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CLUSTER ANALYSIS OF THE IMPACT OF CURRENCY REGIME TYPE ON FEATURES OF THE SPREAD OF FINANCIAL CRISES

The paper presents the results of research on the impact of currency regime type on features of the spread of financial crises. The focus is on constructing a neural network to identify groups of countries exhibiting similar behaviour in the dynamics of the index of flexibility in the effective exchange rate, exchange market pressure and external public debt markets in times of sudden changes in the environment. The alpha-criterion for optimality constructed in this way is based on the use of a concordance coefficient. The result of modelling is a self-organization map with a hidden layer consisting of six clusters. This cluster structure allows us to analyse the relationship between the type of currency regime and the consequences of the global crisis in 2007–2009 for the domestic financial markets of the investigated countries. It is found that the result of the division is significantly influenced by the proximity of administrative boundaries and historically predetermined close trade and economic channels of interaction between economies. The results obtained can be used to formulate directions in the currency policies of developing countries, including Ukraine.

Keywords: *financial crises, clustering, neural network, self-organization map, macroeconomic indicator*

1. Introduction

Over the past 30 years, the world has seen a dramatic increase in the number of financial crises. Above all, this has happened due to accelerating globalization, liberalization of domestic financial markets and, as a result, the increasing financial vulnerability of economies. These objective trends have strengthened the role and the influence of the financial sector within the world economy. This, in turn, has caused a high degree of dependence of the welfare of individual countries on negative changes in the economies of their partner countries. When a crisis occurs, the degree of vulnerability and the depth of subsidence

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of key macroeconomic indicators transfer through financial channels, above all, depending on the specifics of the organization and regulation of the domestic financial market. One of the main elements used by central banks and governments in establishing or influencing the exchange rate of a national currency to foreign currencies is their currency regime. In the context of globalization and the high mobility of capital, this exchange rate regime plays an important role in regulating a country's economic development.

Analysis shows that, in the early 1990s, the use of fixed exchange rate regimes and currency peg mechanisms were preferred worldwide. Since the mid-90s, the share of countries where central banks have been using a managed or free float regime has been increasing. During the analysed period, the global economy was swept by currency crises, which significantly affected not only the source country, but also partner countries, primarily those located geographically close to the source countries and having historically close trade and economic ties with them. We may assume that these events led to a change in the currency regime in a number of countries. For example, in the so-called tequila crisis, when a fixed exchange rate between the peso and the US dollar made the Mexican economy highly uncompetitive, the result was a shift to a floating exchange rate regime.

This paper tests the hypothesis that there is an association between the type of exchange rate regime and the severity of the consequences of the most recent global financial crisis of 2007–2009. Particular attention is paid to emerging economies, in particular Ukraine.

2. Literature review

The problem of formulating rules for domestic currency regulation has become particularly relevant after the rejection of the Bretton Woods system. This was followed by the abolition of the system of fixed exchange rates and the formation of several interim agreements on the estimation of exchange rates. The experience of the Central Banks from providing fixed exchange rate regimes or hard pegging has shown that, in the context of financial crises, such policies contribute to increasing the financial vulnerability of a country. However, the problem of identifying the consequences of the choice of a particular currency regime in an open economy is extremely difficult. For example, Baxter and Stockman [1] did not find significant differences when currency regimes were changed during business cycles.

But the crises of the 1990s and the early 2000s showed that fixed-exchange-rate regimes and different types of hard pegs contribute to currency speculation, which intensifies a crisis (see also Table 1).

Table 1. Financial crises from 1990 to 2001

Year	Country	De jure exchange rate regime at the beginning of the financial crisis
1994	Mexico	fixed-exchange-rate
1997	Thailand	fixed
1997	Indonesia	managed floating
1997	Malaysia	managed floating
1997	South Korea	managed floating
1998	Russia	pegged exchange rate within horizontal bands
1998	Brazil	crawling peg
1999	Ecuador	crawling bands
2000	Turkey	crawling peg
2001	Argentina	currency board

Source: Based on the IMF Annual Reports on Exchange Arrangements and Exchange Restrictions (1994–2001).

After the crises in Mexico (1994), Thailand, Indonesia, and Korea (1997), Russia and Brazil (1998), Ecuador (1999), Turkey (2000) and, next, the collapse in Argentina (2001), the number of studies in the field of the interconnection between the exchange rate regime and the level of vulnerability of a financial system to a speculative attack on the currency market has skyrocketed. According to some authors, such crises as the Asian flu and tequila crises are a clear demonstration of the superiority of flexible exchange rates, since in most cases these crises occurred in countries with some kind of peg system.

For example, Chang and Velasco [3] developed a monetary model of an open economy. Based on this model, it was shown that the regime of a fixed exchange rate promotes currency speculation, which intensifies a crisis. On the other hand, according to this model, a floating exchange rate regime completely eliminates the possibility of currency and banking crises occurring simultaneously in a small open economy. Similar assumptions were made by Eichengreen [4]. The corners hypothesis states that countries should move away from intermediate exchange regimes towards either the hard peg corner or the floating corner. But after the failure of Argentina's currency board in 2001, the corners hypothesis began to lose popularity.

With regard to the experience of five Asian countries hit by the 1997 crisis, most researchers agree that protection of official parity in each of them made the Asian financial crisis possible and that after this crisis, with the exception of Malaysia, these currencies were forced to switch to a floating regime [5]. However, despite a massive shift to floating exchange rates after the Asian crisis, the central banks of most countries continued to conduct currency interventions to prevent significant fluctuations in the exchange rate. This effect was called fear of floating [2]. At the same time, there are studies supporting the so-called bipolar view of the relationship between the type of currency regime and vulnerability to crisis. (see, for example, [5, 7]). In accordance with this approach, extreme regimes (fixed or floating) are disciplinary, while intermediate regimes are crisis-prone.

3. Cluster analysis based on a self-organizing map

Neural networks provide an effective approach to classifying multidimensional data arrays. The main disadvantage of such methods is the process of selecting the optimal internal structure and the number of neurons in the hidden layer of the self-organizing map (SOM). The process of modelling with the help of neural networks is based on the iterative selection of parameters that achieve the maximum of the quality function, which, as a rule, does not have the properties of continuity and smoothness. Therefore, a significant drawback of such an approach is the impossibility of guaranteeing the optimality of the methods and algorithms used. Among the main advantages of SOM, note the simplicity of implementation, accurate approximation, the ability to process new data in real time.

3.1. Formation of the training sample

Within the framework of this article, the task of clustering is to divide a given set of countries into groups inside which the dynamics of selected financial indicators during the specified period will be similar. At the preparatory phase of the study (Fig. 1), a training sample was formed that included 33 countries of different degrees of economic development, internal financial markets and types of foreign exchange rate regime. The analysis of theoretical concepts (cf. [6, 8, 13, 15]) and empirical data allowed us to select three key indicators that characterize the dynamics of the currency market of an arbitrary country. Namely, index of the effective flexibility of the exchange rate (FLT), exchange market pressure (EMP), and external public debt.

A formula for the first index used by the model was proposed by Poirson [16]:

$$FLT_t = \frac{ME_t}{MR_t} = \frac{\sum_{k=0}^{11} | E_{t-k} - E_{t-k-1} | / E_{t-k-1}}{\sum_{k=0}^{11} | R_{t-k} - R_{t-k-1} | / H_{t-k-1}} \tag{1}$$

where E_{t-k} – is the nominal exchange rate k months prior to the present moment t, R_{t-k} – net foreign exchange reserves minus the value of gold held in month $t-k$, H_{t-k} – monetary supply in month $t-k$.

The FLT-index characterizes the ratio between the absolute value of the average change in the nominal exchange rate each month over the course of a year (ME_t – monthly average over the past 12 months) and the absolute value of the average monthly change in foreign exchange reserves over the course of a year normalized with respect to the money supply in the previous month (MR_t). The value of this index varies from zero – in the case of a fixed exchange rate regime, to infinity. Large values indicate a free floating regime.

The index of exchange market pressure was obtained from the model proposed by Kaminsky and Reinhart [10]:

$$EMPI_{i,t} = \frac{\Delta e_{i,t}}{e_{i,t}} - \frac{\sigma_e}{\sigma_r} \times \frac{\Delta r_{i,t}}{r_{i,t}} + \frac{\sigma_e}{\sigma_{\text{int}}} \Delta i_{i,t} \tag{2}$$

where $e_{i,t}$ – exchange rate of country i based on the chosen base currency in period t, σ_e – standard deviation of the exchange rate $(\Delta e_{i,t}/e_{i,t})$, $r_{i,t}$ – international currency reserves of country i during period t, σ_r – standard deviation of international currency reserves $(\Delta r_{i,t}/r_{i,t})$, $\Delta i_{i,t}$ – nominal interest rate in country i in period t, σ_i – standard deviation of the nominal interest rate.

The EMPI index increases with the depreciation of the national currency, increasing foreign reserves and rising nominal interest rates.

Thus, an array of output data consists of $33 \times 3 \times 12 = 1188$ elements, where 12 is the duration of the study period, which includes quarterly data for the calculation of selected indicators during the crisis of 2007–2009. All of these data were obtained from the official site of the International Monetary Fund.

For our task it is useful to scale the inputs and targets so that they always fall within a specified range. So in the next step we converted the array of output data by normalizing the values of each row to fall in the interval [–1, 1]. It is assumed that the original output data have only finite real values, and that the elements of each row are not all equal:

$$x'_{ij} = \frac{(\max - \min) \times (x_{ij} - x_{\min i})}{(x_{\max i} - x_{\min i})} + \min \tag{3}$$

where x'_{ij} – the jth value in the ith row of the normalized data array, x_{ij} – the jth value in the ith row of the output data array, $x_{\min i}$ – minimum value in row i, $x_{\max i}$ – maximum value in row i, max = 1, min = –1.

The last step in the preparatory phase is the choice of the topology of SOM (the number of neurons in the hidden layer). The maximum number of neurons can be determined using the empirical inequality [9]:

$$N_r > \frac{N_c}{e} \qquad (4)$$

where N_r – number of rows in the normalized data array, N_c – number of clusters in SOM, e – acceptable error in the coefficients.

The size of the maximal acceptable error in the coefficients is set to be equal to 0.2. Hence $N_c = 7$.

3.2. Determination of the optimal topology of SOM based on a nonparametric criterion

Finding the optimal topology of SOM is the process of finding the number of neurons in the architecture of the hidden layer that provide the extremum of a defined objective function. The problem of choosing the optimality criterion is complicated and does not have a single unified solution.

The purpose of the study is to construct an SOM decomposition into clusters which have a high level of similarity according to changes in the selected indicators within each group.

In our research, maximizing the Kendall coefficient of concordance was used as the optimality criterion. Its advantages are: clear interpretation, no restrictions on the homogeneity of data, the possibility of numerical assessment of the level of similarity of reactions in dynamic systems within the boundaries of a limited scale.

The Kendall coefficient of concordance characterizes the degree of consistency between a set of variables that is estimated on the basis of a set of output data [12–14]:

$$W = \frac{12S}{m^2(n^3 - n)} \qquad (5)$$

where n – length of the time series ($n = 12$), m – number of countries included in a particular cluster (takes values from 1 to 60), and S is given by:

$$S = \sum_{i=1}^{n} (R_i - \overline{R})^2 \qquad (6)$$

where R_i – the sum of ranks for the ith object $\left(R_i = \sum_{j=1}^{m} R_{ij} \right)$, $\overline{R}$ – the average sum of ranks for all the objects. R is a vector of ranks from 1 to 12. Each row in each of the three matrices of indicators separately for each country is a vector of such ranks such that the maximum value of the indicator was assigned rank 1, and the lowest value of the indicator was ranked 12.

In the case of tied ranks, the formula to calculate the coefficient of concordance is as follows:

$$W = \frac{12S}{m^2(n^3 - n) - mT} \tag{7}$$

where T is the correction factor for tied ranks:

$$T = \sum_{k=1}^{g} (t_k^3 - t_k) \tag{8}$$

where t_k – is the number of tied ranks in group k of g groups of ties. This sum is computed over all groups of ties found in all m variables of the input data.

This procedure is repeated for all the rows of the matrices (m multiplied by the number of countries in a cluster). Under these conditions, the ith object in Eqs. (6), (7) is described by the vector of elements R_{ij}, which are the ranks of all the countries of the given cluster in the ith period.

The value of the concordance coefficient indicates whether there is a similarity in how a target indicator (in our case, the set of indicators is FLT, EMP, external debt) varies within a group of countries. The value of the concordance coefficient is in the interval $0 \le W \le 1$. If $W = 0$, then the sequence of the ranks of different countries within a cluster in the corresponding period is completely uncoordinated (discordant). If $W = 1$, the result is interpreted as complete coincidence in the dynamics of the studied parameters. The closer W to 1, the greater the consistency observed in the initial series of data for different countries within the same cluster is.

During the modelling phase, SOM is configured and the optimal architecture determined. This process is cyclic. In each iteration, the automated system builds a structure of clusters and distributes the training sample to the classes. In accordance with the approach developed at the preparatory stage, the value of the objective function $\alpha_{N_C}^m$ is calculated as:

$$\alpha_{N_C}^m = \sum_{i=1}^{N_C} \sum_{j=1}^{l} W_{ij}^m \tag{9}$$

Iterations of this algorithm are continued until all the possible structures of clusters have been checked. The largest value of the objective function corresponds to the optimal structure of SOM. In the general case, the process of modelling SOM based on the Kendall coefficient of concordance is shown in Fig. 1.

Achieving the maximum value of the objective function indicates the end of the training of the neural network and determines the optimal structure of clusters. Using the coefficient of concordance allows us to divide the training sample based on 33 countries into groups by similarity according to the dynamics of financial macroeconomic indicators (FLT, EMPI, external debt) during the global crisis of 2007–2009. The results obtained by the study allow us to analyse the relationship between the type of currency regime and the reaction of domestic financial markets to sharp changes in the environment.

3.3. The simulation process

Figure 1 shows the model of a trained neural network presented in Simulink blocks. The main subsystem here is Layer1, which is detailed in Figs. 2, 3.

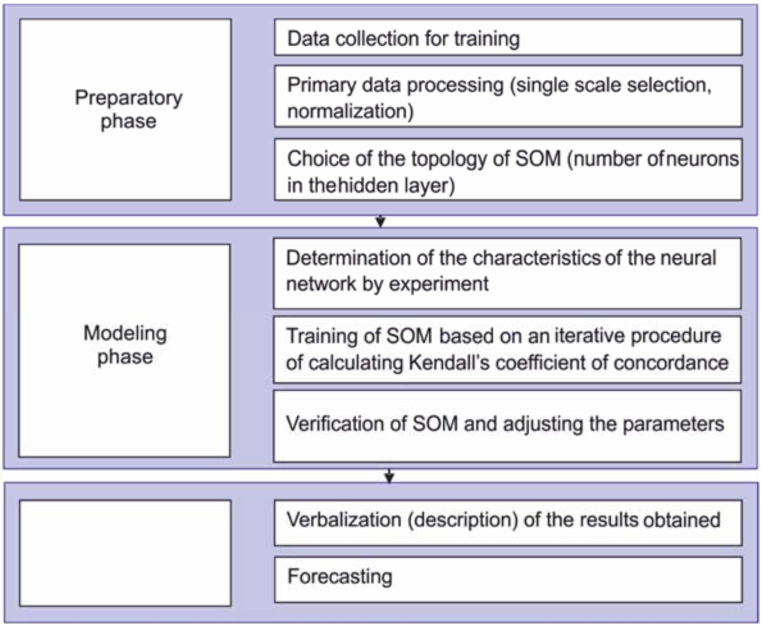

Fig. 1. Modelling process based on an SOM

The block Delays1 delays an input normalized data array according to the length of the delay parameter *d*, which in our case is equal to zero. The next block, IW, forms a cell array of input weight matrices. The Netsum block initializes the function for calculating a layer's net input by combining its weighted inputs and biases. The transfer block Compet calculates a layer's output from its net input. The whole simulation process was performed in MatLab.

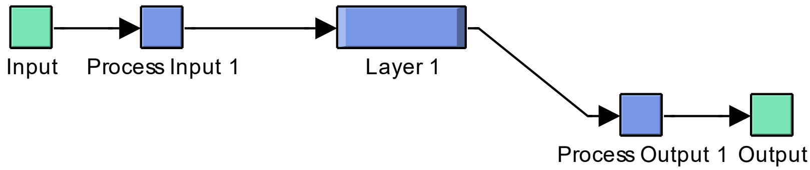

Fig. 2. Model of a trained neural network presented in Simulink blocks

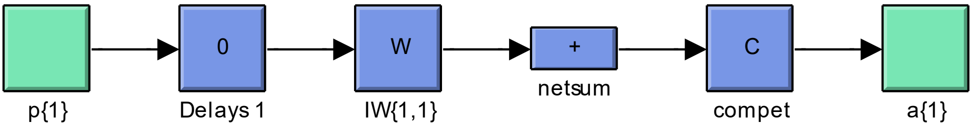

Fig. 3. Subystem of SOM-model Layer1 block

4. The result of modelling

The result of modelling is an SOM with a hidden layer consisting of six clusters. The neuron net obtained has an optimal structure, according to the coefficient α, and clusters the set of input countries in the following way:

First cluster: Albania, Bosnia and Herzegovina, Brunei Darussalam, Bulgaria, Croatia, Czech Republic, Denmark, Euro Area, Estonia, Israel, Latvia, Lithuania, Macedonia, Malaysia, Montenegro, Philippines, Singapore, Switzerland, Thailand, United States.

Second cluster: Australia, Canada, Hungary, Indonesia, Kiribati, New Zealand, Norway, Poland, Samoa, Republic of Serbia, Sweden, Tonga, Vanuatu.

Third cluster: Armenia, Bangladesh, Georgia, Moldova.

Fourth cluster: Iceland, India, Nepal, Romania, South Korea, Turkey, United Kingdom.

Fifth cluster: Azerbaijan, China P.R., Mainland, Special administrative region of China Hong Kong, China P.R., Macao, Japan, People's Democratic Republic of Lao.

Sixth cluster: Belarus, Cambodia, Kazakhstan, Kyrgyz Republic, Mongolia, Russian Federation, Sri Lanka, Tajikistan, Ukraine, Vietnam.

Analysis of the relationship between the type of currency regime and the consequences of the global crisis in 2007–2009 for the domestic financial markets of the investigated countries is more convenient to carry out using Table 2.

In the first cluster, more than half of the countries (55%) had floating exchange rate regimes at the beginning of the crisis: independently or managed floating. 40% – de facto, had a hard peg currency policy. In general, the economies that were assigned to cluster number one were characterized by a recovery which happened shortly after the fall in the main macroeconomic indicators, the maximum fall of which occurred in quarters 2–3 of 2008.

Table 2. Clusters of countries according to the reaction of domestic financial markets to the 2007–2009 crisis

Cluster	De facto exchange rate regime in April 2007 according to IMF classification		Country
First	floating arrangements	independently floating	Albania, Euro Area, Israel, Philippines, Switzerland, United States
		managed floating	Croatia, Czech Republic, Malaysia, Singapore, Thailand
	soft peg	pegged exchange rates within horizontal bands	Denmark
	hard peg	currency board arrangements	Bosnia and Herzegovina, Brunei Darussalam, Bulgaria, Estonia, Lithuania
		exchange arrangements with no separate legal tender	Montenegro
		other conventional fixed peg arrangements	Latvia, Macedonia
Second	floating arrangements	independently floating	Australia, Canada, New Zealand, Norway, Poland, Sweden
		managed floating	Indonesia, Republic of Serbia
	soft peg	pegged exchange rates within horizontal bands	Hungary, Tonga
	hard peg	exchange arrangements with no separate legal tender	Kiribati
		other conventional fixed peg arrangements	Vanuatu, Samoa
Third	floating arrangements	managed floating	Armenia, Bangladesh, Georgia, Moldova
Fourth	floating arrangements	independently floating managed floating	Iceland, South Korea, Turkey, United Kingdom, India, Romania
	hard peg	other conventional fixed peg arrangements	Nepal
Fifth	floating arrangements	independently floating	Japan
		managed floating	People's Democratic Republic of Lao
	soft peg	crawling pegs	Azerbaijan, China P.R. Mainland, China, P.R., Macao
	hard peg	currency board arrangements	special administrative region of China Hong Kong
Sixth	floating arrangements	managed floating	Cambodia, Kazakhstan, Kyrgyz Republic, Russian Federation, Sri Lanka, Tajikistan
	hard peg	other conventional fixed peg arrangements	Belarus, Mongolia, Ukraine, Vietnam

Source: Derived by the author, based on [3–9] and database of IMF Annual Reports on Exchange Arrangements and Exchange Restrictions, https://www.imf.org/External/NP/pp/2007/eng/112707.pdf, accessed on 30.10.2017.

Let us consider the distribution of types of currency regime for the optimal structure of clusters (Fig. 4).

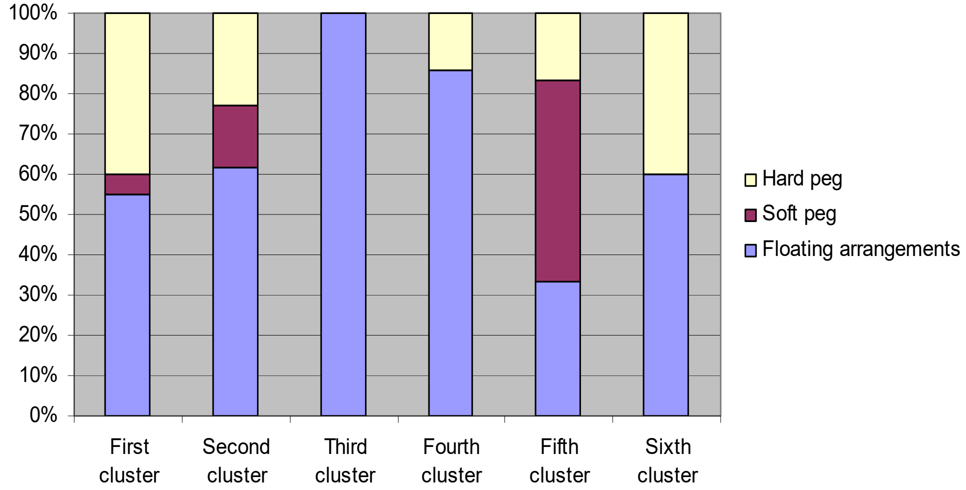

Fig. 4. Distribution of types of currency regime for the optimal structure of clusters
Source: Derived by the author, based on Table 2

It should be noted that the first cluster includes the United States. This is natural – a drop in GDP, exchange rate, and so on. The indicators in the United States were not catastrophic (as in the countries of the 6th cluster), despite the fact that the wave of structural imbalances in the financial sector began in the USA, which subsequently quickly transferred to other economies.

Countries included in the second cluster are characterized by the highest level of similarity in the dynamics of the selected indicators for the entire SOM ($\alpha = 2.186$). However, the structure of this group according to currency regime is heterogeneous: 61% – floating exchange rate regimes, 22% – hard peg, 17% – soft peg.

The smallest sized cluster, and only one which comprises countries all having the same type of currency regime (float), is the third cluster.

86% of the fourth cluster had a float exchange rate regime in April 2007. The other 14% had a hard peg regime.

The economies in the fifth cluster are almost evenly distributed between the three currency regimes: float/soft peg/hard peg, 33/49/18. It should be noted that for the SOM optimal architecture, the α function for the fifth cluster is equal to 1.57, indicating a level of similarity between the trajectories of FLT, EMPI and public debt which is above average. Therefore, it is not possible to make a clear conclusion about the relationship between the type of currency regime and the effects of the crisis on domestic financial markets.

However, based on the results of the geographical distribution of clusters, we conclude that it is typical of countries that are located in the same geographical region and have historically tight trade links to exhibit a high level of similarity in the reaction of domestic financial markets to the spread of an economic crisis.

To confirm this, consider the structure of the sixth cluster according to the type of currency regime and the economies that belong to it. The core of this cluster consists of seven countries (Belarus, Kazakhstan, the Kyrgyz Republic, Mongolia, Russian Federation, Tajikistan, Ukraine) with a compact location, common borders and a long shared history. This set is 70% of the whole group. 60% had a floating currency regime, 40% – hard peg.

Cluster analysis of the data leads us to the following conclusions:

The fastest rate of recovery of the examined macroindicators and the shortest period required to recover to the pre-crisis level are characteristic of the countries belonging to the first three clusters. The monetary policy of more than 70% of the countries included in these groups is guided by the principles of non-intervention or insignificant intervention in the formation of the exchange rate of the national currency (corresponding exchange rate regimes – float and soft peg). In April 2007, all of the other economies had *de facto* hard peg exchange rate regimes, but used the currencies of neighbouring and major developed economies, also belonging to the relevant clusters, as the exchange anchor. For example, Kiribati, Vanuatu and Samoa are satellites of Australia that use the Australian dollar as a monetary unit. Hence, their inclusion in the second cluster is logical and explains the high level of similarity in the dynamics of these domestic financial markets.

Almost all the countries that were part of the CIS fell into the sixth cluster. They have the worst post-crisis dynamics and it took a long time for their financial markets to recover to pre-crisis levels. This group also includes Ukraine. During the 2007–2009 crisis, the hryvnia lost 60% of its pre-crisis value. It is fair to note that the countries belonging to the 6th cluster are characterized by a high level of corruption[2] and a lack of transparency in the legal regulation of the financial sector of the economy.

Countries with close historical trade-economic ties and common geographic boundaries are characterized by a high level of similarity in the behaviour of their financial markets in times of sudden changes in the environment (for example, cluster number two includes Australia, New Zealand, Tonga, Kiribati, Vanuatu and Samoa; cluster number five includes China P.R.: Mainland, special administrative region of China Hong Kong, China P.R., Macao, Japan and the People's Democratic Republic of Lao).

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[2] As evidenced by the CPI index data available from the link: https://www.transparency.org/research/cpi/cpi_2007/0

5. Conclusion

A neural network has been constructed which divided the original sample into six groups. Countries included in a single cluster are characterized by similarity in the dynamics of the following macro-indicators during the global crisis of 2007–2009: FLT, EMPI and external debt. The optimality criterion for the clustering procedure is based on the alpha-index, a coefficient of concordance. Iterative maximisation of the α index, the optimal architecture.

This made it possible to evaluate the impact of the type of currency regime on features of the passage of financial crises. Among the main findings of the study, the following should be noted:

• Better recovery and shorter recovery times are typical of countries with a floating exchange rate regime or a soft peg.

• Ukraine and countries that were part of CIS have the worst post-crisis dynamics and it took a long period of time for their financial markets to recover to pre-crisis levels. They belong to the same cluster. The currency regimes in this group vary from floating to hard peg.

• Countries with close historical trade-economic ties and common geographic borders are characterized by a high level of similarity in the behaviour of their financial markets in times of sudden changes in the environment.

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