prices as well as banking sector indicators help to predict vulnerable states of the economy in EU countries. Ortiz and Ugarte [15] introduced an Early Warning System Indicator (EWSI) of banking crises based on a non-linear (Gomperzt curve) panel data model of credit deepening, and calculated the probabilities of banking crises and estimated dynamic thresholds for the EWSI indicators for 68 developed and emerging countries based on the credit gap.

In addition to the existing advances in the field of analysis of economic and financial crises, in this study we will pay attention to the development of conceptual statements, which formalizes the relationship between indicators that determine the state of financial and trade channels of financial crises and the dynamics of indicators that characterize the resilience of the economy after the beginning of the crisis within a country. The use of these statements may shed new light on the predicting scenarios of national economies behavior during the crisis in global capital markets.

The purpose and objectives of the study

The purpose of the study is to develop conceptual statements and an appropriate mathematical classifier model, which formalizes the relationship between indicators that determine the state of financial and trade channels of financial crises in the last quarter of the latent period, and the dynamics of indicators that characterize the resilience of the economy during two years after the beginning of the crisis within a country.

To achieve this purpose it is necessary to solve the following tasks:

- a critical analysis of existing theoretical approaches to forecasting processes of cross-border crises spread on the financial market and their impact on the resilience of individual national economies;

- developing a methodological approach to the division of the studied objects into clusters, within which the dynamics of the selected indicators of resilience is similar;
- carrying out a computer experimental study of the developed system on historical data of financial crises.

Methodology and experimental study

Since the 1990s, several waves of economic crises have swept the world economy, negatively affecting all countries of the globe at different times and in different ways. According to the modern concept of “economic crisis”, first of all, there is a financial crisis that has a cyclical, structural and systemic nature [16]. In this case, the common prerequisites for crises are:

- liberalization of the financial sector;
- imperfection of the international capital market (irrational activities, speculations, financial bubbles, asymmetry of information);
- hopes for external sources of funding;
- crisis infection, domino effect, panic, herd behavior.

A feature of modern crises is the time-distributed processes of cross-border spread of negative trends to other countries from the source country, in whose economy systemic disruptions in the functioning of the financial sector occur and are recorded for the first time. Large amounts of capital are moving rapidly around the world in response to changes in interest rates and exchange rates, and these cross-border flows can have a negative impact on the balance of local financial markets and economies [17]. Moreover, national (local) and international (regional) crises, as a rule, quickly grow into global ones, primarily due to the global Internet and the accelerated pace of transition to electronic money.

Due to global Internet connection, the movement of financial flows has no time and geographical restrictions, and the possibility of existence in electronic form allows money to circulate in the world ten times faster than any goods or services. The result of such specific “mobility” is the low predictability of the consequences and the geography of the spread of negative trends in the financial sector of a particular subject of the world economy.

In the modern economic literature, there is no single definition of the term “financial crisis”. Usually, the financial crisis is considered

as a deep disorder of the system of payment and settlement relations, accompanied by:

- 1) sudden devaluation of the national currency;
- 2) problems with sovereign debt service;
- 3) mass bankruptcy of credit and financial institutions;
- 4) a significant decline in the exchange rate value of government securities and securities of the largest enterprises of the country, which shares are included in national stock indices.

According to the common classification proposed by the IMF [18], modern financial crises can be divided into four groups according to the type of financial relations, which is the primary source of crisis phenomena:

- currency crises;
- sudden stop crises (so-call SS crises);
- debt crises;
- bank crises.

The theories of *currency crises* are the most clearly formulated. According to the IMF, a currency crisis occurs when “a speculative attack on the exchange rate leads to devaluation (or sharp depreciation of the currency), a significant expenditure of foreign reserves or a sharp rise in interest rates” [18].

Over the past four decades, three generations of models have been developed to explain the causes of currency crises.

The developing of the first generation of models was caused by the collapse of the Bretton Woods monetary system based on the gold standard, the transition to the Jamaican currency system, and the introduction of floating exchange rates. These models are described in the main works by Krugman [19], Flood and Garber [20], and therefore they are called “KFG” models. Together, these models and their modifications constitute the theory of balance of payments deficit.

For the first time, Krugman formalized the model of the crisis under the influence of the balance of payment deficit: he claimed that in a fixed exchange rate regime the main cause of the crisis is the financing of the budget deficit by increasing public debt [19]. Over time, this leads to a critical reduction in international reserves, and once their level reaches the limit, the country’s central bank is no longer able to maintain a fixed exchange rate. Subsequently, Krugman model became more complicated, additional variables were introduced (distrust of the existing currency regime, the level of price

flexibility, the probability of speculative attacks, changes in public debt, government policy, etc.), alternative currency regimes after giving up fixed exchange rate were also considered [19].

The second generation of models consider the possibility of establishing multiple equilibrium situations in the foreign exchange market. The developers of this type of model argue that doubts about whether the government is willing to support the peg of the exchange rate can lead to various market equilibria or currency crises.

Mechanisms for establishing multiple equilibrium are realized through the concept of so-called “self-fulfilling” crises. This is one of the latest concepts in the list of assumptions about the causes of financial shocks. First proposed in the work by Obstfeld [21], it considers the behavioral approach in explaining the causal links of the “avalanche” growth of negative trends in the economy. The emergence of third-generation models was caused by the Asian crises of the late 1990s. Leading economic theorists such as Corsetti, Pesenti, and Roubini [22], McKinnon and Pill [23], and Krugman [24] believe that the main cause of these financial crises was an imbalance in key macroeconomic factors, not just changing market expectations. The main macroeconomic factors that did not meet the desired level in the second half of the 1990s cover a balance of payments deficit, foreign debt of commercial banks and corporations, budget deficit, real exchange rate, foreign exchange reserves, investment in the corporate sector, the ratio of savings and investment, debt and profitability of commercial banks, indices of confidence and financial weakness, monetary policy, debt service, the dynamics and structure of capital inflows and outflows and political instability. As it can be seen from the above factors, the crisis of 1997-1998 revealed a number of interrelated problems that existed in the public, financial and corporate sectors.

Therefore, the third generation of crisis models in foreign exchange markets explores how a rapid deterioration in macroeconomic balances due to fluctuations in asset prices, including exchange rates, can lead to a currency crisis.

The results of empirical studies do not allow us to conclude which generation of models provides the best approximation and prediction of currency crises. For example, Blanco and Garber applied the KFG model to the Mexican devaluations of 1976 and 1981-82 and showed an abnormal accumulation of crisis probabilities immediately before the devaluation [25].

In general, the KFG model works well when changes in macroeconomic indicators become abnormal, and does not record the beginning of negative processes in the foreign exchange market in the case of moderate instability in money demand and a gradual increase in volatility in changes in macroeconomic indicators.

The next type of financial crisis is a *suddenly stop crisis*. Models of this type of crisis are directly related to disruptions in external financing. They are similar to the models of the latest generation of currency crises, and also focus on the mismatch of the country's balance of payments in foreign currency, as well as, in addition, the level of development and formation of the financial and corporate sectors. However, researchers in this area tend to place more emphasis on the influence of international factors on "sudden stops" in capital flows (for example, changes in international interest rates or spreads on risky assets).

The fundamental work in the development of SS-crises is the research by Calvo and Reinhart [26]. Studies of changes in the direction of capital flows conducted by Calvo and Reinhart showed that in 7 cases out of 15 under the influence of capital outflows or inflows in developing countries, economic fluctuations exceeded 10% of GDP. Moreover, in countries where a banking crisis arose as a response to the "sudden stop" of capital, the decline in production averaged 13.3%. In those economies where there was a currency crisis, the fall was 12.3%.

Let us consider the basic theoretical concepts in determining the causes of *debt crises*.

Developing countries are not able to provide a level of accumulation sufficient for stable economic growth on their own. The necessary financial resources can be attracted from outside and expressed in the accumulation of public debt. Empirical studies show that although secure debt thresholds for such indicators as default and inflation depend on specific countries, for the vast majority the following statement is true: if the level of external debt of a developing country exceeds 30-35% of GDP – the probability of external debt crisis is growing significantly [27].

In most crisis cases, it is difficult to determine the fundamental causes of default on external sovereign debt. The vulnerability of the economy, which increases the risk of a debt crisis, may be related to financial integration processes, economic policy and the institutional

environment. It is important to note that debt crises in the vast majority of cases occur in tandem with crises of sudden stop, currency or banking crises, which greatly complicates the identification of the root causes that provoke the default of external debt.

The fourth type of financial crises are *banking crises*. Despite the fact that banking crises are quite common [28], they remain poorly studied in economic theory. In essence, the financial stability of a banking institution directly depends on the behavior and expectations of its depositors. Another important feature is that the problems of one bank can very quickly spread to the entire banking system.

The fragility of the financial stability of banking institutions creates problems for their management and coordination of the entire system. Financial institutions are forced to dispose of capital, which contains a high share of borrowed funds. Therefore, banking and other similar forms of financial intermediation have unstable financial obligations. These features create the preconditions for a quick outflow of capital, when investors or other depositors have taken action to withdraw equity just because of fears or rumors that other investors are planning similar transactions. Small shocks can turn into a mess in the markets and even a financial crisis.

The analysis allows us to draw the following conclusions. Methodologies based on basic theories explaining different types of crises can be used to identify and, accordingly, classify crises. In practice, however, this is not easy. This is partly due to the fact that the frequency and types of financial crises have changed over time. In practice, for identifying and classifying crises it's used a wide range of quantitative and qualitative methods, the choice of which in each case is based on subjective opinion of the researcher. Historical retrospective also shows that crises have evolved over time. For example, currency crises were dominant in the 1980s, while banking crises and SS-crisis became more prevalent in the 1990s and 2000s.

The analysis of the crises of the last thirty years shows that financial crises are of all types and territorial coverage.

Therefore, in the study we did not differentiate financial crises by types and will determine the duration of crisis processes within each country, based on our own definition of the object of study and quantitative measure to determine the main elements in the time structure of cross-border crisis in financial markets, that have clear economic interpretation.

According to the terminology proposed in [29], the process of cross-border spread of the financial crisis consists of two periods:

1. latency period – lasts until negative changes in the financial sector of the source country through financial and/or trade transmission channels will lead to a decline in key macroeconomic indicators in the country under study. It can still be defined as a period of buffering, or the imbalances accumulation in the economy. The length of the latency period is determined by the degree of integration and development of the domestic financial market of the country to which the crisis has been transferred. It also identifies the time for developing economic incentives and corrective actions that can mitigate the effects of the financial crisis.

2. response period – lasts from the beginning of the crisis within the country under study until its end, when for some time there will be a steady growth of macroeconomic indicators such as gross domestic product, national currency, international reserves, and reducing public debt. The response period depends on the state of the country's economy, the level of development of legal legislation governing monetary and financial relations, the level of trust in public administration by the population, the level of corruption in the region. The last two points significantly affect the inclusion of internal channels of crisis and, to some extent, determine the stability of the economy of the country under study and the length of the response period.

It is clear that the resilience of individual economies to financial shocks, which is appeared in changes in the gross domestic product, the value of the national currency, the price of external government bonds, etc., varies from country to country. Therefore, the objective task is to classify the studied countries according to the initial macroeconomic conditions that characterize the financial or trade channels of contagion.

To do this, one can try to apply the already developed system, which is used by the International Monetary Fund and the United Nations. However, the analysis of research on the preconditions and consequences of the global financial crisis of 2007-2009 suggests that the reaction of different economies to the global financial crisis and the subsequent recovery of key macroeconomic indicators differs significantly and is not similar within the IMF classification [30]. In their research, experts from the International Monetary Fund and the

United Nations use their own classification of countries according to the level of economic development, which covers 181 member countries. According to it, there are: developed market economies and emerging economies.

Let us illustrate the statement about the influence of the initial macroeconomic conditions, that characterize the channels of contagion, on the depth of damage to the economy during the spread of financial crises.

The resilience of the economy of any country to the processes of cross-border spread of crisis phenomena is usually assessed on the basis of changes in indicators: gross domestic product; exchange rate of the national currency; part of the country's international investment position, which characterizes the country's external liabilities to non-residents; international reserves; the value of external government bonds. The dynamics of these indicators characterizes the state of the economy of the studied country and the impact of crisis processes on household incomes.

Based on statistical information about the global crisis of 2008-2009 in 31 countries [31], we built a data field (Fig. 1), where the location of each point will be determined by the coordinates:

- horizontal axis – percentage change in the country's international reserves: 1st quarter of 2009 to 1st quarter of 2008;
- vertical axis – percentage change of the national currency exchange rate to the special drawing rights (SDR) at the end of the period: 1st quarter of 2009 to 1st quarter of 2008.

Both indicators are calculated according to the IMF methodology [30] and are available on the official website of the organization.

The sample includes two types of countries according to the IMF classification:

1. a group of countries with developed economies (Australia, Canada, Czech Republic, Denmark, Estonia, Eurozone, Hong Kong, Iceland, Israel, Japan, New Zealand, Norway, South Korea, Sweden, Switzerland, United Kingdom, United States of America);

2. a group of countries with emerging economies (Brazil, Croatia, Georgia, Hungary, Kazakhstan, Kuwait, Moldova, Paraguay, Peru, Poland, Russian Federation, Romania, Turkey, Ukraine).

Let us denote groups of countries with different levels of economic development according to the IMF classification using markers of two types: dark gray circles – a group of countries with developed

economies; light gray circles – a group of countries with emerging economies (Fig. 1).

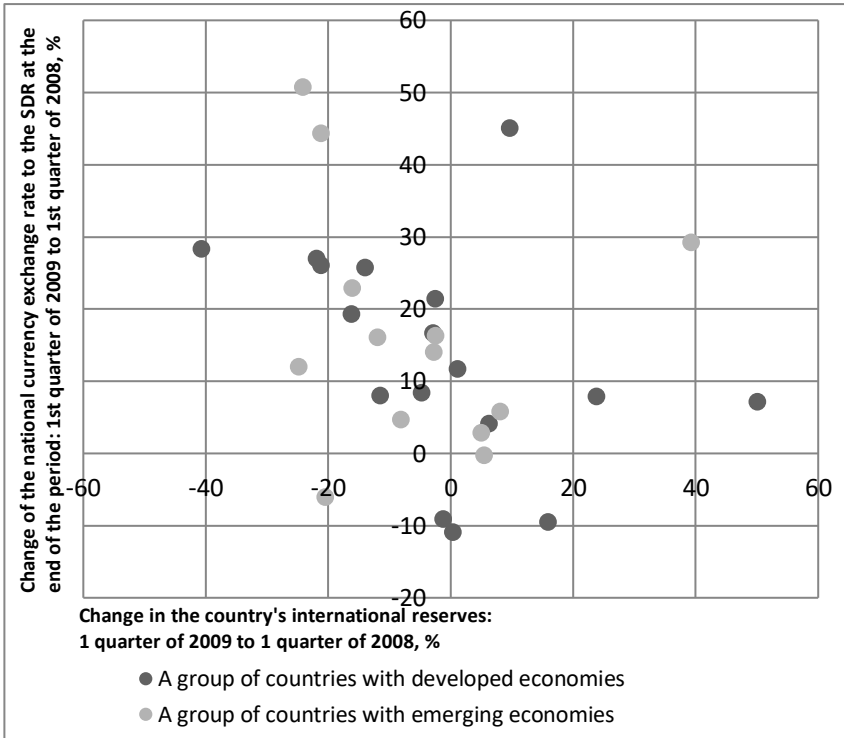


Fig. 1. Spot chart of the impact of the crisis of 2008–2009 on the indicators of economic stability of the world

Analyzing Fig. 1, the authors came to the conclusion that it is expedient to divide the scattering points of the recipient countries on the proposed coordinate system into nominal four zones:

1) recipient countries characterized by a high level of resilience to the processes of cross-border spread of the financial crisis: during the selected period there is a strengthening of the value of national currencies or a constant exchange rate and an increase in international reserves. This group includes 3 countries: Hong Kong, Japan, Kuwait;

2) countries with a sufficient level of economic resilience to the processes of cross-border spread of crisis phenomena, which recorded

an increase in the value of the national unit through the use of official international reserves, as evidenced by the decrease in the latter. This group includes two countries: The United States and Moldova;

3) a group of countries most affected by the crisis is to the left of the ordinate axis and above the abscissa axis. However, the variation in the values of the selected characteristics within this group is very high and, although all countries are characterized by a depreciation of the national currency and a decrease in official international reserves, the magnitude of these changes is in some cases incomparable. For example, this includes Ukraine and Poland, where the value of the national currency depreciated by 50% and 44%, respectively, and the Eurozone countries and Latvia, which lost about 8% of the official exchange rate of their own currencies. In general, this group includes Australia, Brazil, Croatia, Czech Republic, Eurozone, Kazakhstan, Latvia, New Zealand, Norway, Peru, Poland, Romania, Russian Federation, South Korea, Sweden, Turkey, Ukraine, United Kingdom of Great Britain.

4) a group of countries for which it is difficult to draw unambiguous general conclusions about the level of resilience during the global financial crisis of 2008-2009. It is characterized by a significant depreciation of the national currency (Hungary and Iceland) and a slight depreciation of the exchange rate (Canada, Denmark, Estonia, Georgia, Paraguay, and Switzerland) against the background of increasing official international reserves. A total of eight countries.

Fig. 1 makes it possible to see clearly that the consequences of the global financial crisis of 2008-2009 differed significantly for different countries. The primary reason for this, according to the authors, is the difference in the initial macroeconomic conditions that characterize the channels of infection at the end of the latent period.

Interestingly, each zone included countries of each of the two groups according to the typology of the International Monetary Fund. This makes it possible to see clearly that this classification system (into developed and emerging economies) is not convenient and universal for modeling the cross-border spread of crises between countries with different levels of economic development, and does not meet the objectives of the study.

The analysis of existing research and the results obtained by the authors based on the dynamics of certain macroeconomic indicators

for 31 countries with different levels of economic development, convincingly confirm the need to take into account the initial macroeconomic conditions that characterize the channels of infection.

From this point of view, the problem of studying the peculiarities of the crisis in the financial markets includes the task of differentiating countries by the level of response to external financial shocks or, in other words, by type of behavior. In particular, the relevance of this issue is emphasized in the World Economic Outlook of the IMF [30].

The task of finding a classification that meets the needs and objectives of the study, forms certain requirements for mathematical tools. First of all, it is the ability to work with multidimensional data and take into account nonlinear relationships between the elements of the sample.

We formulate a methodological approach to the classification of dynamic economic systems based on their characteristics. According to this approach, a mathematical model-classifier based on the dynamics of selected indicators for a certain period of time (during the latency period) should determine possible scenarios of economic behavior of the studied country. Behavior in this case will be understood as changes in macro indicators, which are most sensitive to sharp changes in the economy of the studied country during the crisis and the negative dynamics of which characterizes the depth of damage to all spheres of economic activity and directly affects living standards. In contrast to early warning indicators [12-15], which characterize the state of financial and trade channels of cross-border spread of crisis phenomena, which form a set of initial conditions in which the economy is located, the consequences of crisis phenomena are almost the same for all existing studies in this area: GDP, % to the previous period; real exchange rate to SDR, in % to the previous period; international reserves, in % to the previous period; external public debt, in % to the previous period; interest on external government bonds, in % to the previous period.

For the practical implementation of the classification process it is necessary to have a reference system of classes, which will break the statistical set of source data into groups of countries. Each group will be characterized by the similarity of the dynamics of these macro indicators during the crisis. There is no such reference system of classes for this problem. So, it's necessary to create it. For this purpose, the study will use the Kohonen neural network [32].

To choose the most rational structure of the Kohonen map, which will effectively cluster the objects of study, avoid creating an excessive set of scenarios that will describe the individual relationships between selected indicators, and increase the flexibility and versatility of the solutions, it was decided to use the author's approach [33] to determine the set of classes (number of neurons), each of which will include countries with similar patterns of response to the spread of crisis phenomena, based on the concordance coefficient:

$$W = \frac{12 S}{m^2(T^3 - T)}, \quad (1)$$

where T – the number of observation periods to be ranked; m – number of observation sets (cluster's countries); S – is given by:

$$S = \sum_{t=1}^T (R_t - \bar{R})^2, \quad (2)$$

where R_t – the sum of the ranks of the t^{th} period of observations ($R_t = \sum_{j=1}^m R_{tj}$); \bar{R} – the average sum of ranks for all countries for the entire observation period; R_{ij} – rank of the j^{th} country of a certain cluster in the t^{th} period.

In terms of the problem to be solved, the variables included in expressions (1) and (2) have the following interpretation: T – the length of the time series ($T = 8$ quarters of monitoring the dynamics of indicators of stability of an individual country); m – the number of countries included in a particular cluster (takes values from 1 to M – the total number of countries included in the training sample).

R_{ij} ranks range from 1 to 8 depending on the values of indicators that characterize the resilience of the economy to the processes of cross-border spread of crises. Ranks are determined separately for each country so that the maximum value of the indicator is assigned a rank of 1, and the lowest value of the indicator received a rank of 8. The number of ranks is determined according to the number of quarters during which the value of stability indicators is investigated (8 quarters after the end of the latent period).

The calculated value of the concordance coefficient (1) indicates whether there is a similarity in how each of the targets has changed within a certain group of countries. The value of the concordance coefficient is in the range $0 \leq W \leq 1$. If $W = 0$, then the sequences of ranks of different countries of the cluster in the respective periods

are completely inconsistent (dissimilar). If $W = 1$, the result is interpreted as a complete coincidence in the dynamics of the studied indicators. The closer W is to 1, the greater the consistency observed in the dynamics of stability indicators for different countries within one cluster.

The use of the concordance coefficient has a number of advantages:

- 1) it has no restrictions on the type of distribution of input data;
- 2) it is not necessary to pre-process the data to relate them to a common scale;
- 3) there are no restrictions on the distribution of scores in the rows of the rank matrix (for example, the normal distribution or linear relationships);
- 4) it has a simple and intuitive interpretation.

To select the optimal topology of the Kohonen map based on the rank coefficient of concordance within the formulated methodological approach to the classification of dynamic economic systems according to the selected characteristics system, a software algorithm was developed and implemented in the MATLAB [33]. After testing on real data, an additional condition was added to limit the redundancy of additional cycles (step 7) and modified the formula (4) to calculate the criterion of optimality (step 5). Finally, the sequence of steps that make up the algorithm is given below:

Step 1. The initial number N_i (i – iteration number of the algorithm) of clusters (neurons) of the Kohonen map is set. At the beginning of the algorithm, this variable is assigned a value 2 ($N_1 = 2$).

Step 2. Normalization of data.

Step 3. On the quarterly data on the dynamics of ten indicators that characterize the state of financial and trade channels of financial crises in the last quarter of the latent period, the Kohonen map is built with the number of clusters specified in this iteration N_i .

Step 4. In quarterly data on the dynamics of the five indicators of sustainability for two years after a latent period, the rank concordance coefficients for the i^{th} iteration of cluster structure were calculated:

$$W^i = \begin{pmatrix} W_{11}^i, \dots, W_{1z}^i, \dots, W_{1Z}^i \\ \vdots \\ W_{n1}^i, \dots, W_{nz}^i, \dots, W_{nZ}^i \\ \vdots \\ W_{N_i1}^i, \dots, W_{N_iz}^i, \dots, W_{N_iZ}^i \end{pmatrix}, \quad (3)$$

where z is the number of the stability index for which the concordance coefficient is calculated ($Z = 5$).

Step 5. The criterion of optimality PO^i is calculated as the average value of the concordance coefficient for the Kohonen map obtained at iteration i :

$$PO^i = \frac{\sum_{n=1}^{N_i} \frac{\sum_{z=1}^Z W_{nz}^i}{Z}}{N_i}. \quad (4)$$

Step 6. There is a comparison of optimality criteria - current and highest in previous iterations: if $PO^i > \max\{PO^1, \dots, PO^{i-1}\}$, then the current structure of the neural network is considered optimal.

Step 7. Iterations of the algorithm continue until the growth of the optimality criterion becomes insignificant (for the author's algorithm – less than 0.005). Further growth in the number of clusters leads to artificial fragmentation of the original set of countries and the formation of clusters that contain only one country.

The result of this algorithm is a system of classes, each of which will correspond to a certain type of reaction of economies to the processes of cross-border spread of crisis phenomena in accordance with the initial conditions. Creating such a system of classes allows us to predict possible scenarios during subsequent macro-imbalances in capital markets.

As a result of the algorithm, a neural network classifier is built that divides the space reference points (each of which has a spatial dimension of ten dimensions and depth characterized temporal duration of the latent period for the study of the country) into clusters of the Kohonen map. In each cluster, the dynamics of such indicators as GDP, the real exchange rate to SDRs, international reserves, guaranteed public debt and the value of external government bonds are similar.

The experimental research allowed us to determine the optimal Kohonen map for 66 countries that were most affected by the 2008-2009 crisis. It is constructed for data at the end of the latent period and has the highest value of criteria (4). This map has nine clusters (see Fig. 2), each of which determines a specific scenario of possible behavior of the economy under the influence of the spread of crisis phenomena on the basis of macro indicators that characterize the state of financial and trade channels.

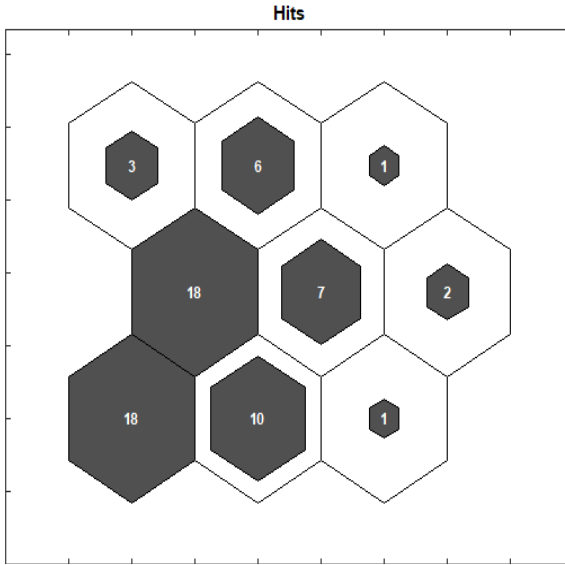


Fig. 2. The structure of the Kohonen map, which characterizes the distribution of countries by clusters at the end of the latent period of the financial crisis of 2008–2009

Each scenario corresponds to the number of the map cluster and is characterized by similar dynamics, defined average levels of change in key macroeconomic indicators (GDP, real exchange rate to SDR, international reserves, external public debt and the value of external government bonds), average latency and response period. It should be noted that clustering was carried out on the basis of initial conditions characterizing the state of financial and trade distribution channels: international reserves excluding gold; the ratio of the monetary aggregate M2 to the volume of international reserves; monetary multiplier; change of the monetary aggregate M0; change in the monetary aggregate M2; foreign currency within the country to a similar figure abroad, the coefficient of monetization of the economy, export growth, import growth, the share of exports in GDP. For each scenario, average, maximum, and minimum values for five resilience indicators are defined. The calculated values are interpreted by the authors as the characteristics of the forecast scenario for any country that is studied based on Kohonen map constructed (Table 1).

Table 1

**STATISTICAL CHARACTERISTICS OF THE PROCESSES OF SPREADING
THE GLOBAL FINANCIAL CRISIS OF 2008–2009 FOR THE ECONOMIES
OF COUNTRIES WITH DIFFERENT LEVELS OF ECONOMIC DEVELOPMENT***

Group of indicators	Indicator		Cluster number								
			1	2	3	4	5	6	7	8	9
Indicators characterizing the level of resilience of economies, % to the last quarter of the latent period	P_1	max.	36	7	13	49	42	48	15	11	17
		min.	2	0	-	12	7	6	2	+1	-
		ave.	18	5	-	29	12	27	9	6	-
	P_2	max.	47	34	13	83	31	13	27	24	5
		min.	+1	1	-	11	1	8	7	+1	-
		ave.	20	15	-	26	13	11,5	15	9	-
	P_3	max.	33	27	17	40	23	15	45	22	25
		min.	+2	+37	-	8	+6	13	5	+13	-
		ave.	16	3	-	20	7	14	23	1	-
	P_4	max.	24	23	24	85	36	29	45	12	18
		min.	11	8	-	26	9	15	23	4	-
		ave.	15	12	-	45	14	19	35	7	-
	P_5	max.	43	22	22	67	35	34	34	14	27
		min.	16	5	-	5	3	16	22	6	-
		ave.	28	7	-	27	11	22	30	11	-
Elements of the temporal structure of the processes of spreading crisis phenomena	T_L	max.	8	7	7	8	8	8	8	6	7
		min.	6	3	-	6	6	7	7	6	-
		ave.	7	5,8	-	7,8	6,9	7,5	7,6	6	-
	T_V	max.	>8	8	>8	>8	8	>8	>8	5	>8
		min.	4	2	-	2	3	>8	4	2	-
		ave.	7	4,5	-	7,1	5,4	>8	6	3,7	-

* Here: P_1 – GDP, change in %; P_2 – real exchange rate to SDR, change in %; P_3 – international reserves, change in %; P_4 – external public debt, change in %; P_5 – interest on external government bonds, change in %; T_L – duration of the latent period, quar.; T_V – the duration of the response period, quar.

If during the considered period there was an increase of the corresponding indicator in the middle of a cluster, in Table 1 it has a "+" sign.

The analysis of the obtained results indicates that the distribution of samples for neural network clusters is consistent with the actual data on the global financial crisis in the world.

Thus, to the first and fourth clusters in Fig. 2, 18 countries were selected (cluster numbering on the Kohonen map is performed from left to right from bottom to top), the vast majority of which are developing countries. The countries of both clusters are characterized by imperfect financial markets and the rules of their functioning (the latter is more relevant to the countries of the fourth cluster). Therefore, the spread of the financial crisis of 2008-2009 to these countries occurred primarily through trade channels, and therefore with a delay, which increased the duration of the latency period by 1 month for the first cluster and 1 quarter for the fourth cluster. The difference in terms of the crisis can be explained by the geographic location of the first cluster countries, which naturally contributed to the close trade ties with countries with developed financial markets - Eurozone, Japan (the United Arab Emirates), China and Hong Kong (Myanmar). The main feature of the first cluster is that despite the significant deterioration of the economic situation in 2008-2009, it is characterized by a much shorter period of recession and recovery. For example, Poland, which had almost a twofold fall in the zloty and a 16% drop in direct investment, already saw GDP growth of 1.7% in 2009.

The countries included in the fourth cluster had the worst dynamics of selected indicators of economic security during the crisis of 2008-2009 and the longest period of recovery and recession. Some of them reached pre-crisis levels of economic growth only in 2011-2012. It should be noted that 9 of the 18 countries of the fourth cluster were once part of the former Soviet Union and had close trade and economic ties during the period under review. This cluster includes, in particular, Ukraine. In 2008, the country's GDP decreased by 5.5%, and in 2009 – by almost 16%. The hryvnia lost more than 50% of its value. The fourth cluster also includes Iceland, a developed country, but during the crisis of 2008-2009 the national currency against the US dollar fell twice and the country for the first time among developed countries turned to the IMF for help.

The second and eighth clusters include the vast majority of countries with developed financial markets, which are tightly integrated into the world. Therefore, the spread of the crisis in 2007-2008 occurred primarily through financial channels. This led to a reduction in the latency period by 1-3 months compared to the first and fourth clusters. In the second cluster the consequences of the crisis significantly affected the analyzed indicators of economic security, in particular, there was a reduction in GDP by an average of 5% in the group, the stock market – up to 2.5%. At the same time, in the countries of the eighth cluster (with the exception of South Korea) there was only a reduction in economic growth. In particular, the eighth cluster includes Canada, a country that historically has close financial and trade ties with the United States (the source country for the cross-border spread of the 2008-2009 crisis). However, since the second half of 2008, as the global economic crisis has developed, the Government of Canada has developed an anti-crisis plan to regulate the economy, which includes support for the financial sector, large, small businesses, certain industries, and infrastructure projects. Also effective were the state social support measures. As a result, it contributed to the stability of the country's financial and banking system. So, since 2008 after the global financial crisis, the Canadian economy has again become one of the strongest in the world among developed economies.

Accordingly, the countries of the eighth cluster are characterized by the shortest terms of economic recovery. Pre-crisis development indicators were achieved by them in the period from 2009 to 2010, and by the countries included in the second cluster – in 2010-2011.

The fifth cluster includes countries that have traditionally close trade and economic ties with the United States (Argentina, Brazil, Maldives, Mexico, Philippines) and Japan (Brunei Darussalam, Thailand, Philippines). Due to this feature, the crises in these countries have primarily caused a massive outflow of investors, which has led to an increase in public debt, reduced international reserves and a decrease in the value of national currencies. The economies of this group were on the rise before the crisis, so the processes of cross-border expansion, mainly through trade channels, led to a slowdown in economic growth. As a result of an adequate and timely program of anti-crisis measures these countries did not have catastrophic consequences, as, for example, in the countries of the fourth group.

The third, sixth, seventh and ninth clusters include the countries that have the lowest living standards according to the UN classification. Their economies are quite isolated from the global financial market, so the effects of the 2008-2009 crisis are the most delayed (up to the 1st quarter compared to other groups) and have caused significant deteriorations in already frankly weak economic systems.

It should be noted that the seventh cluster includes the island countries of the Pacific Ocean with agricultural economies, which share common geographical borders: Samoa, Tonga and Fiji. And the third and ninth clusters include only one country at all – Nepal and the Solomon Islands, respectively.

In the context of the analytical study of the results of clustering based on the data characterizing the state of financial and trade channels of crisis phenomena in the last quarter of the latent period, a petal diagram was constructed (Fig. 3). It reflects the level of similarity (values of concordance coefficients by clusters) in GDP dynamics, the exchange rate of the national currency against SDRs, international reserves, external public debt, interest rates on external government bonds for two years after the latency period.

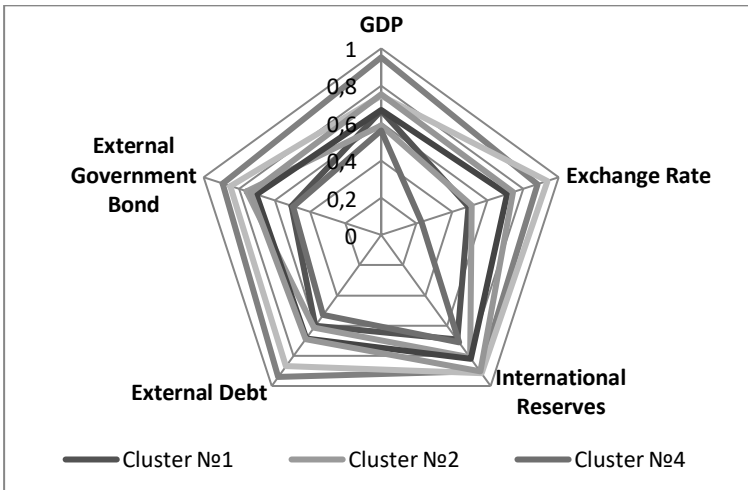


Fig. 3. Petal diagram of the ranking concordance coefficient for clusters, which included more than one country, at the end of the latent period of the financial crisis of 2008–2009

The average value of the concordance coefficient by clusters of the Kohonen map, based on data for the last quarter of the latent period (Figs. 2, 3), is equal to 0.716.

Let us analyze the cause of low values of the concordance rate to the dynamics of the national currency to the SDR in all clusters final card that can be seen in Fig. 3. We assumed that the main reason for this is the difference in currency regimes at the time of the crisis, which led to artificial horizontal or slow-growing trends in the dynamics of the respective currencies. To test this assumption, we will analyze the impact of the exchange rate regime on the consequences of the spread of crisis phenomena in the financial markets.

To this end, we present in Fig. 4 distribution of countries by type of currency regime in terms of clusters of Kohonen map, based on data before the crisis.

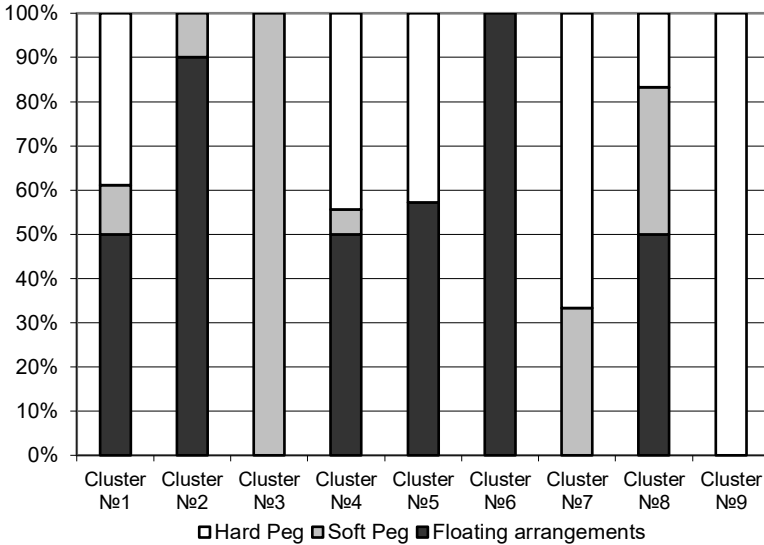


Fig. 4. Generalized structure of clusters of the final Kohonen map taking into account the type of currency regime De Facto at the end of the latent period

The results of countries distribution in clusters in Fig. 4 suggest that the low values of the concordance ratio for the macro-indicator “real exchange rate to SDR” are partly due to the difference in

monetary policy, which is part of the type of currency regime. The analysis of the exchange rate in clusters showed that there is a certain relationship between the type of currency regime and the consequences of the crisis in domestic financial markets.

Thus, the countries of the two clusters in Fig. 2 (second and eighth), which have the best dynamics of this macro-indicator of stability during the response period, at the time of the crisis in 93% of cases pursued a policy of floating exchange rate or soft peg. Other clusters characterized by worse exchange rate dynamics during the response period (for example, the first and fourth) include countries that pursued different monetary policy regimes at the time of the crisis: 50% – countries with different types of pegging and 50% – countries with floating exchange rate.

Thus, it cannot be stated unequivocally that the varieties of floating currency regimes provide the economy with a higher level of stability during the crisis. However, in combination with other effective instruments and measures of macroprudential policy of operation at the end of the latent period and during the response period in the country, the floating exchange rate gives it advantages. Thus, it can be concluded that the type of currency regime does not play a decisive role in the consequences of the processes of cross-border spread of crises in the financial markets. However, it can be an effective tool for stabilization policy during crises. This is evidenced by the frequent cases of transition from one type of exchange rate regime to another during financial crises.

The resulting distribution of economies between clusters also allowed us to conclude that there is a relationship between the peculiarities of the spread and course of the financial crisis in the country, its historical trade and economic ties and the response to these processes in neighboring economies. For example, the first cluster (located in the lower left corner of the map in Fig. 2) included fourteen European countries, which is 77% of the total number of countries in the cluster. The core of the fourth cluster (located first in the middle row of map neurons in Fig. 2) consists of ten countries (55% of the countries included in it – Azerbaijan, the Republic of Armenia, Belarus, Kazakhstan, the Kyrgyz Republic, Mongolia, Russia, Tajikistan, Ukraine) with a compact location, common borders and a long common history. Smaller clusters, such as the seventh and eighth, are almost 100% composed of countries with a

compact geographical location: all countries in cluster № 7 are in Polynesia, and 5 out of 6 countries in cluster № 8 are developed countries in Asia (the second neuron of the first line on Fig. 2).

Conclusions and prospects for further research in this area

The results of the study allow us to conclude that neural network models are an effective tool for early detection of signs of approaching financial crises. Moreover, a quarter before the end of the latent period (where its limits are determined on the basis of the algorithm proposed in [33]) it is possible to clearly predict the probable scenario of events within the economy based on a system of indicators characterizing the deformation processes occurring in financial and trade phenomena. The model built in the study based on the Kohonen self-organizing map can be used to analyze stability to crisis phenomena in the future and predict their consequences for any countries, including those that did not participate in the process of building the model.

The developed methodological approach can be used in solving problems of division into clusters of other objects according to the appropriate sets of classification features. For example, in the tasks of the medical sphere (to work with cardiograms of patients with cardiovascular diseases with a long history of the disease), social sphere (to assess the state of development of countries by living standards, health care, mortality, etc.), marketing activities (search for patterns in users' online queries, selection of contextual advertising, etc.).

An important advantage of the proposed approach, in addition to predicting scenarios of national economies during the crisis in global capital markets, is the ability to determine the elasticity of each of the transmission channel indicators to form an adequate situational policy to adapt to imbalances in the source economy and mitigate cross-border crisis.

References

1. Bank for International Settlement. (2011). *The transmission channels between the financial and real sectors: a critical survey of the literature* (Working Paper No. 18). Basel Committee on Banking Supervision. https://www.bis.org/publ/bcbs_wp18.pdf

2. Forbes, K. (2012). *The “Big C”: identifying contagion* (Working Paper No. 18465). National Bureau of Economic Research. <https://doi.org/10.3386/w18465>
3. Ahrend, R., & Goujard, A. (2015). Global banking, global crises? The role of the bank balance-sheet channel for the transmission of financial crises. *European Economic Review*, 80, 253–279. <https://doi.org/10.1016/j.euroecorev.2015.10.003>
4. Buch, C., & Goldberg, L. (2017). *Cross-Border Prudential Policy Spillovers: How Much? How Important? Evidence from the International Banking Research Network* (Discussion Paper No. 02/2017). Deutsche Bundesbank. <https://dx.doi.org/10.2139/ssrn.2915698>
5. Claessens, S. (2017). Global banking: recent developments and insights from research. *Review of Finance*, 21(4), 1513–1555. <https://doi.org/10.1093/rof/rfw045>
6. Cetorelli, N., & Goldberg, L.S. (2012). Banking globalization and monetary transmission. *Journal of Finance*, 67(5), 1811–1843. <https://doi.org/10.1111/j.1540-6261.2012.01773.x>
7. Billio, M., Getmansky, M., Lo, A. W., & Pelizzon, L. (2012). Econometric measures of connectedness and systemic risk in the finance and insurance sectors. *Journal of Financial Economics*, 104(3), 535–559. <https://doi.org/10.1016/j.jfineco.2011.12.010>
8. Allen, F., & Gale, D. (2000). Financial contagion. *Journal of Political Economy*, 108(1), 1–33. <https://doi.org/10.1086/262109>
9. De Bruyckere, V., Gerhardt, M., Schepens, G., & Vander Vennet, R. (2013). Bank/sovereign risk spillovers in the European debt crisis. *Journal of Banking & Finance*, 37(12), 4793–4809. <https://doi.org/10.1016/j.jbankfin.2013.08.012>
10. Laeven, L., Ratnovski, L., & Tong, H. (2016). Bank size, capital, and systemic risk: Some international evidence. *Journal of Banking & Finance*, 69, S25–S34. <https://doi.org/10.1016/j.jbankfin.2015.06.022>
11. Varotto, S., & Zhao, L. (2018). Systemic Risk and Bank Size. *Journal of International Money and Finance*, 82(C), 45–70. <http://doi.org/10.1016/j.jimonfin.2017.12.002>
12. Babecký, J., Havránek, T., Matějů, J., Rusnák, M., Šmídková, K., & Vašíček, B. (2012). *Banking, Debt, and Currency Crises: Early Warning Indicators for Developed Countries* (Working Paper No. 1485). European Central Bank. <http://doi.org/10.2139/ssrn.2162901>
13. Ferrari, S., & Pirovano, M. (2015). *Early warning indicators for banking crises: a conditional moments approach* (Paper No. 62406). MPRA. https://mpra.ub.uni-muenchen.de/62406/1/MPRA_paper_62406.pdf
14. Behn, M., Detken, C., Peltonen, T., & Schudel, W. (2013). *Setting countercyclical capital buffers based on early warning models: Would it*

- work? (Working Paper No. 1604). European Central Bank. <https://www.ecb.europa.eu/pub/pdf/scpwp/cebwp1604.pdf>
- 15.Ortiz, A. & Ugarte, A. (2015). *Introducing a New Early Warning System Indicator (EWSI) of banking crises* (Working Paper No. 15/02). Banco Bilbao Vizcaya Argentaria. https://www.bbvaresearch.com/wp-content/uploads/2015/01/WP_EWS-SystemVersion-Sep2014_i.pdf
- 16.Lukianenko, D. H., & Bakaiev, O. L. (2003). Hlobalizatsiia ekonomichnoho rozvytku: finansova kryza [Globalization of economic development: financial crises]. *Rynok tsinnykh paperiv Ukrainy (Ukrainian securities market)*, 3-4, 3-14. <http://securities.usmdi.org/?p=22&n=11&s=109> [in Ukrainian]
- 17.Lukianenko, D. H., Poruchnyk, A. M., & Stoliarchuk, Ya. M. (2010). Hlobalni finansovi dysbalansy ta yikh makroekonomichni naslidky. *Zhurnal yevropeiskoi ekonomiky (Journal of European Economy)*, 9(1), 73-92. <http://jeej.wunu.edu.ua/index.php/ukjee/article/view/310> [in Ukrainian]
- 18.Claessens, S. & Kose, M.A. (2013). *Financial Crises: Explanations, Types, and Implications* (Working Paper No. 13/28). International Monetary Fund. <https://www.imf.org/external/pubs/ft/wp/2013/wp1328.pdf>
- 19.Krugman, P. (1979). Model of Balance-of-Payments Crises. *Journal of Money, Credit and Banking*, 11(3), 311-325. <https://doi.org/10.2307/1991793>
- 20.Flood, R. & Garber, P. (1984). Collapsing Exchange-Rate Regimes: Some Linear Examples. *Journal of International Economics*, 17(1-2), 1-13. [https://doi.org/10.1016/0022-1996\(84\)90002-3](https://doi.org/10.1016/0022-1996(84)90002-3)
- 21.Obstfeld, M. (1986). Rational and Self-Fulfilling Balance-of-Payments Crises. *American Economic Review*, 76(1), 72-81. <https://www.jstor.org/stable/1804128>
- 22.Corsetti, G., Pesenti, P., & Roubini, N. (1998). Paper Tigers?: A Model of the Asian Crises. *European Economic Review*, 43(7), 1211-1236. [https://doi.org/10.1016/S0014-2921\(99\)00017-3](https://doi.org/10.1016/S0014-2921(99)00017-3)
- 23.McKinnon, R., & Pill, H. (1996). Credible Liberalizations and International Capital Flows: The “Overborrowing Syndrome”. In T. Ito, & A. O. Krueger (Eds.), *NBER-East Asia Seminar on Economics: Vol. 5. Financial Deregulation and Integration in East Asia* (pp. 7-50). University of Chicago Press. <https://www.nber.org/system/files/chapters/c8557/c8557.pdf>
- 24.Krugman, P. (1999). Balance Sheets, the Transfer Problem, and Financial Crises. *International Tax and Public Finance*, 6, 459-472. <https://doi.org/10.1023/A:1008741113074>
- 25.Blanco, H., & Garber, P. M. (1986). Recurrent Devaluation and Speculative Attacks on the Mexican Peso. *Journal of Political Economy*, 94(1), 148-166. <https://doi.org/10.1086/261366>
- 26.Calvo, G. A., & Reinhart, C. M. (2000). When Capital Flows Come to a Sudden Stop: Consequences and Policy. In P. Kenen, & A. Swoboda (Eds.), *Reforming the International Monetary and Financial System*

- (pp. 175-201). International Monetary Fund. https://mpra.ub.uni-muenchen.de/6982/1/MPRA_paper_6982.pdf
- 27.Reinhart, C. M., & Rogoff, K. S. (2009). The Aftermath of Financial Crises. *American Economic Review*, 99(2), 466–472. <https://doi.org/10.1257/aer.99.2.466>
- 28.Lukianenko, D., & Yushko, I. (2016). Bankivska kryza v Ukraini: hlobalni faktory ta vnutrishni prychny [Banking crisis in Ukraine: global factors and internal causes]. *Rynok tsinnykh paperiv Ukrainy (Ukrainian securities market)*, 5–6, 43–53. <http://securities.usmdi.org/PDF/975.pdf> [in Ukrainian]
- 29.Strelchenko, I.I. (2019). Modeliuvannia protsesiv transhranychnoho poshyrennia finansovykh kryz [Modeling of cross-border spreading of financial crises]. *Neuro-Nechitki Tekhnologii Modelyuvannya v Ekonomitsi (Neuro-Fuzzy Modeling Techniques in Economics)*, 8, 147-175. <https://doi.org/10.33111/nfmte.2019.147> [in Ukrainian]
- 30.International Monetary Fund. (2016, April). *World Economic Outlook: Too Slow for Too Long*. <https://www.imf.org/en/Publications/WEO/Issues/2016/12/31/Too-Slow-for-Too-Long>
- 31.International Monetary Fund. (2020). *IMF Data. Access to Macroeconomic & Financial Data* [Data set]. Retrieved August 11, 2020, from <http://data.imf.org/>
- 32.Kohonen, T. (2001). *Self-Organizing Maps* (3rd ed.). Springer.
- 33.Strelchenko, I.I. (2017). Vybir optimalnoi topologii neuronnoi merezhi v zadachakh klasyfikatsii dynamichnykh ekonomichnykh system [Selection of a neural network optimum topology in problems of dynamic economic systems classification]. *Neuro-Nechitki Tekhnologii Modelyuvannya v Ekonomitsi (Neuro-Fuzzy Modeling Techniques in Economics)*, 6, 142–157. <http://nfmte.com/assets/journal/6/Strelchenko.pdf> [in Ukrainian]

The article was submitted on 2020, December 6